JOINT EVENT

ICCS23 - 23rd International Conference on Composite Structures & MECHCOMP6 - 6th International Conference on Mechanics of Composites

Faculty of Engineering, University of Porto, Portugal

1-4 September 2020

Book of Abstracts

António J.M. Ferreira

Nicholas Fantuzzi

Michele Bacciocchi

Welcome Address

The abstracts collected in this book represent the proceedings of the conference ICCS23 (23rd International Conference on Composite Structures) and MECHCOMP6 (6th International Conference on Mechanics of Composites), 1-4 September 2020. This book aims to help you to follow this Joint Event in a timely and organized manner. Papers are selected by the organizing committee to be presented in virtual format. Such arrangement is due to the effects of the coronavirus COVID-19 pandemic. The event, which should have been held at FEUP-Faculty of Engineering, University of Porto (Portugal), follows the success of the first five editions of MECHCOMP and the first twenty-two editions of ICCS. As the previous ones, this event represents an opportunity for the composites community to discuss the latest advances in the various topics in composite materials and structures.

Conference chairs

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Contents

Abstracts

Advances in 3D and 4D printing technologies

Influence of additional heating during laser PBF on mechanical properties the Ni-Al intermetallic composites

abst. 2659
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Shishkovsky Igor (i.shishkovsky@skoltech.ru), Skolkovo Institute of Science and Technology, Russian Federation
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The study was devoted to a detailed experimental study of the implementation conditions of the laser powder bed fusion (L-PBF) process of special-purpose 3D parts from pre-alloyed nickel aluminides (NixAly intermetallic phases) to fabrication critical parts for aerospace applications. Optimal regimes of SLM for the 3D part of the simplest shape were experimentally determined. Additional efforts were done to evaluate the effect of additional heating the base platform up to 300–500 0C and to study the characteristics of the microstructure and mechanical properties in the result of such operations. Optical and scanning electron microscopy, the X-ray diffraction analysis and EDX microanalysis were used for describing the sequence of phase – structural transformations in the created 3D samples. The conducted mechanical and tribological testing allowed to evaluate the relationship between the laser PBF parameters and data on strength, linear wear, roughness, fracture rupture for 3D parts after the SLM process. Keywords: laser powder bed fusion (L-PBF), nickel aluminide composite, chamber heating and laser annealing

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Investigation of 3D Printed Pyramidal Lattice Core Continuous Filament Carbon Fiber Reinforced Thermoplastic Matrix Sandwich Panels by Various Production Parameters

abst. 2285
Repository

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Today, sandwich structures produced using carbon fiber reinforced thermoplastic polymers (CFRTP) with Low density, excellent mechanical properties and application areas are important research subjects in the composite material studies. In this study, composite sandwich panels having pyramidal lattice core structures were produced by using a manufactured special 3d printer. The production of CFRP monofilament used in this sandwich structure was realized in an external extruder with a specially designed mold. These sandwich structures typically consist of two parts, but in this study, they are produced by monolithically as combined core and surface plates by using additive manufacturing techniques. In this study, the printer used was specially developed and sandwich composite panels were produced by using particular printing head setup, laser and printing path mechanisms. The effect of printing parameters and printing paths on mechanical performances were investigated. Mechanical performance of these sandwich structures were obtained by using static compression, quasi-static and

impact three-point bending experiments. With these developed technologies, their contribution to the development of ultra-lightweight composite structures has been examined.

Analysis of composite beams, plates and shells

Refined layer-wise models for nonlocal analysis of magneto-electro-elastic plates

abst. 2124
Repository

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Size-dependent theories of continuum mechanics are an important tool for structural and material modeling in engineering applications, with particular regard to those involving micro- and nano-scales. Among various approaches proposed in the literature to account for the effect of the microstructure via continuum models, the Eringen's nonlocal elasticity model incorporates important features of material behavior via a differential stress-strain relationship involving a scale coefficient, or characteristic length, depending on the material microstructure [1]. In the framework of Eringen's nonlocal elasticity, plate theories have been reformulated for homogeneous and multilayered configurations also extending the models to multifield problems. The literature review reveals that the proposed two-dimensional models for multilayered plates are based on the equivalent single layer with some limitations. Indeed, the equivalent single layer models do not allow to accurately capture the through-the-thickness distribution of the unknown fields. Additionally, in the nonlocal material behavior framework, the proposed equivalent single layer theories account for a unique value of the characteristic length common to all of the layers, whereas this parameter can exhibit meaningful variability for layers of different materials. Here, nonlocal layer-wise plate theories for the analysis of magneto-electro-elastic multilayered plates are presented. They are obtained assuming Eringen's nonlocal behavior for the layers. The plate governing equations are obtained via the Reissner's mixed variational theorem (RMVT), assuming the generalized displacements and generalized out-of-plane stresses as primary variables. These are expressed as through-the-thickness expansions of suitably selected functions, considering the expansion order as a formulation parameter [2]. Different advanced high order nonlocal plate theories are then generated using a layer-based assembly algorithm of the so-called fundamental nuclei associated with the variable expansion terms. The use of the LW approach and RMVT allows for (i) the explicit fulfillment of the transverse generalized stress interface equilibrium, which is crucial for a correct description of the plate fields, (ii) the straightforward analysis of plates with layers exhibiting different nonlocality characteristic lengths. To illustrate the features of the proposed nonlocal plate theories Navier solution results are presented and discussed. Additionally, finite elements are developed basing on the proposed theories and their performances discussed. References [1] A. Eringen, Nonlocal Continuum Field Theories, Berlin: Springer, 2002. [2] E. Carrera, Developments, ideas, and evaluations based upon Reissner's mixed variational theorem in the modeling of multilayered plates and shells, Applied Mechanics Review, vol. 54, no. 4, pp.301–328, 2001.

Nonlinear bending analysis of sandwich panels with lattice cores

abst. 2204
Repository

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Architected lattice materials are a new class of lightweight materials that integrate concepts from materials science, structural mechanics and manufacturing. Such materials have the characteristics of the base material (e.g. a metal or a polymer) as well as the lattice structure, which is driven by architected design. The production of these new man-made materials from a variety of base materials at reasonable costs has been enabled by advances in manufacturing technologies, including laser-welding for large-scale structures such as cruise ship and bridge decks, and additive manufacturing (3-D printing) for smaller scale applications in micro-electro-mechanical systems, metamaterials and biomechanics, to name a few. Here, a displacement-based, geometrically nonlinear finite element model is developed for lattice core sandwich panels modeled as 2-D equivalent single-layer (ESL), first-order shear deformation

theory (FSDT) micropolar plates. The nonlinearity is due to the moderate macrorotations of the plate which are modeled by including the von Karman strains in the micropolar strain measures. Weak form Galerkin method with linear Lagrange interpolations is used to develop the displacement-based finite element model. Selective reduced integration is used to eliminate shear locking and membrane locking. The novel finite element model is used to study the nonlinear bending and linear free vibrations of web-core and pyramid core sandwich panels. Clamped and free edge boundary conditions are considered for the first time for the 2-D micropolar ESL-FSDT plate theory. The present 2-D finite element results are in good agreement with the corresponding detailed 3-D FE results for the lattice core sandwich panels. The 2-D element provides computationally cost-effective solutions; in a nonlinear bending example, the number of elements required for the 2-D micropolar plate is of the order 10^3, whereas for the corresponding 3-D model the order is 10^5. Finally, we note that the development of the non-classical micropolar finite element is carried out using standard (classical) techniques, for example, to avoid locking phenomena. The appearance of, for example, both symmetric and antisymmetric shear terms does not essentially lead to any new type of numerical problems.

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abst. 2625
Virtual Room
Wednesday
September 2
17h00

Vibration analysis of single and doubly curved n-layered composite thick shells

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In this paper, free vibration analysis of single and doubly curved n-layered composite thick shells are studied. First-order shear deformation theory is utilized to develop layer-wise shell theory. Hamilton's principle is used to derive the governing equations of motion and boundary conditions. The resulting eigenvalue problem is solved using the generalized differential quadrature (GDQ) method and natural frequencies are obtained. The study covers both positive and negative Gaussian curvature with different curvature ratios. The accuracy of the present model is compared and validated with those available in the literature. Finally, a parametric study is performed to show the effects of the lamination schemes and geometrical parameters on the vibration characteristics.

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abst. 2038
Virtual Room
Friday
September 4
10h30

Dynamical analysis of two-directional carbon nanotube reinforced functionally graded composite plates

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The free vibration analysis of two directional functionally graded carbon nanotube reinforced composite (2DFG-CNTRC) plates are studied for various boundary conditions. The effects of the CNT distribution in the y direction on the dimensionless frequencies are investigated and compared with the unidirectional CNT distributions (1DFG-CNTRC) with respect to the variation of the CNT configuration, volume fraction and aspect ratio. Based on the variational formulation, the numerical results are obtained by using a finite element method. It is found that the volume fraction of the CNTs is affected with respect to the y direction and the difference between the dimensionless fundamental frequencies calculated based on the 2DFG-CNTRC and 1DFG-CNTRC configurations is significant. Moreover, for CFFF plates, the difference between the dimensionless frequencies obtained based on the 2DFG-CNTRC and 1DFG-CNTRC configurations is approximately 29% for 5th and 6th modes while the aspect ratio is set to 50.

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abst. 2488
Virtual Room
Wednesday
September 2
16h30

Efficiency analysis of utilisation of advanced materials in SHS profiles subjected to bending

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Tubular profiles are widely used in various structural applications because of their high stiffness-to-weight ratio and exceptional resistance to torsion. The use of advanced materials, such as high-strength steel and fibre-reinforced polymers (FRP), is a current trend of the construction industry. However, the increase of the strength for the same elastic modulus of the material and geometry of tubular profiles is often not proportional to the rise of the load-bearing capacity of the structural element. A test program was carried out to investigate the efficiency of material strength enhancement in the deformational behaviour of square hollow section (SHS) profiles subjected to bending load. Cold-formed steel and FRP profiles were tested. Three types of steel grades (S355, S700, and S900) and two geometries of the cross-section (80×80×3 and 100×100×4) were investigated. Four types of steel beams were tested until failure under the four-point-bending scheme. Linear variable displacement transducers (LVDT) were applied to capture vertical displacements in the pure bending zone. Glass FRP profiles, having similar cross-sectional parameters as the steel counterparts, were tested for the comparison purpose. A digital image correlation system (DIC) was used to monitored local surface deformations of the profiles. The test results demonstrated that the HSS utilisation efficiency is dependent on the shape of the cross-section. The FRP profiles have shown specific failure behaviour. The identification of the optimum configuration of the cross-section was identified as the object for further research.

Alternative Finite Element Modeling Technique Of Filament Winding Composite Pressure Vessels

abst. 2243
Virtual Room
Wednesday
September 2
16h15

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In recent years, composite materials have become prominent in the fields of aerospace industry for such systems having high specific strength. One of those systems is high-pressurized composite vessels used for fuel storage manufactured with filament winding process. In manufacturing of composite pressure vessels, filament-winding is commonly preferred for its being relatively inexpensive, precise, and rapid. In design of composite pressure vessels, the loading types such as internal/external pressure, dead loads, vibration and sloshing can be considered. The focus of this study is finite element analysis modelling of composite pressure vessels fabricated by filament winding method under loading of only internal pressure. Composite filament winding is an automated process providing filament placement on a liner by a robot according to a predetermined path as a function of radius of pressure vessel and filament winding angle. Hence, finite element analysis of composite pressure vessel needs modelling of filament winding angle and thickness variation. This study proposes an alternative modelling and analysing approach in the commercial software ABAQUS for solutions of composite pressure vessels. A generic pressure vessel was modelled with the proposed method in ABAQUS. The results were compared with ones obtained from Wound Composite Modeller (WCM) Plug-in used for analysing of composite pressure vessels in ABAQUS. The results are in compatible with WCM.

Mechanical And Thermal Buckling Of Functionally Graded Axisymmetric Shells

abst. 2305
Virtual Room
Friday
September 4
10h15

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In this paper are presented the mechanical and thermal buckling analysis for functionally graded material (FGM) axisymmetric plate-shell type structures, using a developed model based on the Kirchhoff-Love which includes the transverse shear deformations by introducing a penalty function and a conical frustum finite element, which has 2 nodal circles, and 10 degrees of freedom per node. The continuous variation of the materials mixture is approximated by using a certain number of virtual layers throughout the thickness direction - layer approach. A suitable set of applications, including circular plates and axisymmetric shells, had been performed. The influence of the volume fractions, geometric relations, radius R thickness h and length L, with R/h and L/R, and type of temperature distribution through the thickness are shown. The solutions obtained with the present model are compared with alternative solutions obtained using different models, and are in very good agreement with the alternative solutions. Benchmark results are also presented to be compared with results of alternative new models. Acknowledgments: This work was supported by FCT, Fundação para a Ciência e Tecnologia, through IDMEC, under LAETA, project UIDB/50022/2020.

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abst. 2516
Virtual Room
Wednesday
September 2
17h45

Flexural Strengthening of Unbonded RC Beams with the Advanced Carbon Fiber Polymer (CFRP) Composites

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This research studies the effects of CFRP wraps on strengthening beams with unbonded reinforcement. Beams were subjected to unbonded lengths that varied from 0 to full span and the mode of failure was observed. Beams that failed in bond were wrapped with different lengths of CFRP sheets in order to increase the bond between steel reinforcement and the surrounding concrete. The authors concluded that wrapping beams that are subject to bond failure increases the bond between steel reinforcement and the surrounding concrete, flexural strength, and ductility of the beam. Moreover, when the unbonded length was about 95% of the span length, the CFRP wraps restored 95% of the ultimate strength of the control beam and 74% of the mid-span deflection at ultimate, and shifted the mode of failure from bond failure to flexural failure. However, when the length of the unbond was over the full span of the beam, the CFRP wraps failed to restore the flexural mode of failure even though that they restored 90% of the ultimate strength of the control beam and 47% of the mid-span deflection at ultimate.

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abst. 2493
Virtual Room
Wednesday
September 2
16h45

Advanced Higher-Order Mechanical Modelling of Anisotropic Doubly-Curved Shell Structures

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The large use of thin and thick shells as structural elements in many branches of engineering technologies, has gained an increased attention of scientists and engineers for the development of even more refined approaches, to investigate their mechanical behaviour. In this context, we propose a Higher-order Shear Deformation Theory (HSDT) to study the statics and/or dynamics of different anisotropic shells with different geometries, including latticed panels and shells (also named as gridshells). Latticed, anisotropic and composite laminated structures are widely applied in the design of large-span buildings, such as stadia, courtyards, or aerospace structures, due to their high mass efficiency [1]. Their structural

behaviour is generally studied by means of the classical finite element approach and/or continuous models. In this work, instead, we apply an alternative higher-order mechanical modelling of doubly-curved shells, based on a Differential Quadrature (DQ) or Integral Quadrature (IQ) method, to solve the fundamental equations of the problem in a strong or weak form [2-5]. The proposed approach is checked, first, in its accuracy and reliability, through a comparative evaluation between our results and predictions from literature. It follows a systematic investigation for different combinations of the geometrical and mechanical input parameters, which could be useful for practical design purposes of anisotropic shell element structures. Key Words: Anisotropic materials, Doubly-curved shells, Higher-order theories. REFERENCES [1] A.V. Lopatin, E.V. Morozov and A.V. Shatov. Fundamental frequency of a composite anisogrid cylindrical panel with clamped edges. Compos. Struct., Vol. 201, pp. 200 [U+F02D] 207, 2018. [2] F. Tornabene and M. Bacciocchi. Anisotropic Doubly-Curved Shells. Higher-Order Strong and Weak Formulations for Arbitrarily Shaped Shell Structures. Esculapio, 1st edition, 2018. [3] F. Tornabene, and R. Dimitri. Generalized Differential and Integral Quadrature: Theory and Applications. Chapter 14 of the book entitled "Mathematical Methods in Interdisciplinary Sciences", Wiley, ISBN: 978-1-119-58550-3, Ed. by S. Chakraverty, 2020. [4] F. Tornabene, N. Fantuzzi, F. Ubertini and E. Viola. Strong formulation finite element method based on differential quadrature: A survey. Appl. Mech. Rev., Vol. 67(2), 020801, pp. 1 [U+F02D] 55, 2015. [5] F. Tornabene. General higher order layer-wise theory for free vibrations of doubly-curved laminated composite shells and panels. Mech. Adv. Mat. Struct., Vol. 23, pp. 1046-1067, 2016.

An edge-based smoothed three-node composite plate element with refined zigzag kinematics

abst. 2258
Repository

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Multi-layered composite and sandwich structures have become indispensable in different engineering fields due to their high specific stiffness, strength and tailoring capabilities. Such structures are often built up by a sequence of layers of highly heterogeneous materials like fibre reinforced polymers for the thin outer sheets and a thick core layer of low strength. These types of layer setup exhibit a significant transverse shear deformability leading to a cross-sectional distortion which has to be taken into account in the design process. Among the class of theories for the mechanical analysis of shear-elastic laminated structures zigzag theories provide a good compromise between accuracy and computational cost. The so called Refined Zigzag Theory (RZT) has proven to be one of the most promising among this group. Since its first appearance in 2007 (for beams) and 2009 (for plates) considerable efforts have been made in the development of numerical tools and the assessment of the theory. The present contribution focuses on the numerical assessment of a variant of Versino´s triangular plate element for the analysis of composite and sandwich plates. The RZT ensures that C0-continuous functions can be used in finite element approximations. Thus Versino and co-workers have applied low order (linear) interpolation functions for the kinematic variables with the exception of the transverse deflection for which an anisoparametric approach has been used. This guarantees that no shear locking occurs. An element node has seven degrees of freedom, three displacements concerning the reference plane, two standard rotations as present in the first order shear deformation theory and two additional zigzag rotations. While the deformations show a good convergence (without the necessity of a shear correction factor) a very dense mesh is required to get stresses of satisfying accuracy especially near zones of warping constraints. About 10 years ago G.R. Liu and co-workers presented a new family of methods called the smoothed finite element method (S-FEM) which combines the standard FEM with techniques from the meshfree methods. Studies have proven that S-FEM models behave softer than the FEM counterparts, produce more accurate solutions, higher convergence rates, and much less sensitivity to mesh distortion. They are able to significantly improve the results concerning functional gradients, especially when using elements of low order. This approach has proved to be successful for well-known solid and structural elements like the constant strain triangle (CST), the Mindlin triangular plate element (MIN3) and the discrete shear gap element (DSG). We use the so-called edge-based smoothed element technique (ES-FEM) to

improve the per-formance of Versino´s triangular plate element which includes the CST-interpolation for the in-plane deformations and the MIN3-approach for the transverse deflection of the reference plane. The numerical tests are performed with irregular meshes and show a significant improvement of the convergence rate of deflections for thick and thin plates respectively. In relation to the standard FEM the ES-version shows a lower sensitivity to mesh irregularities and more accurate stress results. Versino D., Gherlone M., Mattone M., Di Sciuva M., Tessler A.: C0-triangular elements based on the refined zigzag theory for multilayered composite and sandwich plates. Composites Part B: Engineering 2013, 44(1), 218-230. Liu G.R., Nguyen-Thoi T.: Smoothed finite element methods. 2010, CRC Press New York.

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abst. 2373
Repository

An efficient approach for buckling and post-buckling analysis of sandwich structures

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This paper aims to propose an efficient and accurate framework for the buckling and post-buckling analysis of sandwich structures. Correspondingly, efforts are made in two aspects, i.e., the model and the nonlinear solver. A robust one-dimensional sandwich model is firstly established, in which the skins are described by Euler–Bernoulli beam theory, while the core layer is approximated by high-order functions. Green–Lagrange strains are used for accurately describing large deformations in both skins and core layer. The resulting nonlinear equations are then solved by an efficient and robust path-following technique, i.e., the Asymptotic Numerical Method (ANM), in which the bifurcation indicator is introduced to precisely detect bifurcation points and the corresponding instability patterns. Several typical instability phenomena are investigated and numerical results demonstrate that the proposed approach is able to accurately characterize the instability phenomena of sandwich structures with few computational cost.

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abst. 2500
Repository

A computational framework to investigate snap-through behaviors of composite shell structures

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This paper aims to propose an efficient and reliable computational framework for studying snap-through behaviors of composite shell structures. Towards this end, efforts are made in four aspects: (1) the shell model, (2) nonlinear solver, (3) detection of critical points and (4) identification of stable states. Firstly, by introducing an extra linear strain into a 6-parameter shell formulation, an equivalent single layer shell model is established, which accounts for large deformations and enables convenient usage of complete three-dimensional (3D) constitutive laws without condensation. Secondly, a power-series based continuation algorithm, i.e., Asymptotic Numerical Method (ANM) is utilized to efficiently trace the complex equilibrium paths. Furthermore, a bifurcation indicator integrated with the ANM is used to accurately detect the evolution of critical points and the corresponding buckling modes. Finally, the nature eigenfrequency is adopted as a criterion to identify the stable/unstable states of a shell at any load level. Snap-through phenomena (e.g., bistability and tristability) of laminated shells are investigated to demonstrate the accuracy and efficiency of the proposed computational framework, via comparison with experiments. The initial geometric imperfection and stacking sequence is found to have a 'stabilization effect' on equilibrium paths and stable configurations. This study provides a reliable and methodological tool for stability analysis of composite shells, and has a potential application for

the design of advanced morphing structures, e.g., the airfoil in aerospace. Acknowledgment: This work has been supported by the National Natural Science Foundation of China (Grant Nos. 11920101002).

Structure-Genome-Driven computing for composite plates

abst. 2501
Repository

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This work aims to propose a Structural-Genome-Driven (SGD) method for the numerical simulation of composite plates. The idea is to correlate data-driven computing with plate models, and drive mechanical simulation by generalized stress and strain genome. Taking the Kirchhoff plate model with complex micro-geometry and variable material properties as an example, the internal work of the plate is determined by internal forces and moments. Therefore, the structural-genome databases consist of two sets: internal force and neutral plane strain, as well as internal moment and neutral plane curvature. Both sets of databases can be constructed offline by practical experiments or numerical experiments such as tension, compression, shear, bending, and torsion. In this work, the databases are constructed by the multiscale finite element (FE2) method. This method can correctly simulate the structural response of composites with irregular micro-heterogeneity. Then, the analysis for Kirchhoff plate model is carried out by assigning to each integration point the best local state (structural genome) from offline databases. Compare to data-driven computing using solid finite element model, SGD computing using plate model can significantly reduce both the dimensionality of databases and the integration points for composite plates. Acknowledgment: This work has been supported by the National Natural Science Foundation of China (Grant Nos. 11920101002).

Data-driven multiscale finite element method for composite structures

abst. 2502
Repository

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This work aims to propose a novel data-driven multiscale finite element method (Data-driven FE2) for the analysis of composite materials and structures. It consists of two steps: the first one is to construct a material genome database by calculating the microscopic problems in the Representative Volume Element (RVE); the next step is to conduct the analysis of the macroscopic problem by using the data-driven approach, in which the main idea is to assign to each integral point the best local state (stress and strain data) from the material genome database. Compared to the classical FE2 method, the proposed data-driven FE2 method allows to separate the correlated scales, namely the microscopic and the macroscopic scales, and to improve significantly the online computational efficiency of structural analysis of composite materials. Acknowledgment: This work has been supported by the National Natural Science Foundation of China (Grant Nos. 11920101002).

Static and Free Vibration Analysis of FGM Beam Based on Unified and Integrated of Timoshenko's Theory

abst. 2054
Repository

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In this paper, a higher-order element based on the unified and integrated approach of Timoshenko beam theory is developed. A two-node beam element with Hermitian functions of a 5th-degree polynomial (4 DOFs per node) called UI element is proposed to solve the problems of static and free vibration. In this proposed element, the Timoshenko beam theory is modified in such a way to prevent shear locking while taking account of the transverse shear effect. The static and free vibration analyses are used to obtain the displacements and natural frequencies of rectangular Functionally Graded Material (FGM) beam for hinged-roll, clamped-free and clamped-clamped boundary conditions and to study the effects of the power-law exponent (coupling of the anisotropic material) on the displacements and natural frequencies. Results of the present work are compared with the published data to learn the effectiveness of the proposed element and to verify the validity of the model theory. The numerical analysis shows that the coupling of axial-bending should be taken into consideration in static and vibration analysis of FGM. The comparison study confirms the accuracy and the efficiency of the proposed element for static and vibration analysis of FGM beam.

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abst. 2628
Virtual Room
Wednesday
September 2
17h30

Finite element analysis of PPF controller efficiency to vibration suppression of composite beam

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A finite element model of a tested composite structure is developed in Abaqus software. The structure consists of glass-epoxy composite beam with embedded Macro Fiber Composite (MFC) piezoelectric actuator and Positive Position Feedback (PPF) Controller. To model individual layers of laminate beam the layup-ply technique is applied. However, to include PPF controller a special subroutine is created. The developed code of control algorithm solves additional second order differential equation using fourth order Runge-Kutta method. Based on measured beam response the subroutine allows to calculate desired control signal. This signal is used to supply proper voltage the piezoelectric actuator. The active patch is defined as piezoelectric material and its generated voltage giving control signal as an electric boundary condition. The numerical dynamic analysis was performed using implicit procedure. The obtained results allow comparison beam responses with and without controller activation. The control subsystem model includes the hysteresis phenomenon of piezoelectric actuator and first order inertial effect of controller. Finally, the PPF controller efficiency to beam vibration suppression is determined. The present study was supported by statutory resources allowed to the Department of Applied Mechanics, the Lublin University of Technology under "The Grant for Young Researchers" no. FNM 30/IM/2019.

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abst. 2534
Repository

The dynamics of microheterogeneous non-symmetric sandwich plates

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One of the most crucial type of composites used nowadays is a sandwich structure. It is a large and diverse group of multi-layered composites, which outer layers are usually made of materials characterised by high mechanical properties, while the inner layers are usually a lightweight and/or porous materials. In literature, one can find many different modelling approaches towards such structures, such as: a broken line hypothesis, first and higher order deformation hypothesis, equivalent single layer theory or Zig-Zag hypothesis. Most of the aforementioned approaches is dedicated to sandwich structures, which are symmetric towards its midplane. In this paper, the modelling of a composite, which is not symmetric towards its midplane, which may be required by a specific engineering issue, is presented. The modelling approach will be based on the broken line hypothesis. It will be shown, that by adjusting several assumptions, with the use of the mentioned hypothesis it is possible to describe the dynamic

behaviour of three-layered not-symmetric sandwich plate. The static analysis of the similar structures was developed by Frostig and Shenhar [1], Magnucka-Blandzi et al. [2] or Chakrabarti and Bera [3]. In our considerations an extension of proposed models will be shown, as it will be assumed, that every each layer of the considered plate can be characterised by a specific periodic microstructure, such as: periodically varying thickness and/or material properties. The derived initial governing equations constitute a system of partial differential equations with periodic, non-continuous and highly-oscillating coefficients, which is very difficult to solve. In order to investigate the behaviour of such structure, the tolerance averaging technique, developed by Woźniak et al. [4,5], will be used. The mentioned technique has a lot of applications in the structural dynamics, such as: vibrations of Timoshenko beams [6], medium thickness plates [7] or shell structures [8]. In the following paper, the issue of the free vibration analysis of a specific sandwich plate will be investigated and the obtained results will be compared with the FEM model. References 1. Frostig Y., Shenhar Y., 1995: High-order bending of sandwich beams with a transversely flexible core and unsymmetrical laminated composite skins. Composites Engineering, 5:405–414. 2. Magnucka-Blandzi E., Kędzia P., Smyczyński MJ., 2018: Unsymmetrical sandwich beams under three-point bending – analytical studies. Composite Structures, 202:539–544. 3. Chakrabarti A, Bera RK., 2002: Nonlinear vibration and stability of a shallow unsymmetrical orthotropic sandwich shell of double curvature with orthotropic core. Computers and Mathematics with Applications, 43: 1617–1630. 4. Woźniak C. (eds.), 2010: Mathematical modelling and analysis in continuum mechanics of microstructures media, Publishing House of Silesian University of Technology, Gliwice. 5. Woźniak C., Michalak B., Jędrysiak J., 2008: Thermomechanics of microheterogeneous solids and structures, łódź Technical University Press, łódź. 6. Domagalski ł., Świątek M., Jędrysiak J., 2019: An analytical-numerical approach to vibration analysis of periodic Timoshenko beams. Composite Structures, 211:490–501. 7. Baron E., 2006: Mechanics of periodic medium thickness plates (in Polish). Publishing House of Silesian University of Technology, Gliwice. 8. Tomczyk B., Szczerba P., 2018: A new asymptotic-tolerance model of dynamic and stability problems for longitudinally graded cylindrical shells. Composite Structures, 202:473–481.

Semi-analytical optimal solution for maximum buckling load of simply supported orthotropic plates

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abst. 2035
Virtual Room
Friday
September 4
08h30

The buckling behavior of rectangular orthotropic plates under axial compression with simply supported boundary has been studied for a long time. To improve the structural efficiency, the stacking sequence of laminate should be optimized to maximize the critical buckling load. In this work, the discrete stiffness parameters are introduced and they are employed to derive the theoretical optimal ply orientation corresponding to the maximum critical buckling load at layer level, in which the buckling mode shapes are calculated analytically based on a previous study. Afterward, the optimal ply orientation based derivation is performed to obtain the optimal stacking sequence of the laminate, where a sign vector is involved to minimize the bending-twisting coupling effects. As a result, two laminate optimal design problems are solved: maximizing the critical buckling load with a fixed thickness or minimizing the thickness with buckling constraint. Two numerical examples are adopted to verify the derived optimal solutions, and finally, the theoretical optimal ply orientations with various load ratios and aspect ratios are provided.

HOHWM for free vibration analysis of FGM nanobeams

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abst. 2183
Virtual Room
Friday
September 4
15h45

The higher order Haar wavelet method (HOHWM) is adapted for vibration analysis of functionally graded nanobeams. The complexity analysis of the HOHWM is performed. It has been shown that in the case of vibration analysis and particular boundary conditions both the FGM and small scale have impact on complexity of the HOHWM. Special attention is paid on cantilever beam. The local and nonlocal boundary conditions are analysed in the case of several particular load conditions.

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abst. 2665
Repository

INFLUENCE OF SPATIALLY VARYING MATERIAL PROPERTIES ON THE BIMOMENT NORMAL STRESSES BY WARPING TORSION

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Abstract. In the contribution, the influence of the spatially varying material properties on bimoment normal stresses by non-uniform torsion of the Functionally Graded Material (FGM) beams is investigated. The FGM beam finite element [1,2] is used for calculation of the primary variables like the twist angle, the part of the bicurvature, the bimoment and primary and secondary torsional moments for the homogenized beams. The warping part of the bicurvature caused by the bimoment is considered as an additional degree of freedom at the beam nodes. The Multi-Layers Method (MLM), [3], and the Reference Beam Method (RBM), [4] are extended for homogenization of the spatially varying material properties and relevant stiffnesses in the real beam onto effective longitudinally varying ones in the homogenized beam for its non-uniform torsion. The warping and Deformation Effect due to the Secondary Torsional Moment (STMDE) is considered in torsional elastostatic analysis of straight FGM beams. The secondary variables are calculated for the real beams with spatially varying material properties. The focus of the numerical investigation is on research of the influence of the varying material properties on the warping ordinates and the bimoment normal stresses distribution in the FGM cross-sections. An effect of the cross-sectional walls thicknesses on the bimoment normal stresses distribution will be studied and evaluated. The obtained results are compared with the ones calculated by a very fine mesh of standard solid finite elements. Acknowledgement: The authors gratefully acknowledge financial support by the Slovak Grant Agency of the project VEGA No. 1/0102/18. References: [1] Aminbaghai, M., Murin, J., Kutis, V., Hrabovsky, J., Kostolani, M., Mang, H.A. Torsional warping elastostatic analysis of FGM beams with longitudinally varying material properties. Eng. Struct. (2019) 200: 100694. [2] Murin J, Aminbaghai M, Hrabovsky J, Balduzzi G, Dorn M, Mang HA. Torsional warping eigenmodes of FGM beams with longitudinally varying material properties. Eng Struct (2018) 175: 912 – 925. [3] Murin, J., Aminbaghai, M., Hrabovsky, J., Gogola and R., Kugler, S. Beam finite element for modal analysis of FGM structures. Eng. Struct. (2016) 121: 1- 18. [4] Kugler, S., Fotiu, P.,Murin, J. On the access to transverse shear stiffness and to stiffness quantities for non-uniform warping torsion in FGM beam structures. J. Mech. Eng. (2019) 69: 27-56.

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abst. 2328
Repository

Analytical modeling of fatigue crack growth in Fiber Metal Laminates

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Fiber metal laminates (FML) are layered materials consisting of fiber-reinforced polymers and metals. FMLs are featured by excellent resistance to fatigue crack growth, which is ensured by the 'bridging effect' - a load transfer from already cracked metal layers into intact fibers through the adhesive joint. As a consequence of the 'bridging effect', the stress intensity factor at the already formed fatigue crack tip is decreased which strongly reduces fatigue crack growth rate, when compared to the monolithic metals. Many analytical, experimental and phenomenological models have been invented to predict fatigue crack growth rate in FMLs. However, most of them require a cumbersome calculation of crack tip opening displacement and bridging load over the delamination shape. This study aims to present a new simplified analytical model, based on Classical Lamination Plate Theory for the prediction of fatigue crack growth in FML with arbitrary layup and configuration, as well as for arbitrary crack lengths. The proposed model is based on the concept of load redistribution corresponding to fatigue crack growth. Analytical predictions were validated by a series of experimental tensile-tensile fatigue crack growth tests performed on fiber metal laminates reinforced by glass, carbon and hybrid glass/carbon fibers, while a good convergence of results was obtained. Acknowledgements: This research was financed by the National Science Centre, Poland [UMO-2016/23/N/ST8/02033].

The post-critical behaviour of compressed plate with non-standard play orientation

abst. 2205
Repository

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Thin-walled carbon/epoxy composite plate elements with a central cut-out under compressive loading are investigated. The work focused on the original concept of this element, for use as elastic or load-bearing elemen and whether possibility to shape their structural rigidity by changing the cut-out geometry or the laminate's lay-up. The natural, lowest buckling mode of thin-walled plates under compression is flexural mode. This mode exhibits a small postcritical rigidity and is reached at low loads. The calculations carried out earlier show that plates with forced higher form of buckling are characterized by stable, progressive paths of post-critical equilibrium, enabling their use as elastic elements. The characteristics of such elements can be designed in a wide range by changing the geometrical parameters of the cut-out (height and width) as well as by changing the angle of fiber arrangement. The aim of the study, partially revealed in this abstract, requires a thorough analysis of the effect of the B matrix form on the coupled composite behaviour. Coupling stiffness matrices of unsymmetrical laminates have been thoroughly described by, among others, York, Altenbach. The commercial ABAQUS program using the finite element method was used to develop the discrete model and perform numerical calculations. Experiment was performed on a universal testing machine. The obtained results are of significant practical importance in the design of structures with elastic elements, allowing to achieve the required maintenance characteristics of the device. The research reported in the paper was conducted under the project UMO-2017/25/N/ST8/01066 financed by the National Science Centre Poland.

Analysis on the characteristics of the railway track with two-dimensional Meta dampers employing impact particles

abst. 2257
Repository

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Tuned particle impact damper was proposed as a rail vibration control treatment. When the dampers are mounted on the railway track, the effect of the meta damper occurs. In order to evaluate the rate of attenuation of vibration along the rail beam with different types of meta dampers, an infinite length of railway beam on a continuous two-layer foundation is considered. The equation of motion of the rail

beam attached with two-dimensional meta dampers was induced by the Hamilton's principle. Assuming the displacements the system as harmonic responses, the wavenumber, the frequency-dependent bending stiffness, the decay rate and loss factor of the rail track can be calculated. Thus the relationship between two-dimensional motion of the meta damper and railway track vibration can be indicated.

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abst. 2458
Repository

Experimental study on mechanical behavior of three-layer toughened sandwich glass with trilateral simple support

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To study the mechanical behavior of three-layer toughened sandwich glass with trilateral simple support under in-plane bending load, a total of sixty-four specimens with different test parameters were experimentally investigated in this paper. The main parameters of specimens include thickness of single layer, supporting width and loading length. It was demonstrated that the specimens failed with all pieces of cracks combined together as an entire unit rather than separated into a large number of glass fragments. What's more, the cracks appeared only in the lower layer of the toughened sandwich glass, which extended in a way similar to the spider web. The ultimate bending strength and bending rigidity of the toughened sandwich glass are enhanced with the increase of the thickness of single layer, the supporting width and the loading length. Among the above parameters, the thickness of single layer plays a leading role in enhancing the ultimate bending strength and bending rigidity of the toughened sandwich glass. Nevertheless, the supporting width only has a slight effect on enhancing the ultimate bending strength and bending rigidity. In addition, the simplified design formulas were presented to evaluate the ultimate bending strength of three-layer toughened sandwich glass with trilateral simple support under in-plane bending load, which was verified to be reasonable and accurate.

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abst. 2662
Virtual Room
Wednesday
September 2
17h15

A Novel GBT-Formulation for Thin-Walled FGM-Beam-Structures Based on a Reference Beam Problem

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The mechanical properties of long to moderately short beams are typically analyzed under the assumptions of Classical Beam Mechanics (CBM), where any in-plane cross-sectional deformations (distortions) are neglected. Out of plane warping deformations are only included if non-uniform warping torsion is incorporated. However, it can be shown by examples in [1] that the dynamic response of shafts with rectangular thin-walled box-type cross-sections will be heavily affected by distortions. In these examples CBM predicts only the first torsional mode correctly, while at higher frequencies gross deviations from the exact solutions are encountered. This deficiency can be resolved by applying a Generalized Beam Theory (GBT), where a two-step algorithm includes distortions and warping deformations. The first step encompasses a cross-sectional analysis, where warping and distortions fields are defined, and in a second step, termed member analysis, those deformation fields are weighted along the axial dimension. (see e.g. [2]). The novelty of this approach lies in the fact that warping and distortions fields are evaluated from the dynamic analysis of a Reference Beam Problem (RBP). In this RBP the cross-section is discretized by plane Semi-Analytical Finite Elements (SAFE). The SAFE approach [3] interpolates three-dimensional displacements of the RBP with plane element shape functions over the cross-section and a Fourier series expansion along the beam's length. In the Fourier series representation, we select sine functions for lateral and transverse displacements and cosine functions

for axial displacements. Convergence of the SAFE approach compared to 3D-continuum formulations is proven by increasing the wave numbers. The key idea of the proposed procedure is to use only the FIRST wave number for a free vibration analysis (modal analysis) of the RBP. Each resulting eigenvector in ascending order of the corresponding eigenvalues (resonance frequencies of the RBP) is split up into couples consisting of out of plane warping fields and in-plane distortion fields (see [1]). Since in-plane distortions primarily influence the mechanical properties of thin-walled beams, the efficiency of this formulation can be further enhanced by using one-dimensional line elements in the cross-sectional discretization instead of plane elements. Then, the SAFE approach has to be reformulated regarding a novel Semi-Analytical Finite SHELL Element (SAFSE) shear elastic concept, where at each node three displacements and three rotations have to be interpolated. This concept requires the incorporation of drilling rotations which are included via a recently published functional [4]. Arbitrary inhomogeneities throughout the wall-thickness can be introduced by proper homogenization procedures, delivering a highly efficient and accurate method for the dynamic analysis of thin-walled composite and FGM structures. Acknowledgment: The authors gratefully acknowledge financial support by the Slovak Grant Agency of the project VEGA No. 1/0102/18. References: [1] S. Kugler, P. Fotiu, J. Murin, Analysis of Shells, Plates and Beams: A State of the Art Report, Springer, 2020, Ch. Beam Dynamics Using a Generalized Beam Theory Based on the Solution of a Reference Beam Problem. [2] E. Sapountzakis, A. Argyridi, Influence of in-plane deformation in higher order beam theories, Journal of Mechanical Engineering - Strojnicky Casopis 68 (3) (2018) 77–94. [3] O. C. Zienkiewicz, R. L. Taylor, Finite Element Method: Volume 2, Solid Mechanics (Finite Element Method), Butterworth-Heinemann, 2000. [4] S. Kugler, P. Fotiu, J. Murin, A highly efficient membrane finite element with drilling degrees of freedom, Acta Mechanica 213 (2010) 323–348.

Analysis of composite laminated thin shells in finite deformation using p-version curved C1 finite elements with QRM geometries

abst. 2475
Repository

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For thin shell analysis, the kinematic model based on the classical lamination theory (CLT) is considered to be very efficient and robust, and able to produce sufficiently accurate results. However, the difficulty of satisfying the C1 conformity, especially on curve element boundary, makes this model less popular in standard displacement based finite element community. In the authors' recent work, novel p-version curved C1 finite elements were developed for thin plates, and very good convergence performance was achieved. In this work, the proposed elements will be extended to the analysis of laminated thin shells with general curved shapes. The difficulty of satisfying the C1 conformity on surfaces is simply solved by the interpolation of normal derivatives on Gauss-Lobatto nodes. Since high-precision geometry model is required in the p-version finite element discretization, the quasi region mapping (QRM) technique, which is very similar to the differential quadrature (DQ) method, is employed as a general method to create highly accurate curved meshes. Implementation details are also addressed for real-life CAD models. Benchmark problems of large-deflection and post-buckling analysis of laminated thin shells are presented to illustrate the accuracy as well as fast convergence of proposed method.

Three-Dimensional Elasticity Analysis of Sandwich Circular Cylindrical Shell by Numerical Integration Approach

abst. 2018
Repository

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Sandwich panels are used in a variety of engineering applications such as aircraft, construction, and transportation where strong, stiff and light structures are required. The major concern in the case

of sandwich panels is the delamination between core and face-sheets arising from the mismatch of properties between the core and the face sheets. Studies show that the resistance of sandwich panels to this type of failure can be increased by varying the material properties of the core. Hence the concept of a functionally graded (FG) material is being actively explored in sandwich panel construction. The accurate analysis of the stresses acting on the transverse planes, which are responsible for delamination is also very important. Only three dimensional (3-D) elasticity theories take into account all the stresses in the analysis and provide an accurate estimate of them. Therefore in the present work, a 3-D elasticity solution is presented using a numerical integration technique for a sandwich circular cylindrical shell with FG core. The sandwich circular cylindrical shell considered here is assumed to be in a state of plane strain. The shell is symmetric with respect to its mid surface. The modulus of elasticity varies exponentially whereas the Poisson's ratio is held constant. The proposed method is a numerical integration approach that makes use of all the equations of 3-D elasticity without making any simplifying assumptions in the formulation, and then the solution is obtained using a numerical integration technique. Also, the proposed approach is based on mixed formulation technique, hence the displacements and stresses are evaluated simultaneously with the same degree of accuracy.

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abst. 2450
Repository

NONLINEAR FORCED VIBRATIONS OF LAMINATED COMPOSITE CONICAL SHELLS BY USING A REFINED SHEAR DEFORMATION THEORY

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Nonlinear forced vibrations of laminated composite conical shells are investigated by using a higher-order shear deformation theory that includes rotary inertia and geometric nonlinearity in all the kinematic parameters. The system was discretized by using trigonometric expansions. The convergence of the solutions was studied versus the number of degrees of freedom retained in the model. The nonlinear vibration response of laminated composite conical shells to harmonic excitation was studied for different cone angles: hardening and softening response were found according to the geometry. Due to the axial symmetry, a one-to-one internal resonance appeared, as well as quasi-period vibrations. The effect of different lamination sequences on the nonlinear forced vibration response was investigated.

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abst. 2498
Repository

BUCKLING MODES AND CRITICAL BIAXIAL STRESSES IN CRUCIFORM SPECIMENS UNDER COMPRESSION

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This work presents an analytical and numerical novel investigation about the elastic stability of cruciform specimens of symmetric $\pm 45^{\circ}$ angle-ply CFRP laminates biaxially loaded. The use of an anti-buckling device is proposed to reduce the risk of instabilities in the compressed arms of the sample. Therefore, the investigation is focused on the buckling features of the tapered central region of the specimen that is submitted to biaxial loads. As first step, the free-surface of the central region is isolated and modelled as a rectangular thin-plate, either simply-supported or fixed. Then, an analytical study is developed based on the use of buckling effective lengths (-coefficients) for calculating the bifurcation values from the buckling modes found numerically. Afterwards, this methodology facilitates the estimation of the bifurcation stresses in the tapered region of the cruciform specimen with design purposes. Besides, virtual testing allows to understand the influence of the arms-to-centre thickness-ratio on the compressive load that destabilises the cruciform sample for deciding its optimal geometry in presence of compression. Along with the determination of the stability region in the biaxial plane, this is the first investigation in which the pseudo-ductile effects of $\pm 45^{\circ}$ angle-ply CFRP laminates under biaxial loading are predicted using the Tsai-Wu criterion. The results are compared successfully

with experimental observations from biaxial testing, in which the geometry of the cruciform specimen is adapted to present good failure modes at different loading ratios.

Critical buckling loads of three-phase composite plates reinforced by oriented straight fibers and Carbon nanotubes

abst. 2090
Repository

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The critical buckling load of a structure represents the value of an external applied force that could generate its loss of stability. It is well-known that the structural behavior of plates is also affected by the application of in-plane compression loads. A rapid deflection could happen in this circumstance due to the buckling instability, when the so-called critical buckling load is reached. Laminated composite plates are affected, as well. The main aim of the research is to provide useful outcomes to design laminated and sandwich plates reinforced by both randomly oriented Carbon nanotubes (CNTs) and straight oriented fibers. In fact, CNTs have allowed to improve the mechanical features and the structural response of a composite structure. The introduction of such reinforcing nanoparticles in a polymeric matrix, combined with the usual straight fibers, allows to modify the buckling resistance of such structural systems. The three-phase layers are characterized by means of a multiscale approach. The theoretical framework is developed starting from the bases provided by the Reissner-Mindlin theory for laminated plates and the von Kármán hypothesis for the definition of the nonlinear terms of the strain field. The solutions are achieved numerically by means of the Finite Element Method and validated through the comparison with the experimental and theoretical results available in the literature.

Modeling of material nonlinearity in reinforced concrete beams and shells for seismic analysis

abst. 2351
Virtual Room
Friday
September 4
15h00

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The main objective of this research is to create a structural reinforced concrete shell finite element model that accounts for nonlinear material behavior in seismic analysis. This shell model should be relatively accurate and computationally efficient in order to be integrated into finite element analysis softwares. In addition, this model should be convenient for pushover and nonlinear time history analysis. We should note that material nonlinearity in structural elements can be modeled in two forms: concentrated or distributed. Concentrated nonlinearity approach considers all the nonlinear behavior to be occurring in zero length point hinges while the rest of the element remains elastic linear. For one dimensional finite elements (beams), this approach gives acceptable results. However for two dimensional finite elements (shells) and in order to get acceptable results, the nonlinearity needs to be distributed all over the surface element and not just concentrated in point hinges. As a consequence and since our target is to model shell elements, we will be modeling the nonlinearity in a distributed form (fiber hinge for beams and layered shell for 2D elements). The fiber hinge concept consists in dividing the

reinforced concrete beam section into a set of longitudinal fibers. Each fiber follows the nonlinear uni-axial stress strain curve corresponding to its specific material (unconfined concrete, confined concrete or steel reinforcement). The overall behavior of the section is then obtained from the summation of all the fibers. Same concept applies to 2D shell elements (layered shell) but instead of having longitudinal fibers acting in one dimension, we have layers acting in two dimensions. At first, the proposed approach is implemented on a Reinforced Concrete (RC) beam element for validation. Once the approach is validated, we implement it for modeling RC shell elements. As a startup, a fiber hinge beam model was implemented in Matlab and the Newton-Raphson method was used for nonlinear calculations. This model is validated under static constant loads, quasi static cyclic varying loads and dynamic loads (by using a direct integration nonlinear time history analysis based on Newmark method). After validating all the beam models, an extension from beam to shell element (fiber hinge to layered shell) is presented. In addition, a perspective of this work is to improve the modeling of viscous damping for the nonlinear time history analysis.

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abst. 2311
Repository

Bending, Vibrations And Buckling Of Cross- And Angle-Ply Nano Plates Using Strain Gradient Theory

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Nanomaterials and nanostructures are emerging technologies in engineering and industry. Such structures generally made of different materials have a global behavior which depends on the material nano scale. Classical Laminated Theory (CLT) is not sufficient to capture some effects present in nano plates therefore a novel strain gradient theory which depends on a nano scale length parameter is preferred. The static analysis of Kirchhoff nano plates subjected to uniformly (UDL) and sinusoidally (SSL) distributed load is computed as well as vibrations and buckling problems. The solution is found in analytical form using classical Navier approach which is valid for simply-supported plates and cross- and angle-ply lamination schemes. Dimensionless outcomes in terms of transverse displacements, and normal and shear stresses, are given to changing aspect ratio and non local ratio, also making a comparison with the classical theory. Moreover, different geometries and material properties for isotropic, orthotropic cross- and angle-ply laminates are considered, and numerical simulations are discussed in terms of plate aspect ratio and non local ratio. A comparison with the classical analytical solution is provided whenever possible for buckling loads and fundamental frequencies.

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abst. 2383
Repository

A Study of Acoustic Noise Reduction for Wide Frequency Range Using Composite Meta-materials

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Unlike outside noise, the noise of household appliances, which is the noise generated in closed homes, is likely to cause discomfort to residents. In particular, dishwasher is regarded as a major noise source in homes because water is sprayed to generate water sound on the metal plate of the dishwasher and noise is radiated into the air as it is. It is important to develop damping elements that can cover a wide range of frequencies, as noise from metal collisions of water is distributed over a wide frequency range. Nowadays, many kinds of appliance are applied with felt or rubber type sound absorption materials to reduce noise. However, these factors have the effect of greatly shortening the lifespan, and increasing costs and weight. Friction damping system shows good damping performance at low frequencies and collision system show damping performance at high frequencies in the beam experiments. In order to increase the space and cost effectiveness, the two elements were combined and the structure was tested in the beam. The two damping elements showed a complementary relationship, and resulting in better

performance than when applied alone respectively. To increase the collision effect, acoustic blackholes were applied and show more enhanced in damping performance. From this research, it is expected that this will be a basic research to develop a factor that shows excellent damping performance for a wide range of frequency bands of home appliances

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The influence of the laminate code, curing process parameters and residual stresses on buckling and post-buckling behaviour of thin-walled composite columns with a square cross-section

abst. 2147
Virtual Room
Friday
September 4
10h45

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The object of this study is to investigate the influence of laminate code (layup) and curing process parameters on the formation of residual stresses and, as a consequence, buckling and post-buckling behaviour of thin-walled thin-walled, composite columns with a square cross-section. Under inspection is taken static compression of the columns made of eight-layered glass fibre prepreg tape with five different layups. The cross-sectional dimensions of the columns are equal to (width $\times$ height $\times$ thickness): 80 mm $\times$ 80 mm $\times$ 1.2 mm. The length of the columns is equal to 250 mm. The columns were manufactured using two different types of autoclaving process parameters – the first process type was fast curing on empty aluminium mandrel, while the second one was slow, on full aluminium mandrel. The object of this operation was to obtain a different accumulation of the heat in the core and, accordingly, different distribution of the residual stresses inside the material. Four specimens per each layup group and particular process type were later subjected to static compression. The tests were performed on an Instron universal test stand with a constant compression rate equal to 1 mm/min. To gather information about the deformations of the columns, contactless digital image correlation system GOM ARAMIS ® was employed. Thanks to this, it was possible to inspect the equilibrium paths, calculate critical forces and determine post-buckling stiffness of the columns. The results were compared and this enabled to state how the laminate code and curing process parameters affect the stability of the columns.

On the bifurcation buckling and vibration of porous nanobeams

abst. 2512
Repository

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In the present paper, effects of porous material on bifurcation buckling and natural vibrations of nanobeams are investigated based on the higher-order nonlocal strain gradient theory. The displacement field of the nanobeam satisfies assumptions of Reddy higher-order shear deformation beam theory. The displacements gradients are assumed to be small so that the components of the Green-Lagrange strain tensor are linear and infinitesimal. Effect of Winkler-Pasternak foundation on mechanical behavior of nanobeam is also considered. The constitutive relations for functionally graded porous material are expressed by nonlocal and length scale parameters and power-law variation of material parameters in conjunction with cosine functions. It created a possibility to investigate the effect of functionally graded materials with diverse distribution of porosity and volume of voids on mechanics of nanostructures. The Hamilton's variational principle is utilized to derive governing equations of motion of the composite nanobeam. Analytical solutions to the boundary value problems are obtained in closed-form. Validation of obtained results and comprehensive parametric studies are presented. For the first time, the critical porosity is defined and examined for bifurcation buckling analysis of elastically supported nanobeams with symmetric distribution of porosity. Influence of axial forces and types of porosity distributions on eigenfrequencies of functionally graded nanobeams is studied. Classical theory without nonlocal effects is obtained as a special case when values of nonlocal and length scale parameters are taken to be the same. It is established that these phenomena are valid for all considered distributions of functionally

graded material and volume fractions of voids. Acknowledgements: Project financing through the program of the Minister of Science and Higher Education of Poland named "Regional Initiative of Excellence" in 2019 - 2022 project number 011 / RID / 2018/19 amount of financing 12,000,000 PLN.

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abst. 2627
Virtual Room
Friday
September 4
08h45

Wave propagation in thin pretwisted and delaminated composite strips

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Thin pretwisted composite strips are being used as structural components in the field of aerospace in rotors of helicopter, turbine blades, propellers, etc. Structural analysis and monitoring the health of such components is necessary for an assembled unit to deliver its functionality. Nonlinearity and coupling between different modes associated with pretwist along with the anisotropy of the material complicates the theoretical framework and analysis of pretwisted strips. Modeling and analysis is further complicated if damage is present in the structure. In this work, thin pretwisted composite strips with delamintions have been modeled using variational asymptotic method (VAM). Within this framework, the actual 3D problem is conceived to be a combination of a 2D cross-sectional analysis followed by a 1D analysis. In general, both 2D cross-sectional analysis and the 1D problem can be nonlinear. Delamination is modeled using sub-laminate method. The energy of the strip is expressed explicitly in terms of the geometrical small parameters, naturally present in the structure, and delamination size. The 1D dynamic governing equations for the strip are determined using the Hamilton's principle; these are subsequently used to compute the transient response of delaminated strips using the spectral finite element method (SFE). In this method, the response is determined in the frequency domain and inverted to time domain using the inverse Fourier transform, which is know to be computationally efficient compared to a standard time domain computation using the finite element (FE) method. Consequently, the use of SFE is expected to yield faster results from reduced computations than the FE method for analyzing and monitoring delaminated strips exposed to high frequency excitations. Additionally, it is also shown that VAM and SFE based modeling strategy is also suitable for the inverse problem of damage detection.

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abst. 2686
Virtual Room
Friday
September 4
09h15

Non-linear Vibration of Multi-scale Composite Plate under Non-uniform In-plane Periodic Load

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The non-linear vibration of a randomly distributed carbon nanotube fiber-reinforced composite (CNTFRC) plate under the action of different types of non-uniform in-plane periodic loadings are presented in this article. The effective mechanical properties of lamina of the plate are estimated in two steps. Firstly, the Eshelby-Mori-Tanaka technique is used to compute the effective mechanical properties of randomly distributed carbon nanotubes (CNTs) in a polymer matrix. Secondly, the effective properties of the CNT embedded polymer matrix reinforced with uni-directional carbon fiber are estimated using the rule of mixture technique. The composite plates are modeled considering von-Kàrmàn non-linearity and higher-order shear deformation theory (HSDT). The non-uniform loads are modeled using a different distribution of edge loads such as parabolic, partial and concentrated loads. The analytical expression for stresses distribution within CNTFRC plate due to above mentioned loads is derived by solving the in-plane elasticity problem using Airy's stress approach. Using these stresses, Hamilton's principle is applied to derive the non-linear partial differential equations for non-linear vibration of the CNTFRC plates. Employing Galerkin method, the non-linear partial differential equations are transformed into

a set of non-linear ordinary differential equations. the non-linear ordinary differential equations are solved by using Incremental Harmonic Balance method for analyzing the non-linear vibration behavior of the CNTFRC plate. Finally, the influence of different parameters such as different types of CNT agglomeration models, CNT mass fraction, static and dynamic load factors and different types of non-uniform in-plane loadings on the non-linear vibration of the CNTFRC plate are performed and obtained results will help in appropriate design of CNTFRC plate against nonlinear vibration.

Nonlinear Dynamic Response and Dynamic Instability Study of Laminated Composite Plate

abst. 2689
Virtual Room
Friday
September 4
09h30

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A finite element nonlinear dynamic response and dynamic instability study, of laminated composite plates, subjected to transverse and/or uniform in-plane harmonic edge loading along the two opposite edges, is presented in this paper. The eight-noded degenerated shell element with isoparametric formulation with first order shear deformation theory and C0 continuity of the nodal primary variable is used to model the plate. In this study both linear and nonlinear dynamic response and dynamic instability analysis of the plate are performed. In the nonlinear case, the Green-Lagrange strain displacement relationship with Total Lagrangian approach is adopted in the formulation of the system matrices. The governing nonlinear dynamic equilibrium equation of the plates is solved using both dynamic implicit and explicit formulation in combination with the Newton-Raphson iteration method. The effect of amplitude and frequency of the dynamic load, on the response of the plates are considered in the present study and the results are reported. The nonlinear amplitude-frequency analysis is carried out using IHB(Incremental Harmonic Balance) method.

Analytical solution for viscoelastic composite shells

abst. 2485
Repository

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In this work, an advanced analytical formulation for frequency response and damped free-vibration analysis of composite shell structures with viscoelastic inter-layers is proposed. The governing equations are derived from the Principle of Virtual Displacement (PVD) [1] and are solved analytically by the use of the Navier method [2]. Layer-Wise models related to linear up to fourth order variations of the unknown variables in the thickness direction are treated. The modelization of multilayered structure materials takes into account the composite material properties and the frequency dependence of the viscoelastic material. In order to take into account the frequency depedent properties of a realistic viscoelastic layer, the damping behavior is modeled through a fractional derivative Zener model [3]. The novelty and innovation of this work is related to the development of an advanced analytical formulation for damped free-vibration and frequency response analysis of composite shells structures embedding viscoelastic layers modeled by means of fractional derivatives approach. The accuracy of the present analytical formulation is validate through a deep investigation campaign. Isotropic, cross-ply composite and simply-supported shell structures are considered, according to the Navier solution. Various external loads are considered: closed form solution for bi-sinusoidal pressure, constant distributed pressure and concentrated loads. Different lamination sequences and different shell aspect ratios are taken into account to generalize the obtained results. References: [1] J.N. Reddy, An evaluation of equivalent-single-layer and layerwise theories of composite laminates, Composite Structures, 25 (1993) 21–35.

[2] A. Alaimo, C. Orlando, S. Valvano, Analytical frequency response solution for composite plates embedding viscoelastic layers, Aerospace Science and Technology 92 (2019) 429–445. [3] T. Pritz, Five-parameter fractional derivative model for polymeric damping materials, Journal of Sound and Vibration, 265 (2003) 935–952.

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abst. 2640
Virtual Room
Friday
September 4
09h00

Dynamic Instability Analysis of CNT-Reinforced Laminated Composite Plates Subjected to Periodic Non-Uniform Axial Loadings

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The present article deals with the instability characteristics of CNT-reinforced functionally graded laminated composite plates subjected to periodic axial compressive loadings. The CNT reinforced composite (CNTRC) plate adopted in the present study is assumed to be made up of single walled carbon nanotubes (SWCNTs) and isotropic matrix. The effective material properties of CNTRC are evaluated by employing the extended rule-of-mixture (ROM) approach. The laminated CNTRC plate is modeled using First order shear deformation theory and von Kármán type non-linearity. Besides uniform loading, different types of non-uniform load distributions are considered. The dynamic instability problems are solved in two steps, initially: the internal stress distribution within the shell panel due to applied loadings is evaluated by membrane analysis. Subsequently, using these stress distribution and via Hamiltons principle, the equations governing the instability behavior of CNTRC plates are derived. Galerkin's method is used to reduce the governing partial differential equations to a set of non-linear ordinary differential equations in case of dynamic analysis. Besides, parametric study the obtained numerical results from the present investigation illustrates the effects of CNT volume fraction, CNT dispersion profile and non-uniform load distributions on the instability characteristics of CNTRC plates under periodic loadings.

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abst. 2306
Repository

A study of hygrothermal effect on buckling and post-buckling behavior of Reissner-Mindlin composite panels with internal delamination

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This paper presents a theoretical study on buckling and post-buckling of Reissner-Mindlin composite panels with internal delamination under hygrothermal environment. The constitutive equations are formulated to take into consideration of the hygrothermal stress from material expansion due to temperature change and moisture absorption. Based on von Karman nonlinear geometric relationships, a novel first order shear deformation theory is proposed by introducing a nonlinear contact mechanism occurred at the interfaces of the delamination. Governing equations are solved using separation of variable in conjunction with the asymptotic method. Postbuckling equilibrium path of the delaminated panels characterized by the in-plane load vs deflection amplitude curves is obtained according to Galerkin approach. The analysis is in effect by comparing the solutions with those from classic theory and from ABAQUS finite element analysis. It shows that neglecting the transverse shear strain will lead to the overestimation of the buckling load and the post-buckling strengthening effect. By developing matlab program, parametric studies are carried out to examine the influence of the temperature and the humidity on the buckling and post-buckling performances of the composite panels for different delamination depth and length. It is found that the composite panels always undergo post-buckling strengthening and increasing the temperature or humidity will result in the decreasing of the buckling load of the composite panels, regardless of the size and depth of the delamination.

New mathematical models of thermo-elasticity problems for thin biperiodic cylindrical shells

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Thin linearly thermo-elastic Kirchhoff-Love-type circular cylindrical shells with a periodically micro-heterogeneous structure in circumferential and axial directions (biperiodic shells) are analysed. Periodic inhomogeneity means here periodically variable shell thickness and/or periodically variable inertial, elastic and thermal properties of the shell material. The dynamic thermo-elasticity problems of these shells are described by partial differential equations with highly oscillating, non-continuous, periodic coefficients. Hence, these equations are too complicated to be applied for investigations of engineering problems for such shells. To obtain averaged equations with constant coefficients, a lot of different approximate modelling methods have been proposed. Periodic cylindrical shells (plates) are usually described using homogenized models derived by means of asymptotic methods. Unfortunately, in the models of this kind the effect of a cell size on the overall shell behaviour (called the length-scale effect) is neglected. This effect can be taken into account using the non-asymptotic tolerance averaging technique. The fundamental concepts of this approach are those of tolerance relations determined by tolerance parameters and related to the accuracy of the performed measurements and calculations, slowly-varying functions, tolerance periodic functions, fluctuation shape functions and the averaging operation. The basic assumptions of this modelling technique are called the micro-macro decomposition and the tolerance averaging approximation. The first assumption states that the displacement and temperature fields can be decomposed into macroscopic and microscopic parts. The macroscopic part is represented by unknown averaged displacements and temperature being slowly-varying functions. The microscopic part is described by the known highly oscillating periodic fluctuation shape functions multiplied by unknown slowly-varying temperature fluctuation amplitudes and displacement fluctuation amplitudes. The second assumption states that in the course of modelling the terms of the orders of tolerance parameters are neglected. The aim of this contribution is to formulate and discuss three new averaged mathematical models for the analysis of selected dynamic thermo-elasticity problems for the biperiodic cylindrical shells under consideration: non-asymptotic tolerance (length-scale) model derived by applying the tolerance modelling technique outlined above, asymptotic model neglecting the length-scale effect and combined asymptotic-tolerance model, which makes it possible to separate the macroscopic description of some special thermo-elasticity problems from their microscopic description. The proposed averaged models have constant coefficients. The starting equations are the well known governing equations of linear Kirchhoff-Love theory of thin elastic cylindrical shells combined with Duhamel-Neumann thermo-elastic constitutive relations and coupled with the known linearized Fourier heat conduction equation in which the heat sources are neglected. For the micro-periodic shells under consideration, these equations have highly oscillating, non-continuous and periodic coefficients. The unknown temperature field in the starting equations is treated as the temperature increment from a certain constant reference temperature (the zero stress temperature). We assume that the temperature increment is small and that the material characteristics of the shells (the specific heat, the thermal conductivity moduli, the elastic and thermo-elastic moduli, the mass density) are independent of temperature. Consideration are restricted to the shells with constant temperature along thickness. From this restriction it follows that only the coupling between temperature and membrane stresses occurs in the Duhamel-Neumann stress-strain-temperature relations whereas the coupling of temperature and bending stresses is absent.

abst. 2673
Virtual Room
Friday
September 4
09h45

Nonlinear bending of sandwich plates with functionally graded graphene reinforced porous nanocomposite core under various loads based on a four-unknown refined theory considering the thickness stretching effects

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Nonlinear bending of sandwich plates with a functionally graded graphene reinforced porous nanocomposite core and two metal skins subjected to general boundary conditions and various loads, such as point loads, different linear loads and uniform loads, is presented. A popular four-unknown refined theory accounting for the thickness stretching effects is employed to model the mechanics of the sandwich plates. The governing equations is derived from the nonlinear Von Karman strain-displacement relationship and the principle of virtual work, and solved by the classical finite element method in combination with Newton downhill method. The accuracy and efficiency of the present theory is confirmed by comparing the obtained results with those available in the open literature. Further, Parametric study is carried out on the effects of the graphene weight fraction, boundary conditions, porosity coefficient, various loads and layer thickness ratios on the nonlinear central bending deflections of the sandwich plates. In addition, Numerical results reveal that the adopted higher order theory can significantly improve the simulation of the transverse deflection in the thickness direction.

Bio-inspired design of composites

A numerical study of bioinspired nacre-like composite cylinders subjected to compression and bending loading

abst. 2583
Repository

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In this work, a multi-layered bioinspired composite cylinder, with a design based on the structure of the nacre shell, was investigated. The bioinspired structures were subjected to uniaxial compression and three-point bending test, and their mechanical behaviour was compared with a monolithic structure. The structures were made of layers of aluminium alloy comprising square and Voronoi tablets, and epoxy resin as an adhesive between the tablets and the layers. The geometry of the cylinders was: a length of 50 mm and inner diameter of 7.5 mm. The total thickness was 2 and 3 mm, for nacre-like cylinders consisting of 2 and 3 layers, respectively. The waviness of the layers, resembling the natural nacre material, was generated using a sinusoidal function. The cylinders were loaded in compression parallel to their longitudinal axis, and loaded in three-point bending perpendicular to their longitudinal axis. The investigation of this work was carried out using finite element simulations employing the software Abaqus/Explicit. The aluminium alloy material used for the tablets was simulated using the Johnson-Cook constitutive and fracture models and its mechanical behaviour was validated with a tensile test. Cohesive elements were used for the epoxy resin and validated using a delamination test. The numerical results showed that the bioinspired structures subjected to compression exhibited lower energy absorption when compared to the monolithic structure. It was found that using a rigid adhesive slightly increased the energy absorption of the bioinspired structures when compared to a ductile adhesive. In compression, the peak strength was higher for the bioinspired structures when compared to the monolithic structures. The three-point bending test simulations showed that the bioinspired cylinders exhibited better energy absorption at first crack, when compared to the monolithic structures. The bioinspired structures also exhibited a more ductile behaviour and a smooth force-displacement curve, which is in contrast to the behaviour of the monolithic cylinders, which exhibited large force peaks and force fluctuations. The numerical results showed that the bioinspired cylinders have the potential to perform well in impact and protective applications, in which, energy absorption should happen in a controlled manner without large decelerations; however, further experimental and numerical investigations should be performed to assess the performance of these bioinspired structures. This work was financially supported by CONACYT Ciencia Básica 2017-2018, grant No. A1-S-8864.

The structure of composites based on carbon nanotubes and biopolymers for bioelectronics

abst. 2050
Repository

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Today, there are many different types of composites based on carbon nanotubes. They are used in various spheres from electronics to medicine. Nanotubes are attractive to electronics because of their

excellent electrical, thermal, magnetic properties and mechanical strength. Carbon nanotubes have dimensions close to those of the main components of the natural extracellular matrix, their mechanical properties are similar to the properties of protein structures. Therefore, using a given configuration of nanotubes, it is possible to ensure the structure of composites, which is similar to the structure of biotissues. Thus, nanotube-based composites can be used as a part of a bioelectronic device implanted in a body. In this regard, the aim of our work is to create a method for the formation of biocompatible electrically conductive composites for cell and tissue engineering. Biopolymers were used as matrices for composites: proteins — albumin and collagen, and amino sugar — chitosan. Albumin performs the function of transferring biologically active substances. When added to the composition of implants, it performs binding functions. Collagen is the main protein of connective tissue. Collagen fibers have high strength due to the close arrangement of the polypeptide chains, this allows tissue elasticity. Aminosugar chitosan is a powerful sorbent of natural origin. The absorbing base of chitosan is crustacean chitin (linear polymer). Single-walled carbon nanotubes (SWCNT) were used as a reinforcing filler of a matrix of biopolymers. The average diameter of SWCNT was 1.4-1.6 nm, length 0.3–0.8 m. We produced homogeneous aqueous dispersions from biopolymers and SWCNT. The concentration of nanotubes was 0.1-0.001 wt.%. Albumin with a concentration of 25 wt.% and collagen, 1 wt.%, as well as the chitosan, 2 wt.%, were added to the aqueous dispersion of SWCNT. Further, these dispersions were deposited layer by layer on a substrate and irradiated with laser radiation. We developed a laser setup that generated pulsed laser radiation (wavelength - 1064 nm, pulse duration - 100 ns, frequency - 100 kHz, power of up to 10 W). Laser radiation was moved along the dispersion layer using mirrors of a galvanometric scanner. The trajectory of the focused radiation was set by a computer model. As a result of irradiation, a phase transition from liquid to solid (rubbery) form occurred and a series of layers of albumin, collagen and chitosan with SWCNT were formed. We controlled the temperature with a thermal imager. We did not allow the dispersion to increase above 80 Celsius degrees. We found out a mechanism for the functionalization of SWCNT by biopolymer molecules inside a composite using IR and Raman spectroscopy. We determined that SWCNTs covalently bind to oxygen atoms of surface amino acid residues of biopolymers. The internal and surface SWCNT nanostructures in composites were studied using SEM and AFM. We observed a branched tree structure of a carbon nano framework. The formation of C–C bonds occurred in the regions of defects of neighboring SWCNTs in the framework upon laser heating. It was found that the diameter of SWCNT increased by several nm due to their functionalization with biopolymers. The composites had a bimodal pore distribution: 1-5 and 100-200 microns. Such porosity of composites is necessary, on the one hand, for innervation and vascularization, and, on the other hand, for the penetration of cells into them. The presence of a carbon nano framework inside the nanocomposite provided an electrical conductivity of about 1 S/m. We demonstrated better cell viability (fibroblasts, mesenchymal stem) on composites than on control coverslips. It was achieved due to a significant degree of cell adhesion to composites with a special structure. We also demonstrated electrical stimulation of cell growth using the developed device. Cells grew much faster on the surface of composites when we passed electrical signals through them.

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abst. 2077
Repository

Adjustments of biotic degradation in flax-PLA by mimicking pine tree micro-structure with rosin

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The current bio-composites typically involve flax reinforcements and poly lactic acid (PLA) based matrices. The reason is the need to decrease the use of fossil-based raw materials and also to develop compostable materials for load-carrying applications. However, the control of biotic degradation is difficult without using synthetic and essentially toxic additives, such as various biocides. In general, the control of both biotic and abiotic degradation mostly refers to the adjusting of the rate of degradation. Some ideas have been studied to improve the decomposition of mass-production thermoplastics by microbes [1]. In pine trees, rosin is a multi-functional component responsible of numerous features;

rosin is protecting wood against various microbes and infections [2]. In flax-PLA composites, especially for low temperatures, the flax reinforcement represents the weakest link in the event of biotic and aerobic composting. In this work, we apply rosin impregnation (pine gum rosin, Forchem, Finland) to understand the effects of rosin as natural additive in compostable composites. In this work, we prepare PLA-rosin-flax laminates (2003D, Ingeo; flax by Biotex) by using hot pressing. Prior to pressing, PLA-rosin blends are prepared by using a twin-screw compounder. The quasi-isotropic laminates are cut into tensile specimens (ISO 572) and interlaminar shear strength (ILSS) specimens (ASTM D2344). Specimen are tested in ambient conditions before composting and after composting. The composting refers to soil burial type testing, where the soil was a low-nutrient mixture of peat and forest mulch (peat/mulch ratio of 20/5 volume/volume). Commercial activators are used to initiate the microbial activity during composting. The interfacial strength between PLA and flax as well as the effect of rosin is determined using microdroplet testing (Fibrobotics, Finland) to reveal changes in interfacial performance. The results showed that the rosin significantly affects the processing of PLA-flax composites due to the PLA-rosin blending at high temperature. High concentrations of rosin lead to a lower viscosity of the blend and out-gassing within hot pressing. Therefore, the rosin content should be kept at a minimum, i.e. clearly below 10% (weight/weight). In general, the antibacterial effects of rosin are extremely high at 10% concentrations [3]. Surprisingly, even at a 10% concentration of rosin, being a small molecular weight additive, does not significantly decrease (-8%) the strength of the PLA matrix – either before or after soil-burial tests. After two weeks of composting, the tensile tests indicated that the addition of rosin either into the matrix or flax clearly leads to higher ultimate deformation compared to the values before composting and clear bi-linear (load-extension) behavior. Based on the overall trend in ILSS values compared to tensile tests with matrix specimens and composites, is concluded that rosin affects the interfacial strength between flax filaments and PLA. Optimization between the design composting requirements and mechanics (interfacial strength) is needed for this type of nature-mimicking composite materials. References: [1] Koutny, M. at al. Biodegradation of polyethylene films with prooxidant additives. Chemosphere 2006;64: 1243–52. [2] Sjöström, E. (1993), Wood chemistry - Fundamentals and Applications, Academic press. 2nd Ed. [3] Kanerva, M. et al. (2019), Antibacterial polymer fibres by rosin compounding and melt-spinning, Mat Today Communications 20, 100527.

Use of bio-composites for the manufacturing of a full electric microcar

abst. 2022
Virtual Room
Friday
September 4
15h30

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Bio-composites, or Natural Fiber Composites (NFCs), are biodegradable materials, which can be a valid alternative to Fiber-Reinforced Plastics (FRPs). The introduction of biomaterials in the production process reduces significantly the need of petrochemical products derived from fossil fuels. In fact, for instance, plant fibers are not toxic and derive from natural materials which are readily available and can help to promote healthier and safer workplaces. Obviously, these applications are highly sustainable due to their recyclability. The aim of the present work is to design a two-seats micro car with a bodywork in bio-composite material, with electric propulsion and high-end electronic equipment on board for a safe and sustainable urban mobility. The micro car will be produced in two versions: one with a carbon–linen composite shell and another one in bio-composite denim (e.g. cotton). The use of biomaterials keeps the same mechanical properties of standard composite panels and achieves precise weight targets for better efficiency and energy consumption for full-electric vehicles. As a consequence, the used of NFCs provides important growth opportunities of GDP and GDP-pro-capita to many developing Countries that still base their own economy mainly on agriculture. The project includes also the construction of a car shelter, or garage, with photovoltaic tiles recharging the full electric car battery, with an off-grid system, in order to define a whole zero emissions mobility system.

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abst. 2079
Repository

An integrative approach for load-dependent FLM SFRP structures: From optimisation to final parts

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In comparison to other composite manufacturing processes, Additive Manufacturing (AM) offers particularly high potential to produce structural components that are suitable for the loads applied, as AM processes allow for modification of global topology (material distribution) as well as local microstructure (for example, fibre orientation). Among AM processes, especially Fused Layer Modeling (FLM) seems suitable for load-dependent structures. It allows for exploiting high design freedom through both complex geometry and local microstructure (FLM printing paths) while, at the same time, being a relatively low-cost and readily available AM technology when compared to other processes like Laser Sintering (LS, relatively expensive; implementation of local material orientation much more difficult) or Stereolithography (SLA, similar concerns). The authors thus aim to propose a Design for Additive Manufacturing (DfAM) optimisation approach for load-dependent FLM short-fibre reinforced plastics (SFRP) parts, consisting of four steps: 1. Bio-inspired topology optimisation (published in Composite Structures 2018), taking the anisotropic material properties into account in the early design stage; 2. Path creation from the obtained topology-and-material-orientation result to match optimised geometry and load paths as close as possible (focus of this contribution); 3. Generation of manufacturing information (FLM build source); 4. Printing and comparative simulation of different printing paths (directly from build source). The approach aims at providing product developers with a structured and applicable way to develop and compare optimised lightweight FLM structural components.

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abst. 2361
Repository

A study of protective properties of naturally graded insect cuticles and bio-inspired designs

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Insect cuticle exhibits fascinating mechanical performance in their body protection due to their spatial hierarchical architecture. The complex biological composites designed by nature over millions of years has an enormous potential to inspire the designs of excellent biomimetic protective systems. In this study, the spatial hierarchical architecture of insect cuticle is constructed by finite element method to investigate the propagation characteristics of stress waves in it and reveal the in-depth mechanisms of crashworthy protection. The results show that the variations in stiffness gradients through the thickness of the cuticle have a great influence on preventing stress wave propagation. The natural cuticle with discontinuous exponential stiffness gradient across its thickness is found to lead to the minimum value of reaction force between cuticle and internal organs, which can filter out more than 86% of stress wave. Inspired by the naturally graded insect cuticles, we present a composite elastic ring system with programmable stiffness gradients to enhance the protective performance. A modified mass-spring theoretical model, which can precisely predict the mechanical response of the ring systems under impact, is proposed and validated with numerical method and experimental tests. Based on theoretical analysis, the influence of the concavity and convexity of the stiffness curve profiles on protective characteristics have been studied. Compared with concave stiffness gradients, the convex stiffness gradients significantly improve the protective performance as well as reducing the peak value of reaction force greatly. Finally, the influences of the elastic modulus, radius, thickness and mass of rings on the mechanical performance of the bio-inspired composite ring systems are discussed, which helps to optimize the designs of the graded ring systems. The knowledge gained from this work may reveal the protective mechanisms of insect cuticles and serve to inspire further research of developing advanced reusable structures with improved impact resistance capability by programming reasonable stiffness distribution.

Composite Structures

Properties of multi-layered polymer composites with Vectran fiber reinforcement

abst. 2162
Repository

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For several decades, there has been a particular interest in the use of composite materials in the construction of air transport resulting from the need to minimize their weight and reduce production costs. Polymer matrix composites with fiber reinforcement are the most frequently used composites group in the aviation industry. One of the less frequently used modern reinforcement fibers is Vectran fibers, produced from liquid crystal polymer. Recognizing the potential applications of Vectran fibers in the construction of composites used in aircraft constructions, a series of tests was carried out on various properties of composites reinforced with Vectran fibers, and additionally assessed the effect of hybridization of laminar composite reinforcement with the base reinforcement of Vectran fibers. Additionally, knowing the problem of low impact resistance of layered composites, research was carried out to determine the effect of low-energy impact loads on the mechanical properties of such composites. For the purposes of the study, composite panels with three different types of reinforcements were made and experimental studies were carried out to assess the strength and thermophysical properties of the prepared materials. LH 385 epoxy resin with hardener H385 was used as the matrix for all tested composites. Based on the conducted research and analysis of their results, it can be stated that the addition of carbon fibers increases the impact strength of a Vectran fiber-reinforced composite composite as well as its bending and interlayer shear strength.

Mechanical performance of tailor-braided composite beam structures

abst. 2425
Virtual Room
Tuesday
September 1
15h30

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Braiding is a composite manufacturing technique used for the fabrication of multi-scale structures in a multitude of industries. Braid angle, the angle at which reinforcing fibres are oriented with respect to the axis of component, is a controllable manufacturing parameter during the braiding process. Previous studies have reported the braid angle to have a significant effect on the mechanical properties as well as the geometry of the finally produced component. Moreover, the mass of a braided component is also related to the braid angle. A novel concept of tailor-braiding is presented in this work. Tailor-braiding involves controlled local variations in braid angle with the purpose of achieving an improved mechanical response and mass saving. Notably, tailor-braiding does not involve any cost penalty as compared to a traditional braiding process. In the present work, glass fibre tows commingled with polyamide filaments were used to braid multi-layer tubular components with a controlled variable braid angle along the length of the components. Static three-point flexure tests were conducted to evaluate the performance of the tailor-braided beams. The mechanical performance was also compared with beams with constant braid angles. X-ray computed tomography scanning was conducted on the tested beam specimens and the through-thickness propagation of damage was correlated with the load-displacement response. It was shown that tailor-braided beams could be manufactured providing equivalent stiffness and peak load with respect to beams with constant braid angle. Importantly, the tailor-braided beams gave 20%weight saving, which indicates the potential of tailor-braiding in improving the structural efficiency of braided composite components.

abst. 2675
Repository

Hybrid damping treatment of a layered beam using a particle-filled viscoelastic composite layer

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This work deals with the damping capability of an actively constrained viscoelastic particulate composite (VEPC) layer in attenuation of vibration of a beam element. The overall beam is composed in the layered form where a VEPC layer is constrained between the substrate beam and piezoelectric layer. The piezoelectric layer not only constrains the VEPC layer but also acts as an extension mode actuator layer as it is activated by supplying external voltage according to the velocity feedback control strategy. The VEPC layer is a graphite particle-filled viscoelastic composite layer, and its effective properties are estimated using a differential scheme and the elastic-viscoelastic correspondence principle. Based on the theoretically estimated effective properties of VEPC and the velocity feedback control law, a closed-loop finite element (FE) model of the layered beam is derived, and the active-passive damping characteristics of the overall beam are analyzed by varying the volume fraction of inclusion (VFI) of graphite particles within the constrained viscoelastic layer. It is found that the passive damping in the layered beam increases up to a certain value of the volume fraction of inclusion (VFI) where an optimal value of VFI arises for the maximum passive damping. In parallel, the inclusion of graphite particles also enhances the transfer of actuation force from the piezoelectric actuator layer to the substrate beam, where the maximum transfer of actuation force arises at a certain value of the VFI. However, these active and passive actions appear with their maximum values almost at the same VFI so that a significantly augmented active-passive hybrid damping in the layered beam is achieved. The overall study presents a fruitful means of improving the damping capability of the active constrained layer damping treatment through the proposition of a VEPC layer.

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abst. 2331
Repository

SYNERGY OF THE CO-OPERATING OF GRANITE POWDER AND FLY ASH IN CEMENTITIOUS COMPOSITES

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Currently, more and more materials are treated as waste. The natural environment is becoming more and more degraded due to increasing waste material deposition. Granite powder resulting from the processing of granite blocks associated with the production of granite slabs and crushing of granite rocks used in construction. In addition, the lack of the use of materials such as granite powder in industry does not improve the situation. Fly ash is currently one of the most commonly used concrete additives. This trend is particularly used due to the property of fly ash and the hydration characteristics of concrete with its addition. Due to the fly ash, the heat of hydration is reduced and the concrete slows down in the blunt increase of strength, and thus the shrinkage is reduced. A trend has been developing in the scientific literature for several years, which consists in attempting to apply granite powder to a cementitious composites. Research is available that can be part of the partial replacement of cement or fine aggregate in cement mixes. In the event that up to 30% of the amount of cement is required to be replaced with granite powder, without significant compressive cement loss. There is also a trend in the literature to check the joint impact of fly ash along with other concrete additives. Thanks to this, the author decided to plan research that aimed to determine the synergy impact of fly ash and granite powder on the properties of cementitious composite. To do this, a multi-scale granite powder and fly ash addition cementitious composites is produced to determine properties that kind of composites. 22 series of cement sets were made (11 series for the scale of cement pastes, 11 series for the scale of cement mortars) with varied addition of granite powder and fly ash, which are subjected to tests of the properties of cement sets and hardened combined cement. As part of the study, 30% of cement mass in cement mix was obtained, without significant reduction of the cement composite under

compression. In addition to determining the impact of the addition of granite powder on its constituent parameters, its impact on the properties of freshly mixed cement (consistency, start and finish of setting time, bulk density) is also available. The research also determined, that the synergistic using of fly ash with granite powder allows to improve the parameters of the cement composite (less dynamic increase in compressive strength, higher compressive strength after 28 days). The research showed that the joint use of granite powder and fly ash improves the properties of hardened cementitious composites.

Optimised morphing of symmetric cross-ply flexible hinges by minimising the Brazier moment

abst. 2194
Virtual Room
Tuesday
September 1
17h15

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Aerospace and industries where weight savings drive design configurations can benefit from using flexible hinges. These morphing structures use no mechanical hinges for folding. They are, therefore, simpler and lighter than conventional hinged folding structures and do not require lubrication. Applications of this technology are composite deployable booms of circular cross-section designed by Yee & Pellegrino [1] and the concept of a deployable wing proposed by Lachenal et. al [2]. The fact that thin-walled beams under bending exhibit nonlinear behaviour was first explained by von Kármán [3] and later by Brazier [4]. A thin walled tube under bending does not only changes its axial curvature but also its circumferential curvature, i.e. its cross-section flattens. The cross-sectional deformation steadily decreases the bending stiffness of the tube until it exhibits unstable behaviour characterised by a limit point known in literature as the Brazier moment, MBrz. To achieve folding, we replace mechanical hinges with this unstable behaviour. Then, the magnitude of MBrz is an important design consideration since lower MBrz translates in lower stresses induced in the hinge during the folding process. Two aspects make cross-ply laminates attractive for designing flexible hinges. Firstly, the difference between the minimum MBrz of a tube with optimum 4-ply symmetric generic laminate and that of an optimum symmetric cross-ply laminate is relatively small. Secondly, cross-ply laminates do not exhibit extension-shear or bend-twist couplings. These couplings can induce complex deformations which could represent challenges during design. Moreover, available analytical solutions of MBrz [5–8] do not consider their effect. Driven by these premises, we present a numerical minimisation of MBrz in a circular cross-ply fibre-reinforced composite tube of infinite length under bending. The minimisation shows that the optimal stacking sequence for the minimisation of MBrz is [0 90 0] with material dependent volume fraction. With the aim of contributing to the preliminary design of these hinges, we also present an analytical solution of the optimum volume fraction of this laminate. The analytical solution is validated through geometrically nonlinear finite element analysis. References [1] Yee, J. C., and Pellegrino, S., "Composite Tube Hinges," Journal of Aerospace Engineering, Vol. 18, No. 4, 2005, pp. 224–231.doi:10.1061/(ASCE)0893-1321(2005)18:4(224). [2] Lachenal, X., Weaver, P. M., and Pirrera, A., "Concept for a Deployable Wing," Vol. 2, 2014. doi:10.1115/SMASIS2014-7428. [3] Von Kármán, T., "Ueber die Formanderung dunnwandiger Rohre, insbesondere federrnder Ausgleichrohre," Z. VDI, Vol. 55,1911, pp. 1889–1895. [4] Brazier, L. G., "On the Flexure of Thin Cylindrical Shells and Other "Thin" Sections," Proceedings of the Royal Society of London Series A, Vol. 116, 1927, pp. 104–114. doi:10.1098/rspa.1927.0125. [5] Kedward, K., "Nonlinear collapse of thin-walled composite cylinders under flexural loading," Proc., 2nd. Internat. Conference on Composite Materials, Metallurgical Society of AIME, Warrendale, 1999, p. 353–365. doi:https://doi.org/10.1016/S0020-7462(98)00070-5. [6] Stockwell, A., and Cooper, P., Collapse of composite tubes under end moments, 1992, pp. 1841–1850. doi:10.2514/6.1992-2389.

Effect of pulling speed on structural performance of L-shaped pultruded profiles

abst. 2529
Repository

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Pultrusion is a highly automated process of composite materials manufacturing. Even if conceptually simple, the proper tuning of the process involves the careful consideration of several aspects: choice of raw materials, fiber impregnation, pulling force, resin viscosity, heating profile, pulling rate. From the manufacturer's standpoint, it is crucial to maximize volume production at the lowest time and resources spent. However, excessive pulling speed can lead to degradation of mechanical properties, occurrence of internal cracks, and shape distortions of the profiles. Deeper understanding of the relationship between process parameters and quality of the final product is desirable to achieve higher efficiency at the manufacturing stage. This experimental work presents the analysis of the interconnection between mechanical properties, microstructure, and geometrical distortions of L-shaped pultruded profile as well as the dependency of the mentioned aspects on the pulling speed in a conventional pultrusion process. It has been found that profiles pultruded at the highest speed exhibit lower mechanical properties, the appearance of cure-induced cracks, and pronounced shape distortions.

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abst. 2685
Repository

Stress-driven nonlocal integral elasticity for nanostructures

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A number of scale-dependent models have been introduced for analysing the mechanics of nanorods in recent years. The majority of the developed models are based on the Laplacian form of the nonlocal elasticity. Recently, it has been found that the stress-driven nonlocal integral elasticity can be more reliable in estimating the mechanics of nanostructures than the Laplacian-based nonlocal theory. While the constitutive boundary conditions are omitted in the Laplacian form of the nonlocal elasticity, extra boundary conditions associated with the structure curvature are taken into account in the stress-driven theory of nonlocality, leading to more accurate analytical and numerical results at nanoscales. In this work, the stress-driven integral theory, as a reliable theoretical tool for modelling the deformation of structures at ultrasmall scales, is described. The equations of motion for the vibration of nanobeams and nanoplates are presented via Hamilton's principle. In addition to the classical boundary conditions of the nanostructure, the extra boundary conditions related to the basic equation are incorporated into the formulation. A discretisation-based solution approach is developed via the differential quadrature method. The free oscillations of beam and plate structures at nanoscales are studied via the developed stress-driven model.

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abst. 2533
Repository

Dry sliding wear behaviour of ZA27/SiC/Gr hybrid composites with Taguchi optimization

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Dry sliding wear behaviour of ZA27 alloy based hybrid composites, reinforced with silicon-carbide (SiC) and graphite (Gr) particles is analyzed in the paper. The objective was to analyze the influence of tested parameters (graphite content, contact load and sliding speed) on specific wear rate and to

show which factor is dominant. Two hybrid composites produced by compocasting procedure were tested: ZA27/10%SiC/3%Gr and ZA27/10%SiC/5%Gr. The wear tests were performed on a block-on-disc tribometer under dry sliding test conditions at three different loads (10 N, 20 N and 30 N) and three different sliding speeds (0.25 m/s, 0.5 m/s and 1.0 m/s). The scanning electronic microscope (SEM) and energy dispersive spectrometry (EDS) were used for examination of the hybrid composites wear surface. The influence of various parameters on wear behaviour was investigated using Taguchi method. Contact load exerts the greatest influence on specific wear rate, followed by the sliding speed and graphite content. A review of available scientific literature shows that there are not many papers and research related to hybrid composite materials based on the ZA27 alloy. This research provides new information for further development of composite materials with ZA27 alloy reinforced by the SiC and graphite particles and for improvement of their dry sliding wear resistance.

COST AFFORDABLE CARBON-PHENOLIC LAMINATES: PRODUCTION AND INVESTIGATION OF THERMO-MECHANICAL RESPONSE

abst. 2575
Virtual Room
Tuesday
September 1
14h45

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Carbon-Phenolic (CPC) ablatives are composite materials that are nowadays one of the fundamental Thermal Protection Systems adopted in parts of space vehicles exposed to high temperature conditions and of propulsion systems, as in the nozzles of rocket engines. When exposed to high temperature, ablatives degrade with a strongly endothermic charring reaction. Part of the incoming heat is dissipated in this degrading process, thus providing a thermal shield function (Natali et al. [1]). Moreover, the layers of CPCs, at an adequate distance from the surface where the ablative process occurs, may perform as well a structural function, thanks to the strength and stiffness properties provided by carbon reinforced fibers (Wang et al. [2]). These materials are usually produced with expensive in-autoclave processes. In this work, new manufacturing technologies have been developed to increase the cost-effectiveness and reliability of Carbon-Phenolic Ablatives. In particular, out-of-autoclave techniques have been investigated, such as Vacuum Infusion. A research and characterization campaign for different resin formulations that can improve the interlaminar behavior of Phenolic has been performed using an infusion-optimized phenolic resin produced by Hexion. Samples have been produced with a Double Vacuum Bag Infusion process, that allows an enhanced management of gaseous byproducts of crosslinking process of Phenolic. Some specimens have been designed with a tapered profile to be subjected to an Oxy-Acetylenic Torch Pyrolysis Test and to subsequent Four Point Bending tests, in order to investigate different and competitive damage mechanisms. The technological process has been developed including the possibility of embedding a network of sensors in the tapered specimens. Such network, based on Thermocouples and Fiber Bragg Gratings inscribed on Optical Fibers, has been used to record the evolution of temperature and strain inside the samples. Specimens manufactured and tested in this way has shown a good behavior as ablators. From the mechanical point of view, while fully-pyrolyzed material has shown really poor properties, partially-degraded material has shown a way less significant loss of properties, confirming the data obtained with more conventional CPCs (Wang et al.[2]). In parallel, a numerical model has been developed to effectively predict the temperature experienced by the different layers of the laminate, without requiring a detailed simulation of the ablation process. The approach has been based on the implementation in a Simulia/Abaqus FE model of a system of equations proposed in Lattimer et al. [3] to represent the degradation kinetics of fiber reinforced composites. In the model, it is assumed that thermal conductivity, specific heat capacity and latent heat capacity, depend on density variation, which has been calibrated for the CPC material according to the results of a Thermo Gravimetric Analysis presented by Wang et al.[2] Latent heat has been described with three different peaks corresponding to three different degradation mechanism, each one with its own enthalpy[2]. This approach has been validated considering the correlation with literature studies and with the data acquired by the sensors embedded in the specimens subjected to

the Oxy-Acetylene torch tests. Overall, the research presents an integrated experimental and numerical approach to characterize the properties of CPCs laminates produced by using cost-effective processes, which can be effectively adopted as TPS and as structural elements in space vehicles and rocket propulsion systems. Acknowledgements: The research activity has been funded by the project COMETAS (Cost Effective Material and Technologies for Access to Space) funded under the H2020-MANUNET initiative (Ref. MNET17/NMCS-1177). References: [1] Maurizio Natali , Jose Maria Kenny, Luigi Torre, «Science and technology of polymeric ablative materials for thermal protection systems and propulsion devices: a review. Progress in Mater Science, 2016;84:192–275. [2] Wang Tianbo, Zhou Changsheng, Ju Yutao, Chen Xiong. «Mechanical Properties with High Temperature and the Microstructure of Carbon/Phenolic Ablative Composites.» Journal of Wuhan University of Technology-Mater. Sci. Ed., 2012. [3] Brian Y. Lattimer, Jason Ouellette, Javier Trelles,. «Thermal Response of Composite Materials.» Springer Science. Fire Technology, 2011; 47, 823–850.

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abst. 2394
Repository

Optimal design of composite laminated structures for noise attenuation using SGUF and DMS

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The generalized introduction of lightweight composites in the automotive and aerospace industries, while leading to significant weight reductions and associated fuel savings, pose a serious problem of low acoustic performance of these lightweight composites when subjected to mechanical or acoustic excitations. Passive damping technologies are nowadays frequently used to control sound and vibration levels through the use of viscoelastic materials, as these are an efficient way of reducing structural vibrations and providing noise attenuation. This paper addresses the issue of noise reduction in laminated composite plates with viscoelestic layers. A Ritz implementation of the Sublaminate Generalized Unified Formulation (SGUF) is used to obtain the frequency response of the composite panels. The sound transmission characteristics of the panels are evaluated by computing their radiated sound power, using the Rayleigh integral method. The optimal layout of the laminate stacking sequence is obtained, where the design variables are the number of layers in the laminate, the type of material in each layer and the thickness and orientation of each ply. Minimization of both weight and noise radiation are sought with structural constraints (stresses and/or displacements). The optimization is conducted with the Direct MultiSearch (DMS) optimization algorithm, which does not employ derivatives and does not aggregate any of the problem objective functions. Trade-off Pareto optimal fronts and the respective optimal laminate configurations are obtained and the results will be presented, analyzed and discussed.

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abst. 2669
Repository

Cure-induced temperature gradient in laminated composite plate: numerical simulation and experimental measurement

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The tool-part interaction is a key factor leading to the residual stress and process-induced distortion in the composite structures. In this paper, the interaction between the aluminium tool and AS4/8552 composites part is experimentally investigated with the FBG sensor to the thin tool and quantified according to the measured data and shear-lag theory. Subsequently, the obtained tool-part interaction

results are implemented into the finite element of composite C-sections cured on the aluminium tool to numerically predict its spring-in. Meanwhile, the experimental investigation on the spring-in of C-section is also examined to compare to the numerical results. The tool-part interaction experimental results show that the sliding friction interaction exists at the interface prior to gelation but it is relatively very small, and sticking interface condition occurs after gelation until interfacial shear stresses reach the critical values at a certain time in the cool-down, after which the sliding friction continues to be prevalent. Further investigation by numerical analysis and experimental measurement also provides a favourable support for the tool-part interaction experiment.

Free vibration analysis of CNT reinforced plates with non-rectangular shapes

abst. 2023
Repository

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Free vibrationanalysis of Carbon nanotube-reinforced composite plates with non-rectangular shapes have been studied. The plate kinematics is assumed to follow a first-order shear deformation (FSDT) theory.After the coupled equations of motion are derived, the method of discrete singular convolution (DSC) is used for the numerical solution of the problem. Both the regularized Shannon's kernel and Lagrange's delta kernel have been used for spatial discretizing of resulting governing equation ofvibration of CNT reinforced plate. Natural frequencies and are obtained for different cases. Skew, triangular and trapezoidal plates have been solved via discrete singular convolution transformetion method. Wherever possible, the present DSC results are verified by comparison with existing analytical values from the open literature. After then, detailed parametric study related to vibrationhave been obtained and the on the effects of boundary conditions, CNT distributions and volume fraction, aspect ratio, length-to-width ratio, geometric and material parameters have been investigated in detail.

Free vibration analysis of CNT reinforced plates with non-rectangular shapes.

abst. 2055
Repository

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Free vibration analysis of Carbon nanotube-reinforced composite plates with non-rectangular shapes have been studied. The plate kinematics is assumed to follow a first-order shear deformation (FSDT) theory.After the coupled equations of motion are derived, the method of discrete singular convolution (DSC) is used for the numerical solution of the problem. Both the regularized Shannon's kernel and Lagrange's delta kernel have been used for spatial discretizing of resulting governing equation of vibration of CNT reinforced plate. Natural frequencies and are obtained for different cases. Skew, triangular and trapezoidal plates have been solved via discrete singular convolution transformetion method. Wherever possible, the present DSC results are verified by comparison with existing analytical values from the open literature. After then, detailed parametric study related to vibration have been obtained and the on the effects of boundary conditions, CNT distributions and volume fraction, aspect ratio, length-to-width ratio, geometric and material parameters have been investigated in detail.

Rapid Determination of Suitable Reinforcement Type in Continuous-Fibre-Reinforced Composites For Multiple Load Cases

abst. 2655
Repository

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With respect to their extraordinary weight-specific mechanical properties, continuous-fibre-reinforced plastics (CoFRP) have drawn increasing attention for use in load bearing structures. Significant effort has been carried out with respect to optimising CoFRP-components for maximum structural performance [1, 2]. Besides conventional optimisation techniques, e.g. topology or thickness optimisation, CoFRPs offer further potential for tailoring to lightweight requirements: Apart from choice of fibre and matrix material, the inherently anisotropic behaviour gives additional design freedom for engineering, e.g. fibre orientation and stacking sequence. Although offering high lightweight potential, determining a robust optimum with CoFRPs is a great challenge, especially, when multiple load cases need to be considered. This work proposes numerical analysis of principal stresses in multiple load cases to assess the lightweight potential when applying CoFRPs. Three common layups are considered: quasi-isotropic (QI) as well as bidirectional (BD) and unidirectional (UD) reinforcement. Principal stresses and their directions are obtained in Finite Element simulations. In extension of previous work [3,4], an algorithm is presented which methodologically determines the most suitable layup-type and orientation for each element across all considered load cases: Thereby, regions are identified, in which UD, BD or QI, respectively, are most favourable. Subsequently, for each region each element is assigned its optimum material, the simulations are rerun und the evaluation procedure repeated until convergence of the material distribution. The multi-load-case optimisation results are compared against separate optimisation of each individual load case and found to give meaningful results. The methodology is demonstrated using two generic geometries and one real-world load-bearing component. It is found to reliably allocate most beneficial reinforcement types with low computational effort compared to iterative parameter optimisation algorithms and is thus deemed to facilitate a lean part and process design under consideration of multiple load cases. References: [1] H. A. Eschenauer and N. Olhoff, "Topology optimization of continuum structures: A review," Applied Mechanics Reviews, vol. 54, no. 4, p. 331, 2001. [2] D. Peeters, D. van Baalen, and M. Abdallah: "Combining topology and lamination parameter optimisation", Structural and Multidisciplinary Optimization, 52(1), pp. 105–120, 2015. [3] K. G. Durst: „Beitrag zur systematischen Bewertung der Eignung anisotroper Faserverbundwerkstoffe im Fahrzeugbau" (PhD-Thesis in German), Audi-Dissertationsreihe, 3, Cuvillier, Göttingen, 2008. [4] 4. D. Zink, C. Awe and P. Middendorf: "Automated Design Approach and Potential Assessment of Composite Structures: Fast and Analytical Engineering Tool for Multiple Load Cases", Proceedings of 17th European Conference on Composite Materials ECCM17, Munich, 2016

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abst. 2629
Virtual Room
Tuesday
September 1
12h15

3D Simulation of Dynamic Interlaminar Failure in Curved Unidirectional CFRP Laminates

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In this study, progressive interlaminar damage in curved unidirectional CFRP laminates are investigated numerically. 2D and 3D finite element analyses of 30-ply unidirectional L-shaped laminate are performed in Abaqus/Explicit under quasi-static loading where the only failure mode is delamination. Cohesive zone elements are employed at the layer interfaces to simulate delamination initiation and propagation. Results are presented in terms of delamination initiation time, delamination length and speed, and strain energy release rates within the calculated phase angles for both 2D and 3D analyses. Comparison of results from 2D and 3D analyses show that interlaminar crack tip speeds from 2D analysis is higher compare to center and edge interlaminar crack tip speeds throughout the analysis.The

analyses agree well with the experimental results in terms of damage initiation location through the thickness direction and load-displacement trend.

Modal Analysis of the Photovoltaic Roof in a Multi-Occupant Solar Vehicle

abst. 2486
Virtual Room
Tuesday
September 1
09h45

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The effects of vibrations in vehicles can range from simple noise and reduced comfort to a significant decrease in performance, from wear and material fatigue to irreversible damages and danger. A study of the dynamic behaviour is therefore essential during each phase of vehicle design and respect to all sorts of vehicles. A modal analysis on reinforced composite panels and structures is here presented, used to finalize the construction of an ultralight photovoltaic roof. This roof is a crucial part of our solar sport car representing an extreme racing prototype where design and materials solutions, as high strength carbon fiber reinforced polymers (CFRP) and sandwich-structured composites, were involved to optimize the stiffness-to-weight ratio. The modal analysis was performed specifically considering materials properties and anisotropies by a 'layered-shell' model and through-the-thickness Integration Points (IP) in the way to discretize the multi-layered sandwich structure. This Finite Element approach permitted a valid discretization respect to quite large (> 8 square meters) and intricate geometries (three-dimensional quadrangular grids) without exceeding in mesh complexity. Other aspects, as the gravity force or the presence of external constrains, were also included in the evaluation thanks to a pre-static analysis. Experimental evidences were used for validating the numerical model detecting an outstanding accuracy (with errors <2%). The same design procedure was then applied with the scope to modify the pre-existing structural solution toward an optimized version of the roof. Eigenvalues, Participant Factors and Effective Masses were considered in the assessment. The new solar roof was manufactured, mounted on the vehicle, and tested on the road. It offered a better dynamic, but also permitted to add a strategic functionality. The roof is now broken down into two sections, one of which (the rear) will be lastly removed during the next redesign phase with the scope to modify the vehicle destination to a conventional use.

Effective joining of thermoset/thermoplastic hybrid composite joints by UV-irradiating the bonding surfaces

abst. 2503
Repository

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Efficient joining of hybrid thermoset/thermoplastic composite joints is critical to produce high performance lightweight structures while keeping the cost low. Herein, a high-power UV-irradiation technique was proposed to rapidly active the surfaces of PEEK and PPS com- posites for the following co-cure joining with epoxy composites. A single lap-shear joint test and a double cantilever beam test were used to evaluate the mechanical and fracture perfor- mance of the hybrid joints. The experimental results revealed that high structural integrity of the hybrid joints was achieved upon applying a 6 s UV-treatment to the thermoplastic compos- ites. For example, the lap-shear strength and fracture energy of the adhesive bonded hybrid joints were above 25 MPa and 800 J/m2, respectively. Overall, high-power UV-irradiation proved a highly efficient, rapid and low-cost method to treat thermoplastic composites for the co-cure joining with epoxy composites, and hence it demonstrated significant promise in industrial mass production.

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abst. 2163
Virtual Room
Tuesday
September 1
08h15

Impact simulation and shape optimization of an origami crash box made of carbon/epoxy composite material

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Crash boxes are thin-walled structural components of the vehicles designed to absorb energy during impact events at low-medium velocity. In particular, the crash boxes have to guarantee a progressive and controlled energy absorption. In this regard, the maximum force of the crushing process needs to be limited in order to avoid high acceleration experienced by the occupants and permanent plastic deformation of other structural components, such as the rails. Accordingly, the crash boxes are designed with appropriate collapse initiators to ensure a crush efficiency as close as possible to one. Crush efficiency is defined as the ratio between the peak force and the mean force experienced during the impact event. In recent years, crash boxes made of carbon fiber reinforced polymer (CFRP) have found application in the automotive sector. In particular, several authors have demonstrated that composite materials can guarantee greater specific energy absorption when compared to conventional metal structures. However, their brittle failure mode leads to an irregular force trend while crushing. Thereafter, the crushing behavior of the composite material structures can be improved by modifying their geometrical parameters. Among the most promising solutions, the origami structure is increasingly considered for crash boxes. In this work, a numerical simulation of a simplified CFRP origami crash box subjected to axial impact is proposed. The crash box here considered consists of four axially-stacked basic structures. Each basic structure is composed of four trapezoidal faces and four triangular faces. The upper cross section is squared, whereas the lower cross section has an octagonal shape. The structural behavior of the origami component was investigated according to different sizes of the triangular faces. The numerical models were simulated with the finite element commercial code LS-Dyna in its explicit formulation. It was found that the dimensions of the pre-inclined faces of the origami structure significantly affected the energy absorption and the peak force of the impact simulation. In particular, the pre-folded faces served as trigger to induce a progressive and controlled collapse mode. In a first step, constitutive lengths of the basic structure were varied to explore the peak force and maximum energy absorption response. Moreover, the numerical results were compared with the crush behaviour of a conventional squared-section crash box. The comparison confirmed a more balanced performance between the absorbed energy and the peak force of the origami crash box compared to the squared-section structure. In a second step, the optimal shape of the origami structure in terms of crush efficiency was defined in LS-OPT environment. The objective function of the optimization algorithm was set to maximize the energy absorption, keeping the peak force as low as possible. The optimal shape defined presented larger sizes in the top basic structures than in the bottom parts, resulting in more inclined faces. The result suggested that more inclined faces in the top part can guarantee a fracture-triggering effect in the crash box, which ensured a smaller peak force.

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abst. 2537
Repository

Optimization of milling parameters for efficient and economic processing of thermally modified Oak wood (Quercus spp.)

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Thermally modified wood is being used for various end applications. As the material property of wood is affected by thermal treatment, processing of modified wood needs optimization. Optimizing milling parameters with respect to energy input and product quality is of great importance to the manufacturers. This paper studies the interaction of different machine parameters in combination with thermal modification temperature to derive the ideal combination for milling Oak wood (Quercus spp.) in terms of surface quality and energy economy during milling. Oak wood was thermally modified at three different temperature. Different milling parameters such as cutting speed, feed speed, rake angle were studied in relation to surface quality (roughness and waviness) and power consumption during milling (cutting power). Modification temperature affected the quality of machined surface. Increasing cutting speed and feed speed increased the cutting power while increasing rake angle and treatment temperature reduced the cutting power. The most suitable combination for processing Oak wood in in terms of superior surface quality and lower energy use was obtained at a cutting speed of 20 m/s, rake angle of 20°, feed rate of 4 m/min and thermal treatment at 180°C.

BENDING BEHAVIOR OF GLASS FIBER REINFORCED COMPOSITE OVERWRAPPING PVC PLASTIC PIPES

abst. 2330
Repository

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The challenge associated with the use of polyvinyl chloride (PVC) plastic pipelines is to improve their structural integrity without increasing their cost. Currently, PVC pipelines are the most cost-effective method of transporting water and sewage drainage. However, their poor deterioration and mechanical properties cause significant losses and sacrifice the structural integrity of pipelines. Therefore, this study proposes the glass fiber-reinforced polymer (GFRP) overwrapped system to strengthen the external surface of PVC pipes, which will improve pipes' flexural load-carrying capacities. Accordingly, an extensive experimental program is developed and performed to examine the flexural behavior of GFRP composite overwrapped onto PVC plastic pipes. These phases include the fabrication process and different types of tests for evaluating the structural integrity of the GFRP/PVC pipes. The results showed that the proposed overwrapped system significantly improved the flexural carrying capability. The initial flexural failure load increased significantly, with an improvement from 64 to 1140 N. In addition, the ultimate flexural load was improved by a factor of nine. Moreover, the flexural behavior was significantly affected by changes in the fiber orientation angle. It should also be noted that as the pipe diameter increased, the flexural carrying load capacity increased. It is also important to note that the main identified failure modes for GFRP/PVC pipes were dominated by matrix cracking, fiber debonding, and fiber breakage.

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abst. 2580
Repository

Optimal Filler Content for Cotton Fiber Composites based on Mechanical Properties using Artificial Neural Network

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The use of fiber-reinforced polymers in the aerospace and automotive industries continues to increase due to their inherent advantages over traditional materials. Increased usage of these materials is also reported in several other engineering applications that require materials with high strength and rigidity and with low weight components. Natural plant fiber can be an alternative option to construct composites, as they can possess inherent environmental benefits with a readily abundant supply of raw materials from renewable resources compared to fossil sources. Many researchers have considered and investigated the mechanical properties of cotton fiber composites (Dean et al., 2019). They studied the effects of matrix type on mechanical properties and energy absorption capabilities (Mahdi & Dean, 2020). Most of the researchers approached their work by using a series of experiments and via material characterization. In real life, doing manifold experiments is always associated with extra cost and time; which are necessary as the mechanical properties (e.g., tensile strength, ductility index, modulus elasticity, elongation, etc.) do not have any direct correlation which can help the researchers to find the optimal filler content a priori. Such experimental work can be designed to be more cost-effective and time-efficient if the optimal filler content for the composites can be found with the help of a predictive model based on the previous experimental data. The objective of this work is to propose a methodological approach for identifying the optimal filler content for cotton fiber thermoplastic composites based on mechanical properties using artificial neural network. Here, two separate ANN models will be developed. One model will predict the optimal cotton filler content for Polypropylene composite, and another one will search for the optimal cotton filler content for Polyvinyl chloride composite. The developed predictive ANN models will be useful for the future designers of both PP and PVC composite materials. The ANN models will reduce the time and effort of the material characterization, and it will help future researchers to design their experiment using the developed predictive models. The developed approach in this paper can be extended for other composite materials if the necessary experimental data are available. In this work, the ANN models are developed in the TensorFlow backend using Keras library in Python. The necessary experimental data for input were obtained from the Mahdi et al., 2020 works. The hyperparameter tuning method (i.e., the grid search method) was used to find the optimum ANN structure, and the regulations dropout method was used during the training phase to avoid the overfitting. It was found that four hidden layers with 200 neurons each were necessary to build up an effective co-relation between the eight feature independent inputs to 1 dependent out which is the optimal value of the predicted optimum filler content. These dependent variables are the net weight of fiber, initiation energy, propagation energy, total energy, ductility index, tensile strength, modulus elasticity, and elongation. The corresponding weights and activation functions of the ANN models were achieved through the error back-propagation, and the mean squared error value was used as the loss function. Also, the k-fold cross-validation method was used to judge how the models perform outside the test data. Finally, the predictive models were saved with their trained properties for future use. The developed models were successful in predicting the desired optimum filler content based on the given properties while considering the competitive objectives. References: Dean, A., Safdar, N., & Rolfes, R. (2019). A Co-Rotational Based Anisotropic Elasto-Plastic Model for Geometrically Non-Linear Analysis of Fibre Reinforced Polymer Composites: Formulation and Finite Element Implementation. Materials (Basel), 12. Mahdi, E., & Dean, A. (2020). The Effect of Filler Content on the Tensile Behavior of Polypropylene/Cotton Fiber and poly(vinyl chloride)/Cotton Fiber Composites. Materials (Basel), 13.

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abst. 2581
Repository

Predictive ANN Models for Varying Filler Content for Cotton Fiber Composites based on Load-Displacement Curves

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Composite materials are gaining lots of attention in many engineering applications due to their lightweight and stiffness characteristics. Natural fibers like cotton can be beneficial as the filler content due to their abundance in nature and their environmentally-friendly behavior. Recently, researchers have identified the potential use of cotton fiber as filler content in thermoplastic composites (Dean et al., 2019). Mahdi and Dean (2020), have accomplished many experimental load vs. displacement curves analyses by varying the filler content, to estimate the mechanical properties from the obtained load vs. displacement curves. Although the experimental data are presented for a set value fo filler content, the value of the experimental results can be further extended to include a broader range of filler content if predictive models can be developed. In this paper, the objective is to develop a data-driven model to predict the experimental load-displacement curve so that the obtained models can be used further to estimate the tentative load-displacement curve for the in-between values. The developed ANN models for the experimental values can give the researchers leverage to minimize the future number of experiments and the experimental time efforts by the composite designers. The available data sets used considered, the filler content for cotton fiber thermoplastic Polypropylene composite and Polyvinyl chloride composite that varied from 0% to 50% with the 10% interval. Hence, six different experimental load-displacement curves were available for both PP and PVC composites. The proposed approach in this paper is to build the ANN models for all those experimental curves. While developing the model, the focus is to build a common ANN model structured with the same number of hidden layers and neurons, so that the usability of the developed models can be extended to develop the predictive load vs. displacement curve for any in-between values of the fiber mix. The models provide the ability to predict the characteristics of the optimum amount of fiber content, and it allows the designer(experimentalist) to see the impacts of changing the fiber content on the selected mechanical properties. Such predictive models will have a great impact on reducing the time and effort spent on conducting material characterization experiments. Furthermore, researchers can feed the models the desired set of characteristics and determine the outline of their experiments (e.g., the set of filler content that should be investigated). A similar approach can be extended for any kind of composite material if the necessary experimental data are available. In this work, the ANN models were developed in the TensorFlow backend using Keras library in Python. The necessary experimental data for input were obtained from the Mahdi et al., 2020 works. The hyperparameter tuning method (i.e., the grid search method) was used to find the optimum ANN structure, and the regulations dropout method was used during the training phase to avoid the overfitting. It was found that four hidden layers with 200 neurons each were necessary to build up an effective co-relation between the three feature independent inputs (i.e., filer content, specific energy, and displacement) to 1 dependent out, which is the predicted load values. The corresponding weights and activation functions of the ANN models were achieved through the errors back-propagation, and the mean squared error value was used as the loss function. Also, the k-fold cross-validation method was used to judge how the models perform outside the test data. Finally, the models were saved with their trained properties for future use. It was seen that the developed models were successful in predicting the load-displacement curves for varying filler content for cotton fiber thermoplastic composites. References: Dean, A., Safdar, N., & Rolfes, R. (2019). A Co-Rotational Based Anisotropic Elasto-Plastic Model for Geometrically Non-Linear Analysis of Fibre Reinforced Polymer Composites: Formulation and Finite Element Implementation. Materials (Basel), 12. Mahdi, E., & Dean, A. (2020). The Effect of Filler Content on the Tensile Behavior of Polypropylene/Cotton Fiber and poly(vinyl chloride)/Cotton Fiber Composites. Materials (Basel), 13.

Predicting the Load vs. Displacement Curve for Optimal Cotton Fiber Content Composites using Artificial Neural Network

abst. 2582
Repository

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In modern industrial applications, the use of fiber-reinforced polymer (FRP) continues to grow due to its inherent advantages over conventional materials. The inclusion of fibers in FRP reduces the weight and improves the elastic modulus and mechanical strength. As a result, these materials can be made and precisely engineered to possess predefined tolerance limits, low fatigability, high impact tolerance, and excellent compression properties. Nowadays, natural fiber reinforced polymer composites (NFRPC) are widely used for the manufacturing of engineering products (Mohammed et al., 2015). Their abundance, low cost, and biodegradability make them suitable materials for reinforcing agents in the composite. Cotton fiber is a material that attracts the interest of many groups of researchers as filler content in thermoplastic composites (Mahdi & Dean, 2020). Usually, they accomplished experiments and material characterization in the laboratory to observe the changes in the mechanical behavior of the composite materials. Such data is precious for the use of these materials in various applications. The cost and time for such experiments will be reduced significantly if a predictive model can predict the load vs. displacement curve for the optimal cotton fiber content reinforced thermoplastic composite. The objective of this work is to propose a methodological approach for predicting the load vs. displacement curve for optimal cotton fiber content reinforced thermoplastic composites using artificial neural networks. The experimental data available for the modeling is focused on the Polypropylene/cotton fiber composite and Polyvinyl Chloride/cotton fiber composites. Therefore, it is essential to predict the tensile behavior of those composites corresponding to the applied load according to available data. For this purpose, the neural network technique is used to predict the load-displacement curve. At first, the optimal cotton fiber content was determined by the in-house developed ANN models, and later the missing experimental data and gaps in load-displacement curve trend are predicted by the proposed ANN models both for P.P. and PVC composites. It is worth mentioning that the proposed model in this work can also be used to study the different types of fibers that will be investigated in future works. In the paper, the ANN models are developed in the TensorFlow backend using Keras library in Python. The necessary experimental data for input were obtained from the Mahdi et al., 2020 works. The hyperparameter tuning method (i.e., the grid search method) was used to find the optimum ANN structure, and regulations dropout method was used during the training phase to avoid the overfitting. It was found that for P.P. composite ANN modeling four hidden layers with 200 neurons, and for PVC composite ANN modeling four hidden layers with 400 neurons were necessary to build up an effective co-relation between the three feature independent inputs (i.e., filer content, specific energy, and displacement) to 1 dependent out which is the predicted load values for the composites. The corresponding weights and activation functions of the ANN models were achieved through the error back-propagation, and the mean squared error value was used as the loss function. Also, the k-fold cross-validation method was used to judge how the models perform outside the test data. Finally, the models were saved with their trained properties for future use. It was seen that the developed models were successful in predicting the load-displacement curves for optimal cotton fiber content reinforced thermoplastic composites. References: Mahdi, E., & Dean, A. (2020). The Effect of Filler Content on the Tensile Behavior of Polypropylene/Cotton Fiber and poly(vinyl chloride)/Cotton Fiber Composites. Materials (Basel), 13. Mohammed, L., Ansari, M. N. M., Pua, G., Jawaid, M., & Islam, M. S. (2015). A Review on Natural Fiber Reinforced Polymer Composite and Its Applications. International Journal of Polymer Science, 2015, 243947.

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abst. 2524
Virtual Room
Tuesday
September 1
13h45

On effective properties of thin-walled composite flexoelectric thin-walled structures

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We discuss effective material properties of particular thin-walled structures as beam-lattices and layered plates taking into account flexoelectricity. Unlike piezoelectricity, the flexoelectricity can be detected for all dielectrics. It relates the electric polarization with the strain gradient or stress gradient. As the flexoelectricity phenomenon is size-dependent, it is more pronounced at the nanoscale. As a result, the flexoelectricity may play an important role for nanostructured materials. The aim of this lecture is to discuss the effective properties considering torsion and bending. First, we discuss torsional deformations of a pantographic beam-lattice. Following [1] we derive effective piezoelastic and elastic moduli at the macroscale. In particular, we show that the piezoelectric moduli appear as a result of homogenization of the pantographic beam-lattice under some symmetry constraints. In other words, the microstructure should result in non-centrosymmetric properties at the macroscale. In addition we consider bending of layered flexoelectric plates. We analyse the effective properties using various homogenization techniques. The simplest one is the through-the-thickness integration over the plate thickness. Then we discuss both the first shear deformable plate theory with equivalent properties and the layer-wise model of plates. For simplicity we consider isotropic flexoelectric properties. The influence of the flexoelectricity on the effective tangential and bending stiffness is demonstrated. [1] Eremeyev, V. A., Ganghoffer, J. F., Konopińska-Zmysłowska, V., Uglov, N. S. (2020). Flexoelectricity and apparent piezoelectricity of a pantographic micro-bar. Int. J. Engng Sci., 149, 103213.

Heat Conduction Issue in Periodic Laminate Using Finite Difference Method

abst. 2511
Repository

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The heat conduction phenomenon in periodic laminate is considered in this note. This type of laminate is characterized by an irregular structure and in a general case, can be built of many materials. In this case, the laminate made of two materials with various properties is considered. This structure consists of layers with constant thickness and in every layer the volume share of both materials is also constant. Thus the periodic composites are microscopically inhomogeneous and the equations describing the various issues in relation to these structures are the equations with discontinuous coefficients. To replace these equations, by equations with continuous coefficients, the tolerance modelling is used. This technique is presented and developed in many publications and introduces new concepts (like tolerance-periodic function, slowly-varying function or highly-oscillating function) and new assumptions (like micro-macro decomposition). Tolerance modelling can be used in the analysis of heat conduction issues and thermoelasticity or dynamic problems. The obtained tolerance model equations are dependent on two spatial coordinates and time parameter (nonstationary, two-dimensional issue is analysed) and it is not possible to obtain the analytical solution of these equations. To obtain the numerical solution of these equations the Finite Difference Method is used and the results in the form of the pointplots of the temperature are obtained for selected time parameters.

The Effect of Sizing Optimization on the Interface between High Strength Steel and Fiber Reinforced Composite

abst. 2705
Repository

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This paper aims to study the effect of fiber type and fiber orientation on the interface bonding between high strength steel and fiber reinforced composite, where fracture loads for mode I and mode II were examined experimentally. For the effect of fiber types, three different type of fibers were used; namely glass fibers, carbon fibers, and Kevlar fibers. On the other hand, composite with different fiber

orientations were investigated to assess their effects on the interface between the high strength steel and the fiber reinforced composite. Seven different fiber orientations were examined as follows: 0°, 15°, 30°, 45°, 60°, 75° and 90°. Double cantilever beam (DCB) and end-notched flexure (ENF) tests were applied to characterize mode I and mode II fracture toughness, respectively. Results showed that the interface bonding between the high strength steel and fiber reinforced composite and the mode I and mode II fracture toughness has been significantly affected by fiber orientation and fiber types. Keywords: Fracture toughness; Interface; fiber orientation; fiber types; steel.

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abst. 2652
Repository

Delamination-buckling mode analysis of PZT/Metal/PZT sandwich thick plate with rectangular interface cracks under bi-axial compression

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In this work the buckling delamination mode of a cracks' surface contained in a PZT/Metal/PZT sandwich rectangular thick plate is studied and this work is made within the scope of the piecewise homogeneous body model by utilizing the so-called 3D linearized theory of stability loss for electroelastic materials. It is supposed that there are two parallel interface cracks between the face and core layers and this plate is loaded with the uniformly distributed compressive forces acting on all end planes. It is assumed that before the loading, the surfaces of the considered cracks have infinitesimal initial imperfections and it is investigated the evolution of these initial imperfections under the action of the bi-axial compressive forces. The values of the critical buckling forces for the local buckling delamination of the considered PZT rectangular plate around the cracks are determined from the initial imperfection's criteria. Corresponding boundary value problems are solved numerically using algorithm and programs coded in the 3D finite element method by the author. Under some values of the problem parameters, the cracks' edge surfaces evaluate to wrinkles form. The aim of the present study is to investigate and analyze such buckling mode evaluation and the influence of various geometrical and material parameters as well as electromechanical coupling properties on those.

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abst. 2490
Virtual Room
Tuesday
September 1
13h30

1D Hierarchical Ritz Formulation and 2D GDQ-based approaches for the mechanical modelling of thin-walled composite structures

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In the last decades, thin-walled composite structures with different geometries have been largely applied in many engineering applications because of their optimal strength-to-weight ratio. In a context where advanced numerical methods are required for an accurate estimation of their structural behaviour, especially when innovative constituents and materials are involved, we apply, in the present work, two different numerical approaches to treat the vibration response of some selected structural components with different shapes. In detail, we employ the 1D-Ritz formulation with 3D capabilities [1-3] and the 2D Generalized Differential Quadrature (GDQ) method [4-6] both in the strong and weak form, whose results are compared to the ones based on a classical 3D finite element formulation. Thus, a systematic investigation is performed to study the sensitivity of the natural frequencies to different input parameters, namely, the boundary conditions, the length-to-thickness ratio, as well as different material and geometrical properties. The main advantages of the proposed solution techniques, are discussed comparatively, both in terms of convergence and accuracy, for each case study here analysed. Key Words: Hierarchical Ritz formulation, 2D GDQ-based approaches, Higher-order theories, Thin-walled shell structures, Composite materials. REFERENCES: [1] F.A. Fazzolari. Quasi-3d beam models for the computation of eigenfrequencies of functionally graded beams with arbitrary boundary conditions. Compos. Struct., Vol. 154, pp. 239-255, 2016. [2] F.A. Fazzolari. Generalized exponential, polynomial and trigonometric theories for vibration and stability analysis of porous FG sandwich beams resting

on elastic foundations. Compos. Part B-Eng., Vol. 136, pp. 254-271, 2018. [3] F.A. Fazzolari. Thermoelastic vibration and stability of temperature-dependent carbon nanotube-reinforced composite plates. Compos. Struct., Vol. 196, pp. 199-214, 2018. [4] F. Tornabene, N. Fantuzzi, F. Ubertini and E. Viola. Strong formulation finite element method based on differential quadrature: A survey. Appl. Mech. Rev., Vol. 67(2), 020801, pp. 1-55, 2015. [5] F. Tornabene. General higher order layer-wise theory for free vibrations of doubly-curved laminated composite shells and panels. Mech. Adv. Mat. Struct., Vol. 23, pp. 1046-1067, 2016. [6] F. Tornabene and M. Bacciocchi. Anisotropic Doubly-Curved Shells. Higher-Order Strong and Weak Formulations for Arbitrarily Shaped Shell Structures. Esculapio, 1st edition, 2018.

Metamodel based optimisation of manufacturing tolerances for composite laminate parameters under structural constraints

abst. 2158
Repository

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Composite structures made of endless fibre reinforced plastics with their high lightweight potential find more and more applications in industry, though high volume products are found sparsely. To enable composite materials manufacturing in large batch sizes, beside the optimal design of the product and composite structure, the handling of variations in the product, deviating from the nominal design, needs to be considered. As every physical part and process is imperfect, deviations and uncertainties from the nominal design occur and change the behaviour of the product. To cope with this aspect, different approaches like robust design and tolerance management, evolved. Composite structures subject to deviations are challenging for the product developer, due to their anisotropic behaviour and the high number of design parameters. Beside the geometry and the dimensions of the structure, especially the ply and laminate parameters have severe influences on the structural behaviour. Therefore, deviations need to be carefully considered during the design. Especially for high volume products, a method to allocate tolerance values for the ply parameters, e.g. angles, thicknesses or position of local reinforcements, is required to ensure the function of the composite structure. The tolerance values should be specified in a manner, that the effort needed to achieve the tolerances is as small as possible. A new approach for the optimisation of ply parameter tolerances, i.e. variation ranges of the parameters with a given distribution for which the function of the structure can be guaranteed, is presented. To reduce the computational effort, metamodels are used for modelling the structural behaviour of the part. The optimisation procedure of the parameter tolerances of homogenous as well as variable stiffness laminates uses a genetic algorithm. The scrutinised key functions of the composite structure can vary from manufacturing simulation to structural simulation where e.g. strength or geometric tolerances or simply the deformation is evaluated. In the presented work, the approach is applied to a use case with different key functions.

Damage model of woven fabric flax fibre's biocomposites laminates: application to failure prediction of sandwich panel

abst. 2638
Virtual Room
Tuesday
September 1
15h00

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Due to more and more binding regulations on environment, natural fibres and biocomposites have received a growing interest in the past years. Natural fibres have been widely study for production of

panels and laminate and theirs applications in transport industry are now very large. These materials are also provided for unidirectional and woven fabric composite laminates applications. So some part of structure piece could now be realized with these materials and may be replacing of glass fiber. Indeed, Flax fibre has been shown to be comparable to, or even exceed, Glass fibre in specific strength (1300 vs 1350 MPa/g cm3) [8], specific modulus (20–70 vs 30 GPa/g cm3) [5,8], cost-savings by weight (0.5–1.5 vs 1.6–3.25 USD/kg). However in order to design flax fiber composite laminate structures static and dynamic behavior of this type of composite have to be understood. Many authors have described flax fiber composite behavior with experimental studies since 15 years, but few authors have provided numerical behavior damage model. Some exist for impact but not take into account some non-linearity as damage of the fibers. Objective of this work is to present a damage and failure model of flax fiber woven fabric composite laminate and the damage model application to the failure prediction of a specific sandwich panel. First part of the work is devoted to the damage model presentation and identification of all the damage and failure parameter. Model is based on Linde damage model where damages are describe by an exponential function defined with strain criteria and energy at failure. In order to take into account the progressive damage of flax fibers due to the fact that flax fibers non continuous fibers, we define diffuse damage parameters and failure damage parameters. Diffuse damage parameters are expressed according energy and failure damage parameters depend on strain failure criteria. Experimentation is presented in order to identify all the damage/failure parameters. The Diffuse damages identification is realized with cyclic tensile tests. Failure energies are determined with CT/CC tests. The model is implemented in an Abaqus USER Routin. Validation of the model is realized on simple samples. Second part of the work present failure prediction of a new design of a sandwich panel. The core of this panel is realized with a specific shape named "corrugated" in order to minimize the mass and increase his stiffness. After presenting the making process of this panel, 3 point bending tests are realized and analyzed. Two types of failure have been identified. The first one corresponds to a debonding of the upper skin of the panel, the second one to the failure in tensile of the lower skin. Finally a 3D finite element model of the panel using the damage/failure model is achieved and compared to global load-displacement behavior of the panels. Numerical and experimental Damage and failure are compared. References Linde P, de Boer H. Modelling of inter-rivet buckling of hybrid composites. Compos Struct 2006;73(2):221-228. Benedict Lawrence Sya, Zouheir Fawaza, Habiba Bougherarab. Numerical simulation correlating the low velocity impact behaviour of flax/epoxy laminates. Composites Part A 126 (2019). Change Wua,b,1, Kang Yanga,1, Yizhuo Gua, Jun Xuc, Robert O. Ritchied,[U+204E], Juan Guana,b, Mechanical properties and impact performance of silk-epoxy resin composites modulated by flax fibres. Composites Part A 117 (2019) 357–368. Zia Mahboob , Ihab El Sawi, Radovan Zdero, Zouheir Fawaz, Habiba Bougherara, Tensile and compressive damaged response in Flax fibre reinforced epoxy composites. Composites: Part A 92 (2017) 118–133. Fatma Omrani, Peng Wang, Damien Soulat, Manuela Ferreira Mechanical properties of flax-fibre-reinforced preforms and composites: Influence of the type of yarns on multi-scale characterisations. Composites: Part A 93 (2017) 72–81

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abst. 2542
Repository

The effect of synthetic and natural fire-retardants on burning and chemical characteristics of thermally modified Padouk (Pterocarpus soyauxii) wood

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This article focuses on flammability and different modification temperatures on selected combustion characteristics and chemical components determined for teak wood (Pterocarpus soyauxii L. f.). The ThermoWood® principle has been used to modify thermally at 160 °C, 180 °C, and 210 °C. After the thermal modification the wood was treated with an immersion process of the wood specimen with ammonium phosphate-based synthetic flame retardant and arabinogalactan based natural flame retardant. Subsequently combustion parameters such as maximum combustion speed, combustion speed, weight loss, the ratio between maximum combustion speed and time to reach maximum combustion speed together with the effect of thermal modification and flame retardant were measured. The chemical variations of wood have been considerable with large variations in cellulose, hemicellulose, holocellulose, lignin and extractives content. Spearman's correlation was used to study the relationship between chemical changes and combustion characteristics. The results showed that the thermal modification of padauk wood damaged its combustion and ignition properties. After impregnation with the high-quality retardant, the effect of the thermal modification was eliminated. The relative content of lignin, cellulose and extractives had an increase, while the amount of holocellulose and in particular hemicellulose had a decrease.

Thermoelastic metamaterials design using a novel robust topology optimization method

abst. 2061
Repository

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The design of thermoelastic metamaterials based on topology optimization method is not dependent on the intuition of the designers and specific perovskite ceramics. Such composites obtain desirable properties from periodic optimized microstructures (mutual restriction of layers of materials) rather than their chemical composition. However, the thermoelastic properties of base materials vary greatly with temperature; therefore, the constant properties of base material based on room temperature assumption will have a great impact on the equivalent properties of the designed composites. Thus, with uncertainty of base material property incorporated into the composite design, a novel robust topology optimization methodology based on Polynomial-Chaos-Chebyshev-Interval method is proposed, where the robust objective function is formulated by a combination of upper bounds of interval mean and interval variance of the objective value. The three-phase composite design scheme is achieved by multi-material solid isotropic material with penalization method, and the equivalent properties of composites are evaluated by the numerical homogenization method. The thermal expansion coefficients of two base materials are assumed to be a probabilistic variable and a non-probabilistic variable, respectively. The Polynomial chaos and Chebyshev interval functions are used in uncertainty analysis. Several numerical examples results are presented to verify the robustness of the designed composite. The method is non-invasive and general, and it can be utilized in other robust design of multi-material and multi-physics metamaterials

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Design and Analysis of a Carbon-Fibre Sandwich Structure as Safety Cage for a Solar Powered Multi-Occupant Vehicle

abst. 2536
Virtual Room
Tuesday
September 1
14h00

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The use of composite structures represents a design strategy largely utilized in the case of solar race vehicles where weight savings can be immediately transformed into energy efficiency and, essentially, into a better race performance. At the same time, no design assumption can sacrifice safety. This article describes the redesign activity that led to replace the existing titanium alloy roll cage with a carbon fiber reinforced structure, in laminates and sandwiches, as main part of the safety system in a multi-occupant solar prototype. Thanks to an appropriate optimization of materials, lay-up and sandwich-structures it was possible to improve car safety reducing significantly the weight.

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abst. 2704
Repository

Experimental and Theoretical Analysis on Dynamic Behavior of Metal Foam Sandwich Beam under Repeated Impacts

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The phenomena of repeated impacts are very common, especially on ship and ocean structures. When these structures are subjected to repeated impact loadings, the deformation and damage will accumulate as the impact number increases, resulting in the failure and damage of the structures, even resulting in serious accidents. It is reported in this paper that the repeated impact tests of metal foam sandwich beam (MFSB) were performed by using INSTRON 9350 Drop Tower, and the deformation and energy absorption performance of MFSB were analyzed. Besides, based on the rigid-plastic assumption, the theoretical model is established to analyze the plastic mechanical behavior of MFSB suffering from repeated low velocity impacts, in which the bounds of dynamic solution of permanent deflection are derived. Finally, the theoretical predictions are compared with the results of impact tests. Results show that the displacement of the sandwich beam is linearly distributed, and the deflection increases with the impact number, while the increment declines. With the increase of the impact number, the plastic deformation energy produced in each impact decreases, on the opposite, the rebound energy increases. The permanent deflections predicted by theoretical solutions agree well with those obtained from the impact tests, confirming that the theoretical model is capable in predicting the plastic responses of MFSBs subjected to repeated impacts. The proposed analytical model can provide theoretical references and technical supports for the design of the MFSBs under repeated impact loadings.

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abst. 2494
Virtual Room
Tuesday
September 1
17h00

Nonlinear dynamic response of a multilayer piezoelectric nanocomposite microbeam with tip mass

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Most of the MEMS microsensors make use of vibrating microbeams. Carbon nanotube (CNT) reinforced composites (CNTRCs) are innovative nanostructured materials. The nonlinear forced response of multilayer piezoelectric cantilever microbeams reinforced by CNTs with a concentrated tip mass is investigated. The microbeams support is often times considered as a rigid body. In this paper, the

support is taken as a moving base with a mass which is attached by a spring and a dashpot to a rigid support. The geometrically exact formulation based on the Cosserat theory of rods is employed to study large amplitude vibrations. The constitutive law of the nanocomposite layers is based on the Eshelby-Mori-Tanaka homogenization approach while the piezoelectric layers are modeled according to the standard piezoelectric constitutive formulation. The enforced inextensibility and unshearability constraints lead to a partial differential equation (PDE) governing the flexural motion of the multilayer microbeams. The obtained PDE is coupled to the ordinary differential equation for the motion of the shuttle mass. The Faedo-Galerkin approach is implemented to discretize the problem. The method of multiple scales is employed to obtain the frequency response of the system under a primary resonance base excitation. The frequency response highlights the effects of the carbon nanotubes volume fraction, tip mass, and force amplitude. The outcomes reveal that the CNT volume fraction augmentation increases the linear natural frequencies as well as the peak frequency response amplitude of the first mode while decreases the maximum amplitude frequency response of the second mode. Moreover, as expected, the increase of tip mass decreases the linear natural frequencies. On the other hand, it induces no noticeable reduction on the maximum amplitude of the frequency response of the first mode. On the contrary, a small tip mass added to a bare microbeam increases considerably the maximum amplitude of the frequency response of the second mode. Thereafter, more increment in the tip mass magnitude decreases appreciably the maximum amplitude frequency response of the second mode. The generated voltage in the piezoelectric layers increases by increasing the CNT volume fraction under a primary resonance of the first mode while it diminishes when the second mode is excited. The sensitivity analysis for the generated voltage in the piezoelectric layers reveals that the increase of tip mass decreases appreciably the generated voltage for the second mode after an initial enlargement with respect to the bare microbeam while it has approximately no effect on the generated voltage in the first mode. This conclusion highlights the feasibility of the second mode excitation for mass sensing purposes. The same qualitative trends were captured for the generated voltage as well as the frequency response of the microbeam with and without tip mass as well the CNT reinforcement phase. The sequence of piezoelectric layers stacking is an important feature for the acquired generated voltage and can be subject to an overall optimization.

Lateral Torsional Buckling Analysis of Thin-Walled Cantilever Composite Beams with Arbitrary Layup

abst. 2065
Repository

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In this study, lateral torsional buckling of laminated composite cantilever beam with arbitrary layups under a single transverse load at the tip is investigated. Analytical solution is derived using classical laminated plate theory and verified both experimentally and numerically using Abaqus. A differential equation for the lateral torsional buckling with variable coefficients is formulated using the kinematics, constitutive and equilibrium equations. The differential equation is then solved using the infinite series approach yielding closed-form solutions which are favorably compared to the numerical and experimental results confirming their accuracy. The analytical solution can be easily adopted for generally anisotropic (arbitrary layup) thin-walled rectangular beams with different load and boundary conditions. As part of the experimental work, four beams with 0 degree layups and two beams with 90 degree layups each having 4 layers are prepared in the lab. The length-to-height ratio (l/h) varied from 6.67 to 20 for the beams. Lateral and vertical displacements and most importantly the twisting rotation of beam section () is measured accurately using laser pointers for every load increment. Load vs. plots are generated and compared with nonlinear Riks analysis results using Abaqus. A parametric study is also conducted to investigate the effect of various parameters on the buckling response.

Crash Behavior of Double Hat Crashboxes Made of Steel/Polymer/Steel Sandwich Composites

abst. 2103
Repository

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Steel/polymer/steel (SPS) sandwich composites consist normally of two stiff cover sheets with a polymeric reinforced or non-reinforced core layer. These SPS can be tailored considering the properties and thickness of cover sheets and the core layers to deliver desired properties; crash energy and failure mode in the context of the current study. In this study, double hat crashboxes made of SPS were designed due to their potential delivering comparable failure mode under crash loading with a significant lightweight contribution. The forming behavior of the SPS depends on its constituents and the metal/polymer adhesion strength. In the current study, high-formable steel cover sheets in 0.5 mm thickness and thermoplastic non-reinforced polymer core (Polyolefin) in different thickness (0.3 – 1.2 mm) are utilized to deliver the required forming potential. Based on the know-how developed in the Institute of Metallurgy, the SPS are produced by roll bonding with the help of a compatible adhesive agent. Applying the optimum adhesion conditions, the adhesion strength reached 11 MPa, which is enough delivering cohesive failure mode. Forming the flat SPS sheet into hat profiles was performed using a press brake bench, i.e. by a bending process. The bending radius was chosen depending on the thickness of the SPS; thicker SPS required higher bending radii aiming at failure-free hat profiles. After forming, the two single hat profiles were joined using blind riveting and gluing. Different triggering approaches, in the form of cuts and beads, were introduced to the crashboxes, as well. Bead triggers were recommended as they deliver stable progressive folding and high-energy absorption, as well. The influence of the core thickness on the mechanical properties and on the energy absorption was studied. Linear increase of the mean crash force was found with increasing the core thickness due to the increased structural stiffness. Furthermore, the experimental results could be verified with previously obtained empirical models applied on monolithic metallic sheets, where the results reveal very good matching in case of progressive folding failure mode. The effect of the metal/polymer adhesion strength on the crash absorption characteristics and failure behavior under crash loading was one main concerns of this study. The adhesion strength was varied by changing the processing conditions of the adhesive agent (temperature and time) to deliver string and weak adhesion values. The results reveal that weak adhesion strength led to unstable folding behavior of the crashboxes and less energy absorption accordingly. For good adhesion, progress folding can be found until the end of the crash forming. In summary, applying the SPS as crashboxes is promising due to their progressive folding behavior, which is similar to the crashboxes made of formable metallic sheets. SPS have the advantage of tailoring their structure and, accordingly, a significant lightweight contribution can be stated. The energy absorption characteristics can be controlled by the cover sheet/core layer thickness ratio and the adhesion strength. Further investigations are under development in the framework of the DFG project (No. 407352905) including material modeling and finite element simulation of the crash properties of the SPS materials.

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abst. 2692
Virtual Room
Tuesday
September 1
11h15

Thickness effect of anisotropic conductive behavior of carbon fiber reinforced PEEK unidirectional tape

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The conductive anisotropic polymer composites (ACPCs) have important applications like field emission devices and electronic sensors. Conventional anisotropic conductive polymer composites (ACPCs) are difficult to obtain large conductive anisotropy coefficients and present limited mechanical properties. In this paper, novel technology integrated carbon fiber (CF) spread, surface modification with stacking thermoplastic film was used to prepare carbon fiber reinforced polyether ether ketone (CF / PEEK) unidirectional tape with thicknesses of 0.04 and 0.1mm. CF / PEEK unidirectional woven cloth was prepared with PEEK fiber was used as a binder weft, and CF / PEEK unidirectional laminate (UDL) was prepared by thermoforming process. The in-plane and the thickness directional resistivities of UDL were measured by Digital multimeter and in-plane electron mobility was tested by Hall effect system.

The fiber arrangement within in-planes along the fiber direction and the thickness direction of UDL was observed with an ultra-depth microscope. The results show that the in-plane conductivity ratio of ultra-thin CF / PEEK UDL reaches to 377, while conductive ratio in the transverse direction to the thickness direction is close to 1, indicating that thin CF/PEEK UDL presents transverse isotropic electric performance. The results of electron migration indicate in-plane huge anisotropic conductivity also. The results are important for CF / PEEK to be used in field emission devices and electronic sensors.

Characterization of microcracking of NCF composites under hygrothermal aging - Influence of the stitching yarn and ply sequence

abst. 2418
Repository

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Due to their good drapability, the textile Non-Crimp Fabric (NCF) are combined with manufacturing processes such as RFI (Resin Film Infusion) or RTM (Resin Transfer Molding) to produce complex and large composite structures while minimizing manufacturing costs compared to prepreg processes. However, despite the massive developments that have been achieved, the NCF of previous generations do not meet the specifications required by the aeronautical application for durability. The stitching yarn seems to be problematic, as it leads to the formation of resin-rich areas (RRA), thus causing multi-scale heterogeneities. Under the effect of hygrothermal cycling, these RRA are responsible for a large part of the microcracking of the NCF composite. The internal specific morphology of NCF composites is more heterogeneous than conventional laminates, and this morphology has a consensual influence on resistance to microcracking. Hence, the effects of stitching on the microcracking hygrothermal of NCF composites should be evaluated. The objectives of the present study were to define an adapted experimental method for characterization of the microcracking of NCF composites under hygrothermal loading. The impact of different processing parameters on microcracking is discussed, including the use of different orientations of the NCF plies, with different sizes and types of stitching yarn. The NCF composite was loaded 2000 cycles with an accelerated hygrothermal load representative of the operating conditions of a subsonic jet during its life cycle. This loading is composed of 5 blocks of 400 cycles, block including two different loading phases: a first stationary phase where the composite is exposed to 95% RH (Relative Humidity) for 12 hours at 50°C and a second thermal dry loading phase. During this last phase, the composite is cycled 400 times in a temperature range [-54, 80] °C with a heating and cooling ramp of 9°C/min. Each cycle lasts one hour (4×15 min), and this logically gives a duration of 15 min for each temperature rise and decrease and 15 min for each isothermal step at 80°C and -54°C. The studied composites plates [45/-45/0/90]2S (45×40 cm^2) are manufactured with a biaxial carbon NCF called C-PLYTM. The matrix used is a reinforced epoxy resin, called EP2400 PRISMTM. The focus of our analysis was on two different types of stitching yarns, polyamide (PA) 39 dtex (the PA_39dtex yarn is composed of 34 filaments) and copolyamide (CO-PA) 23 and 55 dtex (Copolyamide : fusible bonding yarn, the yarn CO-PA_23dtex is composed of 4 filaments and the CO-PA_55dtex is composed of 8 filaments). In the present study, three types of microcracks in NCF composites have been classified: the first type corresponds to microcracks appearing at the stitching yarn/resin interfaces (resin-rich stitches inducing transverse microcracks), the second type corresponds to those appearing in the carbon fibers/resin interfaces (these transverse microcracks can be detected in conventional fiber composites) and the third type corresponds to those appearing in the filaments/resin interfaces (stitching filaments dispersed in the resin which create heterogeneous areas). An adequate microcrack density has been defined to evaluate all types of microcracking and to take into account the inclination of the fibers of each ply in NCF laminate. The microcracks density are measured after 400, 800, 1200, 1600 and 2000 hygrothermal cycles. A significant difference can be observed between

the samples stitched with polyamide yarn and those stitched with copolyamide yarn. The PA_39dtex laminate, which has the highest microcrack density, reaching 1.4 μc/cm (microcracks/cm). It appears that CO-PA_23dtex laminate tends to produce a lower total μcrack density than PA-55detx. Whereas the last one reached around 0.3 μc/cm, CO-PA_23dtex does not exceed 0.02 μc/cm. This is due to the internal morphology of the material: in PA_39dtex laminate, the RRA are larger and contain many yarn filaments, whereas the RRA of CO-PA 23 and 55 dtex laminates are smaller and contain few yarn filaments. The difference in behavior under hygrothermal loading between stitching yarns and matrix can be attributed to this morphological difference. The PA-23dtex showed no "type 1" μcracks, whereas PA_39dtex begins at 400 cycles and CO-PA_55 dtex at 1200 cycles. Type 2 μcracks were detected only in PET-39 dtex laminate with a density of 0.25 μc/cm. Finally, type 3 μcracks begins already in the first cycles for PA_39dtex reaching a density of 0.52 μc/cm and 0.14 μc/cm for CO-PA_55dtex, while CO-PA_23 dtex resists up to 1600 cycles with a density lower than 0.02 μc/cm at 2000 cycles.

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abst. 2672
Repository

A mesoscale approach for finite element forming simulation of continuously fiber reinforced composites

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A mesoscale approach for modelling nonlinear deformation behaviour in FE forming simulation of continuously fibre-reinforced polymers is presented. The properties of prepreg such as tensile, shear and bending stiffness are predicted using fiber bundle and polymer data. To confirm the validity of the mesoscale model, the experimental and simulation results of bias-extension tests are compared. Then, the approach is applied to a more complex generic geometry as an application test. The results show that a good agreement between forming simulation and experimental tests.

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abst. 2341
Virtual Room
Tuesday
September 1
10h15

Data-driven multiscale simulation of FRP based on material twins (Winner of the Ian Marshall Award)

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Fiber reinforced polymer composites (FRP) are widely used in aerospace and automobile fields, because of their high strength, design flexibility and long life. However, due to the complex multiscale architecture of the composites (especially the reinforcements) at both the mesoscopic and the microscopic scales, it is difficult to establish a connection between microstructure and mechanical behavior. Besides, it is time-consuming and difficult to formulate and solve the complicated multiscale system. The objective of this paper is to present a novel approach to combine Micro-CT and data-driven simulation to solve the mechanical problems of FRP. The recently proposed approach, named Micro-CT Aided Geometric Modeling (Micro-CT AGM), is initially employed to generate material twins from microtomographic images. The geometric features of real fibrous reinforcements are extracted from the material twins to generate RVEs for further microscopic finite element analysis. Then, the finite element models are used to create data points to construct the offline database. Finally, the data-driven FE2 method is employed to solve the online macroscopic problems by searching the data points over the offline database. Thanks to the combination of the material twin and the data-driven FE method, the computing efficiency and accuracy are both improved. Furthermore, since the material twins provide the actual material information, it is possible to introduce the realistic uncertainty into numerical models,

which means that simulations can also illustrate the variability of the material much like experiments. This provides an opportunity to connect the numerical simulations and the real experiments, which contributes to a rather comprehensive database for data-driven computational mechanics.

Concurrent material distribution and fiber angle optimization for fiber-reinforced composite structures

abst. 2699
Repository

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Designing Straight-Fibre Variable Stiffness Composite Laminates

abst. 2279
Virtual Room
Tuesday
September 1
09h15

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The mechanical performance of laminated composite structures can be improved significantly by spatially varying the stiffness properties within the laminate, resulting in a so-called Variable Stiffness (VS) laminate. Typically, the stiffness variation in VS laminates is achieved by steering the fibres within the laminae, resulting in an in-plane variation of stacking sequence and thus an in-plane variation of mechanical properties of the laminate and subsequent load-redistribution within the laminate. The authors propose a different approach to achieving VS laminates, which does not rely on fibre steering. Instead, in-plane variation of the stacking sequence is achieved by stacking patches of unidirectional material or fabric, each of different in-plane dimension. Such a laminate can be designated as straight-fibre VS composite laminate. In the proposed design approach, the laminate is divided into a discrete number of regions, for each of which the stacking sequence is optimised individually. Stacking sequence continuity is enforced by an algorithm inspired on cellular automata (CA) which relies on the application of a set of simple design rules. The result is a laminate consisting of straight-fibre patches, spanning one or multiple regions of the laminate, which all stacked together give the desired VS laminate, a straight-fibre VS composite laminate. The proposed design approach is demonstrated in two ways: 1) its performance in matching a predefined stiffness distribution in terms of lamination parameters, and 2) its performance as tool to design a variable stiffness laminate without prior stiffness distribution available. To conclude, the trade-off between the mechanical performance of the laminate and manufacturing constraints e.g. the maximum number of ply-drops and the minimum dimensions of a patch are discussed, to give an outlook on the feasibility of the construction of straight-fibre variable stiffness composite laminates.

Tolerance modelling of dynamics and stability problems for slender visco-elastic periodic beams on a foundation with damping

abst. 2436
Repository

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The objects under considerations in this note are slender visco-elastic beams with a periodic structure along its axis interacting with a periodically heterogeneous foundation. These beams are made of many identical small elements, which are called periodicity cells. Every cell has the length l, treated as the microstructure parameter. Dynamic or/and stability problems of these beams are described by a partial differential equation. Unfortunately, this governing equation is an equation with highly-oscillating, periodic and non-continuous functional coefficients in x. Hence, it is not a good tool to analyse various problems of these beams. In order to obtain governing equations with constant coefficients different simplified approaches are proposed, which introduce effective properties of the beam. It could be mentioned those methods, which are based on the asymptotic homogenization, cf. [5]. The literature

on the problems of dynamics or stability of periodic beams is extensive. Between various approaches the theory of Floquet-Blochcan be distinguished, as often applied in the waves analysis. This was used in the analysis of the Euler- Bernoulli [1] beam vibrations. In order to evaluate strength and buckling of sandwich beams with variable properties of cores some analytical approaches and the finite element method are also applied, e.g. [3]. However, the governing equations of the above mentioned models neglect usually the effect of the microstructure size on the beam behaviour. Here, the tolerance modelling, cf. [7], will be used to replace the differential equations of periodic beams, having highly-oscillating, periodic, non-continuous functional coefficients, by equations with constant coefficients. This approach was developed for the purpose of analysis of thermomechanical problems of periodic composites and structures in a series of papers, e.g. for dynamic response of micro-periodic beams under moving load [6], for vibrations of thin periodic plates [4], for geometrically nonlinear vibrations of periodic plates [2]. References. 1. CHEN T., Investigations on flexural wave propagation of a periodic beam using multi-reflection method, Archive Of Applied Mechanics 83, 2013, 315-329. 2. DOMAGALSKI Ł., JĘDRYSIAK J., Nonlinear vibrations of periodic beams, Journal of Theoretical and Applied Mechanics 54, 2016, 1095-1108. 3. GRYGOROWICZ M., MAGNUCKI K., MALINOWSKI M., Elastic buckling of a sandwich beam with variable mechanical properties of the core, Thin-Walled Structures 87, 2015, 127-132. 4. JĘDRYSIAK J., Higher order vibrations of thin periodic plates, Thin-Walled Structures 47, 2009, 890-901. 5. KOLPAKO, A.G., Calculation of the characteristics of thin elastic rods with a periodic structure, Journal of Applied Mathematics and Mechanics 55, 1991, 358-365. 6. MAZUR-ŚNIADY K., ŚNIADY P., Dynamic response of a micro-periodic beam under moving load – deterministic and stochastic approach, Journal of Theoretical and Applied Mechanics 39, 2001, 323-338. 7. WOŹNIAK C., MICHALAK B., JĘDRYSIAK J., (EDS)., Thermomechanics of microheterogeneous solids and structures. Tolerance averaging approach, Lodz Univ. Techn. Press, Lodz, 2001, Poland.

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abst. 2007
Repository

Durability of Interface Between CFRP and Damaged RC Members Under Chloride Environment

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The aim of this work is to investigate the effects of corrosion degree and retrofitting method on the durability of interface between carbon fiber reinforced polymer (CFRP) and reinforced concrete (RC) members. A series of accelerated electrochemical corrosion test was conducted on the RC prisms based on Faraday's law. Three retrofitting methods including bonding CFRP directly, bonding CFRP after crack-repairing and bonding CFRP after replacing damaged concrete were considered. Then, a second-corrosion test were conducted on the retrofitted RC prism. After that, the second-corroded RC prism was tested under single shear loading. The result shows that the rusting level of the steel in RC members before retrofitting has a significant influence on the strengthening effectiveness by externally bonding CFRP. As for the specimens with high corrosion level , the retrofitting methods of bonding CFRP after crack-repairing and bonding CFRP after replacing damaged concrete could fully utilize the superior performance of CFRP and consequently improve the durability of the interface between CFRP and concrete.

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abst. 2479
Repository

Large Rupture Strain Fiber-Reinforced Polymer Composites for Civil Engineering Applications: Current Status and Future Opportunities

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Fiber-reinforced polymer (FRP) composites have been widely used in civil engineering communities, for either strengthening existing deteriored reinforced concrete (RC) structures or constructing new structures. Recently, a new category of FRP with a large rupture strain (i.e., referred to as "LRS FRP" in this article) has become increasingly polular. In contrast with conventional FRP composites, LRS FRP composites possess a larger elongation and a lower modulus of elasticity. Since the ultimate state of structures with FRP strengthening generally depends on fracture of the FRP, it is expected that an increase in FRP rupture strain leads to a better performance of structures. LRS FRP composites are particularly suitable for enhancing ductility of strcutures. The authors will present a state-of-the-art review on the basic characteristics of LRS FRP composites and research on structural usage of LRS FRP composites, with further research opportunities associated with LRS FRP composites in civil engineering applications being identified.

OPTIMIZATION OF VARYING STIFFNESS SUPPORT DEVICE FOR HUMAN SUPINE POSITION

abst. 2643
Virtual Room
Tuesday
September 1
15h15

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Supine position is used in a vast set of medical procedures and applications, requiring a human body support device that can provide both patient positioning stability and comfort. These requirements are often difficult to ensure simultaneously for support devices, such as conforming foam mattresses and rigid plaques, given that higher structural stiffness of these devices correlates with positioning stability, conversely to lower structural stiffness which correlates with comfort. An idealization of such support devices as a composite structure with multiple structural stiffnesses may offer a design solution to comply simultaneously with both patient positioning stability and comfort. The present work presents a framework for the design of a human body support device in supine position, based on a varying stiffness composite material approach using for that purpose a multibody system dynamics model. The varying stiffness support device is modelled using multiple springs between the human body in a supine position and a horizontal reference plane corresponding to the base of the support device. An optimization procedure is conducted for an optimal design of the multiple springs' stiffnesses aiming to comply with the requirements of human body positioning stability and comfort. The performance and suitability of the framework developed is discussed in the context of a variable stiffness composite plate approach.

Composite Leaf Springs made of carbon fiber prepregs layers interleaved and co-cured with elastomer material: study of application on an ESR ankle-foot prosthetic device

abst. 2321
Repository

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A gait cycle can be mainly subdivided in two phases, which are stance phase (60%) and swing phase (40%). In the first phase the foot remains in contact with the ground, and the second one consists of the entire time that the foot is in the air. For the structural design of a below-knee prosthetic device, the study is focused mainly on the stance phase which can be subdivided in at least five subphases: initial contact, load response, mid stance, terminal stance and toe-off. The behavior of a human foot in each of these subphases change based on several factors that can be the type of activity, the speed, the bodyweight, the extra-weight carried and the inclination of the ground. Therefore, the design and the characterization of an overall stiffness of ankle-foot prosthesis that approximates the biomechanics of the human ankle-foot is fundamental. In the present study, an Energy-Storing-and-Releasing (ESR) foot prosthesis with three level of elastic parts has been designed, realized and tested. Keeping the same geometry and configuration, different types of mid-level elastic component in terms of stack up sequence and material have been designed, manufactured and tested, and two of them included elastomer material interleaved and co-cured with carbon fiber prepregs. The structural design has been conducted through FEM analysis according to the ultimate test strength in ISO 10328 standard in order to provide a safe device also when loaded four times the 120% of the bodyweight of a 100 kg person. A preliminary and ISO 10328 inspired mechanical proof test has been carried out and it consists of loading separately forefoot and heel with the 120% of the bodyweight of a 100 kg patient, in order to determine the behavior of the prosthetic device during plantarflexion and dorsiflexion. Finally, the FEM analysis and the experimental test results have been analyzed and compared to highlight their differences with the aim of optimizing and validating the 3D Model. Acknowledgments: The research was funded by the European Union's Horizon 2020 Research and Innovation Programme under the Grant Agreement no. 780871 - 2018

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abst. 2300
Virtual Room
Tuesday
September 1
09h30

Concrete Cracking And Deflection Analysis Of Rc Beams Strengthened With Prestressed Frp Reinforcements Under External Load Action

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Fibre reinforced polymer (FRP) reinforcements (laminates, sheets, strips, rods) are considered for retrofitting of RC structures worldwide. Such reinforcements are light, easy to install, corrosion resistant, satisfying aesthetical and design requirements. In order to use full potential of the FRP it should be pretensioned, this way reducing crack widths and deflections. In most cases in practice strengthening will be carried out for structures exposed to external load with initial cracks and deflection. However, there is the lack of experimental and theoretical research of such phenomena when RC structure is strengthened with prestressed FRP reinforcements under external load action. Therefore, here will be presented experimental program for the full analysis of this phenomena. 18 identical RC beams were casted and tested at the courtesy of Vilnius Gediminas Technical University (VGTU): 2 control RC beams, 8 beams strengthened with prestressed carbon fibre reinforced polymer (CFRP) laminates without external load action, 8 beams – under external load action. 4 different prestressing levels were used in both cases: 0 %, 20 %, 40 %, 60 % from the nominal load bearing capacity of FRP. Based on the results theoretical models for calculation are being presented for consideration.

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abst. 2465
Repository

Mechanical and thermal analysis of layered composite made of concrete and epoxy resin modified with titanium (IV) oxide

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The high mechanical performance or thermal resistance is desirable property of materials used in composite structures. The epoxy resin has these two properties. Among many potential applications, epoxy resin can be used both as a protection coating for cementitious concrete substrate and as an adhesive for carbon fiber reinforced polymer in strengthened concrete constructions. However, the durability of the epoxy resin is not high when this material is exposed on temperature changes close to its glass transition temperature. Cyclic temperature changes including glass transition temperature reduce its mechanical properties. The weakest point of the analyzed layered composite is the interphase zone area. The adhesion between the layers can define the durability of the composite structure made of concrete substrate and epoxy resin coating. Due to the different factors which influence on the durability of the layered composite to the epoxy resin adhesion to concrete, the researchers decide to modify epoxy resin with titanium (IV) oxide to change the properties of layered composite. Four concrete specimens with dimensions of 150x150x40 mm were prepared as a substrate for the coating. After 28 days of curing the epoxy resin was applied on the concrete substrate. Three samples of epoxy resin coating were modified with addition of 10%, 20% and 30% of titanium (IV) oxide in relation to the epoxy resin mass. Mechanical analysis was performed by pull-off strength test. The glass transition temperature of modified epoxy resin coating was estimated from heat flow measured with Differential Scanning Calorimetry (DSC). The analysis shows that by modification of epoxy resin by titanium (IV) oxide it was possible to enhance the pull-off strength of layered composite. Moreover, titanium (IV) oxide increased glass transition temperature of the epoxy resin coating. Obtained results show that it is possible to enhance the durability of layered composite made of concrete substrate and epoxy resin coating.

Fabrication of a cylindrical lattice structure by using the electrodeposition resin molding method and its compression properties

abst. 2523
Repository

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To fabricate the CFRP with high-strength and lightness, it is important to design the arrangement of carbon fibers since the carbon fiber is a one-dimensional material. Many studies have been carried out to optimize the arrangement of carbon fibers. In many cases, the most sophisticated structure of CFRP is headed to the lattice structure which maximally utilize the strength and stiffness of carbon fiber. Therefore, the design of CFRP lattice structures have been studied, however, there are many limitations in manufacturing an arbitrary lattice structure by using the current CFRP manufacturing methods such as vacuum assisted resin molding method and prepreg lamination [1]. Previously, the authors have developed the electrodeposition resin molding (ERM) method to fabricate the three-dimensional shaped CFRP [2]. In ERM method, resin was impregnated in the electrodeposition solution and thermally cured. In this study, a cylindrical lattice structure was confirmed to be fabricated by using ERM method. The carbon fiber was assembled in lattice structure using the fixture jig. Further, the compression properties were experimentally clarified and analyzed using the finite element method.

Preparation of interpenetrating metal matrix composite based on metallic glass foams produced by gas pressure infiltration

abst. 2110
Virtual Room
Tuesday
September 1
16h45

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Due to their amorphous structure, metallic glasses exhibit remarkable properties such as high strength, hardness, elastic strain limit and the associated possibility of high elastic energy storage. Conversely, they also exhibit low toughness and high susceptibility to brittle fracture, making them less qualified for the use as monolithic structural components. So far, MMCs with interpenetrating structures have been produced by infiltrating a metal foam with metallic glass, which requires a higher melting temperature of the metal foam than of the metallic glass. As a result, light metal materials such as aluminium and magnesium are not usable for this process because of their low melting temperatures. In this contribution, an open-celled metallic glass foam is produced from Ni-Nb-based glass powder (Ni60Nb20Ta20) by hot pressing and infiltrated with eutectic aluminium alloy AlSi12 by gas pressure infiltration. Due to the high crystallization temperature of the Ni60Nb20Ta20 alloy and the low melting temperature of AlSi12 it is possible to infiltrate the metallic glass foam without crystallization. Porosity of the foam and filling degree of the composite with metallic glass can be adjusted by modifying particle size distribution of the metallic glass powder. In addition, the foams were infiltrated at different processing temperatures and different process times. Resulting microstructure was investigated using X-ray diffraction (XRD) measurements, scanning electron microscope (SEM) and X-ray computed tomography (CT). Characterization shows that process parameters significantly influence the microstructure of the composite.

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abst. 2421
Repository

Experimental study on three-layer laminated glass composite panel under local uniformly distributed loads

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As the application of tempered glass greatly increased in buildings, there will be more chances of tempered glass panel being used in construction in the next few years. This paper presents an experimental investigation on the mechanical properties of three-layer tempered glass panel under uniformly distributed load. A total of sixty-four specimens are tested to investigate the influence of individual layer thickness of tempered glass panel (T), bearing length (BL), and length of loading end (LLE). According to this experiment, the failure modes of tested specimens were observed in detail during load procedure. The effects of the three variables on the ultimate bearing capacity, stiffness and stress distribution of three-layer tempered glass panel are discussed. The results indicate that the three variables have positive effect on bearing capacity and secant stiffness of the three-layer tempered glass panel. And the individual layer thickness of tempered glass panel (T) has the greatest influence on the ultimate bearing capacity and secant stiffness of specimens. With increasing of thickness (T), bearing length (BL) and length of loading end (LLE), the bearing capacity and the stiffness are increased. Based on the results of parametric studies, a number of designed formulae are proposed to estimate the ultimate bearing capacity of three-layer tempered glass panel with bilateral simple bearing under local uniformly distributed load. And the results are compared with the experimental results, the evaluated formulae can be a good guidance for structure design of laminated tempered glass.

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abst. 2426
Repository

Research on vertical capacity of circular concrete filled winding GFRP tubular columns after lateral impact

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Sixty-three circular concrete filled winding GFRP tubular (CFWGT) columns after lateral impact damage were tested, which were used to investigate the behaviour of circular CFWGT columns under compressive loading in this paper. Analysis of effects of GFRP tube thickness, lateral impact height and lateral impact location on mechanical property is given in the investigation. Test results shown that the main influence factor on vertical capacity of circular CFWGT columns was lateral impact damage. Vertical capacity and initial stiffness are decreases as lateral impact height increased. However, the capacity and initial stiffness increase slightly when lateral impact location comes close to the end of specimen. According to the test results, negative effects of lateral impact on the capacity and stiffness of CFWGT columns can be reduced by increasing the GFRP tube thickness. GFRP tube and concrete are both brittle materials. Hence, the CFWGT columns failed suddenly during the axial compressive test. Load-strain curves, value of strain decreased suddenly when specimen failed, are in good agreement with the specimen failed suddenly. Besides, this paper has analyzed the effects of lateral impact on the strain developments of specimen under axial compressive load. The higher the lateral impact height is, the larger the strain value is and the more seriously the specimens are damaged. According to test results, the calculation formula, which was based on a mechanics calculation model, was presented to calculate vertical capacities of circular CFWGT columns after lateral impact, and a great agreement with experimental result had been achieved.

Experimental investigation of fire-exposed steel tubular stub columns wrapped with CFRP sheets

abst. 2445
Repository

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This paper investigates the effects of high temperature (600°C, 800°C, 1000°C and 1100°C) and the layers of CFRP sheets (one, two, three, four) on the behavior of fire-exposed steel tubular stub columns. A total of forty specimens were tested, including thirty-two fire-exposed specimens wrapped with CFRP sheets, eight fire-exposed specimens unwrapped with CFRP sheets. Failure modes, ultimate load-bearing capacity, load-strain curves, load versus displacement curves and initial stiffness at elastic stage and ductility of the specimens are presented in this paper. It was found that the ultimate load-bearing capacity and initial stiffness decreased with the increase of temperature. The load-bearing capacity and ductility of fire-exposed specimens wrapped with CFRP sheets increased with the increase of layers CFRP sheets. The effect of CFRP sheets on circular steel tubular (CST) stub columns is greater than on square steel tubular (SST) stub columns. The largest enhancement of load-bearing capacity of fire-exposed specimens is 59.47%. Based on the experimental results, a formula for the calculation of load-bearing capacity of fire-exposed specimens wrapped with CFRP sheets was proposed, which shows great accuracy and reservation with experimental load-bearing capacity.

Behavior of square pultruded concrete filled GFRP tube (CFGT) columns strengthened with CFRP sheet

abst. 2530
Repository

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This paper presented a test with 108 square pultruded concrete filled GFRP tube (CFGT) columns which were used to investigate the behavior of the columns strengthened with CFRP sheet. Four parameters including GFRP tube thickness, nominal concrete compressive strength, column length and wrap layers of CFRP sheet were set and analyzed in this paper. Furthermore, the effects of these test parameters on the failure mode, ultimate bearing capacity, ductility and initial stiffness were analyzed in this paper. Five categories failure modes were grouped according to the failure characteristics of these columns under axial compressive loading. And it could be found that the cracks of four edges in length directions of GFRP tube was effective confined by CFRP sheet. The test results indicated that ultimate bearing capacity of the columns with CFRP sheet strengthened was greatly higher than that

of the columns without the CFRP sheet strengthened. And the ultimate bearing capacity was further increased by increasing the GFRP tube thickness. The test results also indicated that the ductility coefficient and initial stiffness of the columns were greatly increased because of the strengthened of CFRP sheet. Besides, the strain development of ten square pultruded CFGT columns under axial compressive loading was investigated in this paper. Based on the mechanical mode of square pultruded GFRP tube confined the core concrete and the test result, this paper proposed a calculated formula which was used to predict the ultimate bearing capacity of square pultruded CFGT columns strengthened with CFRP sheet, and a good agreement with the test results was achieved.

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abst. 2611
Repository

Experimental Study on Mechanical Properties of Sandwich Tempered Glass Unidirectional Composite Laminate

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As the application of tempered glass greatly increased in buildings, there will be more chances of tempered glass panel being used in construction in the next few years. This paper presents an experimental investigation on the mechanical properties of three-layer tempered glass panel under uniformly distributed load. A total of sixty-four specimens are tested to investigate the influence of individual layer thickness of tempered glass panel (T), bearing length (BL), and length of loading end (LLE). According to this experiment, the failure modes of tested specimens were observed in detail during load procedure. The effects of the three variables on the ultimate bearing capacity, stiffness and stress distribution of three-layer tempered glass panel are discussed. The results indicate that the three variables have positive effect on bearing capacity and secant stiffness of the three-layer tempered glass panel. And the individual layer thickness of tempered glass panel (T) has the greatest influence on the ultimate bearing capacity and secant stiffness of specimens. With increasing of thickness (T), bearing length (BL) and length of loading end (LLE), the bearing capacity and the stiffness are increased. Based on the results of parametric studies, a number of designed formulae are proposed to estimate the ultimate bearing capacity of three-layer tempered glass panel with bilateral simple bearing under local uniformly distributed load. And the results are compared with the experimental results, the evaluated formulae can be a good guidance for structure design of laminated tempered glass.

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abst. 2338
Repository

The influence of recycled and dispersed carbon fibres on the load-bearing capacity of high performance, self-compacting, fibre reinforced concrete columns.

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In recent years, carbon fibres have been extensively used to reinforce concrete structures. In most cases, the lamination process is carried out using epoxy resin as the matrix. In some cases, especially when reinforcing structural elements made of weak concrete (usually with a compressive strength of no more than 30 MPa), it is possible to replace the epoxy resin with a cement matrix, while at the same time maintaining a sufficient efficiency of the reinforcement. In these tests, elements of mats in carbon fibers that are reinforced with a cement matrix were used as the starting product for fiber recovery. The laminate, which was reinforced with concrete elements, was detached from the concrete surface after testing and subjected to processing in order to obtain clean elements, not containing cement matrix, from the carbon fibers. Then, the obtained carbon fibers, in crushed form, were used to reinforce high performance, self-compacting, fibre reinforced concrete (HPSCFRC). This type of concrete was selected for analysis due to its good workability, high strength, and resistance to dynamic forces. The concrete surface was covered with epoxy resin, and then carbon fiber elements with random fiber orientation were laid on it evenly. The surface of the carbon fibers was then again covered with a layer of epoxy

resin. Samples with 1, 2 and 3 layers of carbon fibers, which were obtained from the recovery and reference samples reinforced using carbon fiber mats, were tested. The obtained results show that it is possible, using the proposed waste treatment process, to reuse carbon fibers to strengthen structural elements made of HPSCFRC, while at the same time maintaining a satisfactory reinforcement of the reinforced concrete. Research has shown that it is possible to re-use carbon fiber to reinforce structural elements using simple processing methods.

Study of the influence of flax/epoxy layers on the damping and eigenvalue of composite structures

abst. 2066
Repository

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Composite structures are present in many areas: The water sport, the naval, the railroad transport, the automotive industry, but also in the leisure activities or in the domain of the renewable energies (for example wind turbines). The advantages of such structures lie in their damping properties and of sound effects and their lightness. Their property of "lightness" offers them an attractive power in industrialization, especially in transport which allows a significant energy saving. There are several types of composites: conventional composites with fiber of carbon, glass, or kevlar, and from now the composites of flax, hemp fibers, that is to say based on natural fibers. These latter are those studied in this work. The aim of this study is to compute the eigenvalues and damping of composites made of flax fibers with an epoxy matrix when the position and the fiber's orientation change in the layers. Here, the layer's damping (denoted by Etak) is introduced in Young's moduli and is considered constant in the following form : Ek = E0 (1 + i Etak) [1]. The homogenization technique is applied in order to have the constitutive equation of the composite structure. To investigate the vibration problem of these structures, a spatial discretization method is applied (the finite element method). An eight nodes quadrilateral C° isoparametric flat shell element with eight degrees of freedom per node is considered. The resolution of the equation of vibration is carried out using the Asymptotic Numerical Method (ANM) [2]. This method associates a high order perturbation method and a homotopy technique. The initial complex problem is linearized and a set of linear algebraic systems is obtained. The damping (Eta) and damped frequency ( ) of the structure, defined from the classical formula of [3] : 2 = 2 (1 + i Eta), are finally determined. References: [1] S. Mahmoudi, A. Kervoelen, G. Robin, L. Duigou, E.M. Daya, J.M. Cadou. Experimental and numerical investigation of the damping of flax–epoxy composite plates. Composite Structures, 2019. 208: p. 426-433. [2] L. Duigou, E.M. Daya et M. Potier-Ferry. Iterative Algorithms for non-linear eigenvalue problems Application to vibrations of viscoelastic shells. Computer Methods in Applied Mechanics and Engineering. vol. 192 (2003), 1323-1335. [3] D.K. Rao. Frequency and loss factor of sandwich beams under various boundary conditions. Journal of Mechanical Engineering Science, 20 (5) (1978), 271-282.

Structural optimization design of multi-bolt single-lap composite joints based on improved characteristic curve method

abst. 2473
Repository

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Composite materials have been widely used in aerospace field, especially in aircraft structures. Bolted joints are main connection methods, and single-lap joints are more representative than double-lap joint. The key to improve the joint efficiency is to improve its bearing capacity and minimize the mass, which requires structural optimization design. Characteristic curve method is a low cost method for bolted joint failure prediction in engineering, and it is appropriate in structural optimization design. However, characteristic curve method is proposed for double-lap joints, which does not consider the significant secondary bending in single-lap joints. In this paper, a structural optimization design strategy was proposed with an improved characteristic curve method. In the characteristic curve method, the characteristic length is a variable influenced by secondary bending moment and thickness of laminates instead of the original constant . In the structural optimization design strategy, the optimization model of load transfer efficiency (joint mass/ failure load) was proposed first by combing the influence parameters. The optimization strategy based on feasible region reduction, model decoupling and one by one optimization was proposed then. In the solving process, main variables and their design ranges were chosen by sensitivity analyses and influence mechanism analyses in the feasible region reduction; the optimization model with more variables was decoupled into sub optimization models with less variables by analyzing the variable correlations in the model decoupling; sub optimization models were solved respectively in the one by one optimization. Combining the improved characteristic curve method, a single-lap single-bolt joint was optimized based on the above optimization strategy, by which the proposed characteristic curve method and the improved optimization strategy were verified.

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abst. 2474
Repository

Buckling and failure analyses of composite cylindrical shells under combined axial compression and external pressure loads

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Thin-walled composite shells are buckled when subjected to significant amount of load. This paper presents a competitive failure analysis framework, in which the semi-linear buckling interacting curve was considered for buckling analysis and the strength ratio was used to obtain the failure interacting curve of composite laminated cylindrical shells subjected to axial compression and external pressure loads. The presented framework agreed well with published results, which verified the feasibility of the framework. Extensive parametric studies were accomplished and presented in order to reveal the failure law of composite. It was found that, the higher ratios of the longitudinal compressive strength to longitudinal modulus and transverse tensile strength to transverse modulus of composite materials, the

more likely buckling-failure occurs, otherwise stress-failure occurs. For geometric studies, it was found that, as the ratio of radius to thickness reduces, the buckling interacting curve increases. Additionally, as the ratio of radius to thickness reduces, the occurrence possibility of stress-failure increases. For material studies, the variation of material properties with the same geometry dose not significantly affect in the shape of normalized buckling interacting curve. Moreover, [90/0/90] stacking sequence offers higher normalized buckling and normalized failure interacting curves for different materials than other stacking sequences [[U+0275]/0/[U+0275]], where 0≤[U+0275]<90.

Reinforced Concrete T-Beams Strengthened by CFRP Composite and Proposed Solutions for the Practice

abst. 2690
Repository

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In practice, beams in reinforced concrete buildings transfer the loads from the floor to the columns. Some of the slabs assist the beams during bending since the beams, which have the effect of bending in one direction, and the slabs are concretely monolithic with the flooring system. For this reason, when designing beams, this piece of the slab is also considered and calculated as T-section. It is known that T-section reinforced concrete beams in the existing buildings have received inadequate engineering service for various reasons and are mostly designed according to the old earthquake building regulations. Therefore, these beams are far from meeting the criteria in current earthquake regulations. One of the most practical methods of strengthening these kinds of beams is wrapping by CFRP composite. However, there are quite different approaches regarding the application of this method in practice. In practice, most of the time, the practitioners are satisfied with the beam body in the strengthening of CFRP composite, while some practitioners are strengthening up to the bottom of the table and others using anchors. In practice, in some cases CFRP application was applied to only side surface while in some cases this application was extended to the bottom surfaces. Furthermore, in some cases anchoring was applied to strengthen CFRP application. It is known that anchoring is the least preferred method due to the difficulty of application. Discussing clear results about the effectiveness of these applications is considered an important achievement for the literature. In this study, the effect of CFRP composite on T-beam behaviour was investigated using seven T-reinforced concrete beams strengthened by various CFRP configurations. These beams were designed as half-scaled and under-balanced. The T-beams were tested under four point loading. At the end of the study, apart from adhering CFRP composite with epoxy, it has been observed that there are significant gains in the ductility of the section by connecting it with anchorages from the corners of the beam. The improvement is seen to be close to that of the beam which was fully wrapping by CFRP composite. In addition, if the CFRP composite does not completely wrap the beam, it is seen that the beam does not reach the bending capacity. At the end of the study, it was seen that the strengthening method that gives the most effective result in strengthening T-section beams with CFRP composite is a 45 degree anchorage type. Keywords: Reinforced Concrete T-Beams, Strengthening, Anchorage, CFRP, Composite, Structures

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Determination of Optimum CFRP composite Amount in Strengthening Reinforced Concrete Beams with Inadequate Shear Strength

abst. 2691
Repository

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Carbon fiber reinforced polymer (CFRP) composite strips are often preferred, especially in order to strengthen reinforced concrete structural elements which have insufficient shear and ductility capacity. The amount of composite material used is extremely important in terms of behavior. There are various mechanical equations for the contribution of CFRP composite to the shear capacity in earthquake regulations. Many factors such as wrapping spacing, wrapping width, wrapping thickness, modulus of elasticity and the number of wrappings are important for capacity gain. However, no matter how much it is used, the effect of this composite material on capacity (ductility and shear capacity) does not change after a certain level. For this reason, the optimum usage amount of CFRP or the golden ratio (optimum level), which is the highest benefit / cost ratio, is actually very important for designers. There is no numerical data about this rate in the literature. Therefore, in this study, it is aimed to determine the optimum CFRP amounts depending on the contribution of the CFRP strips used in strengthening to the behavior by examining the behaviors of under-balanced beams that are insufficient in terms of shear. In the experimental study, 8 reinforced concrete beam specimens with $\frac{1}{2}$ scale were prepared. Specimens were produced in the dimension of 125x250x2500 mm with a rectangular cross section in the tension zone 312, in the compression zone 28 and stirrup spacing 5 / 35 cm. In the study, 8 full CFRP wrapping with different volumetric ratio were applied to the beam in the shear zone. Vertical loading was applied to the beam until the capacity reached capacity. According to the results of the experimental study, it was observed that the damage started to occur as a bending damage after 0.15% of the CFRP composite, and there was no change in the ductility capacity after 0.27%. For this reason, it would be appropriate to keep the amount of CFRP composite to be used between these volumetric ratios in the beams with under-balanced and insufficient shear capacity. Moreover, the unwanted shear failure and brittle power depletion in the beams can be observed for underneath these ratios while unnecessary CFRP composite material would be used for above these ratios. Keywords: CFRP, reinforced concrete beam, shear deficient, strengthening

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abst. 2437
Repository

Static responses of magneto-electro-elastic structures in moisture field using stabilized node-based smoothed radial point interpolation method

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In the present work, the static magneto-electro-hygro-elastic (MEHE) multi-field coupling problems are investigated by a stabilized node-based smoothed radial point interpolation method (SNS-RPIM). The equilibrium equations of magneto-electro-elastic (MEE) material in moisture field are obtained using G space theory, weakened weak (W2) formulation and constitutive equations of MEE structures. In order to further improve the accuracy of the algorithm, the stabilization term is introduced into the system stiffness matrix, which could increase the stiffness of the model. The influence of the moisture concentration on the elastic coefficient is considered, and the results show that moisture environment could affect the stiffness of the structure and cause a change in its natural frequency. The calculation results of SNS-RPIM and finite element method (FEM) are given to study the effect of moisture load on the structural responses. In addition, it can be seen that the developed method could obtain higher accuracy results than FEM with a small number of nodes. And SNS-RPIM is more robust against mesh

distortion, so that problems with complex geometries could be solved well. This article can provide a reference for the design and analysis of MEE devices in moisture environment.

Impact behavior of thin-ply generation aluminum carbon hybrids

abst. 2654
Virtual Room
Tuesday
September 1
16h30

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The article presents the resistance analysis to low-velocity impact for fiber metal laminates consisting of aluminum layers and thin-ply carbon/epoxy composites. Determining the effect of thin-ply layers was compared with fiber metal laminates containing composite layers of conventional thickness. Low-velocity impact tests were carried out at different impact energies 2.5 J - 30 J. To evaluate and compare the responses of conventional laminates and thin-ply laminates, an analysis of significant characteristics describing the dynamic loading process during indenter-laminate interaction was performed. Furthermore, an analysis of the laminate failure process under the impact was carried out, in particular the identification of dominant forms and the area of failure. The results show that the use of thin-ply carbon/epoxy composites does not affect the increase in impact resistance or a significant change in behavior to low-velocity dynamic loads in comparison to laminates with conventional thickness layers. Moreover, it was assessed that the nature of the failure of thin-ply composite layers does not significantly differ from conventional carbon layers. Simultaneously, it was confirmed that fiber metal laminates with thin-plies are an interesting and perspective material solution.

The Effect of Fatigue, Elongation and Elevated Temperature on the Electrical Conductivity of the CFR MWCNT/EP Composite

abst. 2417
Repository

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The aircraft skin is designed to withstand cyclic loads. In cases of many aircraft designed today it is made of a carbon fiber reinforced (CFR) composite based on epoxy resin (EP). The aircraft skin also provides Lightning Strike Protection (LSP). In order to increase the electrical conductivity of the material, the matrix of the composite can be doped with Multi-Walled Carbon Nanotubes (MWCNTs). The aim of this paper is to investigate the effect of fatigue on the electrical conductivity of the CFR MWCNT/EP nanocomposite. Samples with three different mass fractions of MWCNTs in the matrix were tested, namely 0.5, 1.0 and 2.0 wt%. During fatigue testing, apart from fatigue degradation of the material, the sample is lengthened and locally warmed up. Therefore, changes in conductivity of the samples were separately recorded during: fatigue test, static tensile test and heating in a laboratory oven. The results indicate that increase in the temperature of the sample reduces the resistance, elongation of up to 1% has a negligible effect on the conductivity, and the effect of fatigue varies depending on the concentration of nanotubes, with MWCNT 2.0 wt% samples being the most favorable.

INTERNAL PRESSURE CAPACITY OF GLASS FIBER REINFORCED COMPOSITE OVERWRAPPING PVC PLASTIC PIPES

abst. 2332
Repository

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The limitations of PVC pipelines are well known, including their low deterioration and their low fracture toughness properties, which jeopardize their internal pressure capacity. Therefore, this paper introduces a glass fiber-reinforced polymer (GFRP) overwrapped system to increase the PVC pipes internal pressure capacity. Accordingly, an extensive experimental program is developed and performed to examine the performance of GFRP composite overwrapped onto PVC plastic pipes.Accordingly, overwrapped plastic pipes were tested under internal pressure until failure. The results showed that the proposed overwrapped system significantly improved internal pressure capacity. It is also found that GFRP is able to sustain a much higher internal pressure before failing compared to the unwrapped PVC. It was also found that the pressure capacity was significantly affected by changes in the fiber orientation angle. It can be seen that a higher diameter is associated with low-pressure failure. This observation was recorded for both types of tubes (i.e., unwrapped and wrapped PVC pipes). This is because the pressure that can be sustained by a pipe is inversely proportional to the internal diameter of the pipe.

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abst. 2442
Repository

Effect of graphene nanoplatelets on dynamic behavior of CFRP composites

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Composite materials have wide structural applications in different fields however; they are not exempt from limitations and drawbacks. Vast research has been going on to improve their mechanical performance when subjected to quasi-static loading but, investigation and modification of their dynamic behavior is still underdeveloped. For this reason, scientists have been continuously working on developing methods to improve their dynamic characteristics. Nanotechnology has revolutionized the field of composite materials, and Graphene (GNPs) are considered as a very significant reinforcement for developing future generation high-quality fiber reinforced nanocomposites because of their supreme mechanical, electrical and thermal characteristics. In this study, nanocomposite specimens are manufactured using Epon 862 Epoxy resin and T300 6k carbon fibers with different weight percentages of GNPs i.e. 0% as a reference, 0.5%, 1% and 2%. Samples were tested experimentally using the Split Hopkinson pressure bar device (SHPB) to examine their dynamic response and damage behavior at high strain rates. During the dynamic compression tests, a high-speed camera was used to monitor and record the damage kinetics. The experimental characterization showed that the integration of GNPs has greatly influenced the dynamic response and damage mechanism of the Carbon Fiber Reinforced Polymers composite (CFRP). Each percentage demonstrated the enhancement of the mechanical properties of the composite specimens and showed the increase of the dynamic characteristics and fracture resistance.

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abst. 2609
Repository

Development of a re-infiltration system based on pressure control for repairing Carbon-Fiber-Reinforced-Polymer laminates with Barely-Visible-Impact-Damage

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In civil aviation, the availability of fast and cost-effective repairs for impact damaged Carbon-Fiber-Reinforced-Polymer (CFRP) aircraft primary structures is expected to have an outstanding relevance in the near future. These aircraft structures can be damaged during manufacturing and in-service operations, causing mechanical problems in in-service aircraft that must be solved in the fastest way possible before the next flight. Composite materials are very susceptible to strength reductions due to impact events. Approved repairs for CFRP aircraft primary structures of today are mainly based

on bolted-patches and, in special conditions, on bonded-patches. Both are directly derived from the experience with metallic structures in which the damaged area is removed by cutting a hole in the structure and a repair patch is attached to transfer the loads through it. However, removing the damaged area when there is a low-energy impact damage in CFRP laminate seems to be a radical solution. Even more, if it is considered that these are the most frequent impact events during an aircraft life. Low-energy impacts generally cause internal damages with negligible fiber ruptures known as Barely-Visible-Impact-Damage (BVID). BVIDs exhibit typically 3D damage patterns made of matrix cracks and delaminations. Both are failure modes of the matrix that, theoretically, can be stabilized by gluing again the internal cracks without any need to remove the damaged zone. Based on this concept, the repair techniques known as resin injection or re-infiltration have been investigated for CFRP laminates with internal damage since 1990s. This technique consists in infiltrating low-viscosity resins into the internal damage pattern of a CFRP laminate to glue cracks. The resin is infiltrated through small drilled holes that connect the different cracks of the damage pattern. As a result, the pristine shear and compressive strengths of a CFRP laminate can be practically restored. This is a faster and more cost-effective technique than typical patch repairs. However, re-infiltration technique has not been certified by the aeronautical approval authorities for primary CFRP structures up to now. Therefore, in order to upgrade this repair technique, additional developments must be carried out, such as the establishment of a new certification process and the increase of the reliability of the re-infiltration technique. In this research, a re-infiltration device based on open literature has been design, manufactured and tested. This device has been proposed to perform repairs in controlled conditions of rectangular flat CFRP plates with BVID, offering the opportunity to investigate individual aspects of this technique. This is essential to achieve controlled high-quality repairs in the future. The infiltration strategy is laid out based on ultrasonic C-scan inspections, localizing the delaminations along the plate surfaces and, also, their depths. Once the infiltration is finished, the filling rate of the damage pattern is measured by ultrasonic C-scans. Key features of the repair are investigated in this work such as the inlet and outlet hole diameters (0.5, 1.0 and 1.5 mm) and different resin viscosities (140 and 280 mPa·s). The results of this investigation show that, on average, there are no significant differences in the re-infiltration success between the hole diameters tested. This suggests that the choice of the smallest hole diameter could be taken in order to minimize the strength reduction in laminates with open holes. Regarding the results with different resin viscosities, significant differences are observed. On average, the resin with the lowest viscosity reaches approximately 30% higher filling rates.

Statistical Characterization of the Microstructure of the Composite Plates with Induced Defects in Autmotated Manufacturing

abst. 2553
Repository

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Automated Fiber Placement (AFP) is a new robot technology that has the advantage of both the rapid manufacturing process and reducing material waste. However, because of using the fiber tows instead of composite prepreg sheets, new types of defects are introduced into the composite structures during the fabrication process, which can cause geometrical discontinuities and local material inhomogeneities at micro-level of the structure. Although macro-mechanical analyses of the composite structures, including defects, have been intensively conducted in the literature, there is still a lack of knowledge at the micro-level about the structures made using AFP process. In the present study, a statistical characterization is performed to investigate the effect of induced gap on the microstructure of the composite plates manufactured using the AFP process. For this purpose, a comparative ensemble statistical analysis is conducted on the micro images of plate samples with and without manufacturing defects. In order to do this, extensive image processing is performed on the microscopic images obtained from the cross-section views of the samples. The studied statistical parameters include Nearest Neighbor Distance/Angle and individual and joint probabilistic parameters of fiber shape/diameter, and local and global fiber volume fractions. Based on these, observations on the spatial distribution of defects in the manufactured plate are established.

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abst. 2303
Repository

Mechanical Behaviors and Mechanisms for Polyurea under Uniaxial Compression of Wide Strain Rate Loading

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The uniaxial compression experiments were conducted by using Instron mechanical machine and split Hopkinson pressure bars apparatuses on polyurea elastomer. And the wide strain rate loading was achieved from 0.0005 s-1 to 5000 s-1 with the aid of the developed intermediate strain rate loading technique. It is found that the polyurea shares a similar mechanical trend under the investigated strain rate range: it firstly deforms elastically, and nonlinearly comes to yielding, then is followed by strain hardening characteristics. Besides, it presents a distinct strain rate effect: the mechanical parameters, like elastic modulus, yield stress and flow stress, are distinctly increasing with strain rate increasing. Furthermore, the strain rate effect is stronger than the temperature effect which introduced by the adiabatic temperature rise under dynamic loading. Then, an equivalent configuration under compression was proposed based on its constitution of hard/soft phase. And the unit cell modeling was performed to simulate its structural behaviors for investigating potential mechanisms. Finally, a constitutive formula was proposed to describe its mechanical properties under multi-factors, such as large strain behavior, strain rate effect and induced thermal softening effect. Acknowledgment: We would like to thank the financial support by China Postdoctoral Science Foundation (No.3679) and National Natural Science Foundation of China (No.11732012, 11572259 and 11527803).

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abst. 2013
Virtual Room
Tuesday
September 1
08h30

Investigating the behaviour of high performance pseudo-ductile hybrid composite in indentation

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The aim of this work was to investigate the behaviour of thin ply pseudo-ductile carbon/glass hybrid laminates during indentation, with the aim to improve the impact resistance of conventional composite materials. Therefore, a series of indentation tests were performed based on ASTM D7136 on composite plates made from two Quasi Isotropic (QI) designs of thin-ply HS40-carbon/S-glass hybrid configurations, all S-glass, all HS40-carbon and all IM7-carbon laminates. Ultrasonic C-scan and (or) X-ray Computed Tomography (CT-scan) were used to evaluate the damage evolution. Comparing the mechanical results, the hybrids experienced a higher displacement than the all-carbon laminates and showed an improvement in the initial stiffness compared with the all-glass laminate. The total absorbed energy before final fibre failure by the hybrids was much higher than the all-carbon laminates but lower than the all-glass laminates. From the C-scan and CT-scan results for the all-glass and all-carbon laminates, delamination was larger in the middle plies than the upper plies. Contrariwise, the hybrids

showed novel damage mechanisms, i.e. carbon ply fibre fracture and delamination under the indenter, with gradual failure behaviour and less damage at the inner layers. These results open new avenues for designing impact resistant composites through hybridization and introducing new failure mechanisms.

Finite-Volume Method for Saint Venant's Torsion of Arbitrarily Shaped, Homogeneous and Graded Cross Sections

abst. 2644
Virtual Room
Tuesday
September 1
17h30

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We extend our recent finite-volume based approach to the solution of Saint Venant's torsion problems of bars and beams comprised of rectangular sections to enable analysis of arbitrary cross sections characterized by curved boundaries. This is accomplished by incorporating parametric mapping based on transfinite grid generation to enable discretization of the bar cross section by quadrilateral rather than rectangular subvolumes employed in the previous version. The construction of the local stiffness matrix that relates the surface-averaged subvolume warping functions to the corresponding tractions is carried out in the reference plane such that the subvolume equilibrium in the physical plane is satisfied in a surface-averaged sense. This produces explicit expressions for the stiffness matrix elements that may be readily coded. Orthotropic subvolumes are admitted in the method's construction so that bars with heterogeneous and composite microstructures may be analyzed. The convergence and accuracy of the parametric finite-volume method are assessed and verified upon comparison with exact elasticity solutions for bars with curved boundaries, as well as the corresponding parametrically mapped finite-difference solutions. Examples involving structural applications of prismatic bars with curved boundaries illustrate the utility of the developed methodology. These include cross sections that resemble biological constructs with homogeneous and graded regions aimed at enhancing torsional rigidities, as well as homogeneous and graded elliptical cross sections with orthotropic shear moduli aimed at reducing and eliminating warping. It is demonstrated for the first time that by laminating an elliptical cross section with alternating stiff and soft isotropic layers in a manner that mimics orthotropic moduli at the homogenized level, warping can be practically eliminated with sufficient microstructural refinement.

3D printed Nanoclay/high density polyethylene composites

abst. 2468
Repository

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Nanoclay (NC) is blended with the most relatively expensive, highly consumed high density polyethylene (HDPE) resin for developing nanocomposite filament for 3D printing. NC (0.5, and 2 by wt. %) are mixed with HDPE, and filament for a 3D printer is extruded using a single screw extruder. Nanocomposite blend is tested for melt flow properties using a melt flow index (MFI) measuring device. MFI decreases with nanoclay addition. The density of the printed sample increased with an increase in NC content in the nanocomposite. Filament and printed samples thermal study is carried out using differential scanning calorimeter (DSC). The addition of NC led an increase in crystallization temperature and crystallinity with no appreciable change in melting peak temperature. The filament tensile test indicates an increase in tensile modulus and a decrease in filament strength by the addition of NC. Tensile and flexural modulus of printed nanocomposite increases with NC content. Specific tensile and flexural modulus is noted to be improved with NC loading, whereas specific strength decreased in 3D printed nancocomposite.

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abst. 2469
Repository

Numerical and Experimental Analysis of Flexural Properties of 3D Printed Graded Foam

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This paper investigates experimental and numerical analysis of flexural properties in 3D printed functionally graded syntactic foam. High-Density Polyethylene (HDPE) as matrix and Glass Micro-Balloons (GMBs) as filler have been used in the present syntactic foam. The layer of Functionally Graded Beam (FGB) is either a pure HDPE (H0) or syntactic foam with different material configurations (H0, H20, and H40 based on GMB content by % vol.). The flexural properties of H0, H20, H40, and FGB (0, 20, and 40) have been analyzed for flexural behavior using the finite element method. FGB is printed using a fused deposition based 3D printer, and experimental work for flexural testing is carried out as per ASTM D 790-17. The numerical results are validated with the experimental results, which show good agreement. Results reveal that the flexural modulus of syntactic foam increases with an increase in GMBs content. It is also observed that the flexural modulus of FGB increases when graded with high modulus syntactic foam.

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abst. 2470
Repository

Mechanical behavior of additively manufactured sandwich composite

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Among many of the materials used in marine applications, syntactic foams core and sandwich structures are particularly promising because of water uptake in these foams is not significant, even if the face-sheet of a sandwich is damaged. HDPE (high-density polyethylene) filament is used to additively manufacture sandwich skins, and foam filaments (HDPE+GMB (glass micro balloons)) are used to print the core. The optimized parameters are used to prepare blends of 20 and 40 volume % GMB and extrude corresponding feedstock filament to print syntactic foams core and sandwich composite. Syntactic foams of the core and sandwich are characterized under three-point bending configuration. In this study, the experimental results of flexural tests on sandwich structures are compared with a core. Results indicate the sandwich composite's flexural properties are better than core structures. The inclusion of GMB particles in HDPE enhances flexural modulus. Nevertheless, strength is comparable.

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abst. 2471
Repository

Buckling and free vibration response of closed cell foams

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A three-dimensional printed (3DP), low-density polymer matrix syntactic foams are developed using hollow glass micro balloons (GMB) dispersed in the HDPE matrix. This work presents the buckling and vibration response with no load and under critical loading conditions of HDPE/GMB foams under axial compressive loads. Modified Budiansky Criteria (MBC) are used to calculate the buckling load from the load vs. deflection curve obtained from the universal testing machine. Also, the effects of compression on natural frequencies (three bending modes) are examined. It is observed that critical natural frequency and buckling load of foam composite increases with GMB content. But as the axial compression load increase, there is a reduction in natural frequency at all three modes. In mode-1, natural frequency increases under critical loading conditions. The structural stiffness tends to decrease with an increase in the axial compressive load. For all test loads, foams recorded improved stiffness compared to HDPE. Euler-Bernoulli hypothesis is used to validate experimental results.

Effect of axial compressive loads on buckling and vibration response of sandwiches

abst. 2472
Repository

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Sandwich with foam core is synthesized by 3D printing of syntactic foam filaments developed by mixing hollow glass micro balloons (GMB) particles in a high-density polyethylene (HDPE) matrix. Further, sandwiches are subjected to buckling and free vibrational response under axial compressive load. The effect of GMB loading on critical buckling load and the natural frequencies of sandwich foam composites are studied. The load-deflection data from the universal testing machine gives the critical buckling load while conducting experimental modal analysis, natural frequencies of core sandwich structures are obtained. Results reveal that, with an increase in GMB content, natural frequencies and critical buckling load of the foamed sandwich structures increase substantially. Fundamental frequency in the post-buckling regime increases exponentially. The obtained sandwich results are compared with a syntactic foam core. It is observed that 3D printed sandwich foam structures have better vibrational properties than foamed cores.

3D Printing strategy for Sandwich

abst. 2495
Repository

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The three-dimensional printing (3DP) is one of the most popular additive manufacturing technology. Over the past few decades, optimization of feedstock material and 3D printing parameters to achieve the required properties for various applications has been an important field of research. Sandwich structured composites are the special group of composites materials that have become quite prominent because of their high specific strength and stiffness during flexure. HDPE foam filaments are developed by mixing particles of hollow glass micro balloons (GMB). The low density of syntactic foam developed using these materials makes them ideally suited for aerospace, structural, and marine applications. This paper demonstrates the 3D printing sandwich composites. The problems faced in printing sandwich composites are discussed. The optimization of 3D printing parameters is done for sandwich composites. It is observed that good quality core and sandwich structures are obtained without any defects by optimizing printing parameters.

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abst. 2620
Repository

DESIGN AND ANALYSIS OF CONTINUOUS FIBER REINFORCED THERMOPLASTIC COMPOSITE B-PILLAR OF A PASSENGER CAR

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The new regulations introduced in the automotive industry, make CO2 emissions reduced to 95 g / km today. Also, one of the most critical obstacles to the evolution of the automotive sector from internal combustion engines to hybrid and electric motor vehicles is the limited range problem. The best-known solution method for both problems is to decrease vehicle weight. Only 1% of the energy produced by fuel in a vehicle is used to carry the driver. 67% to 75% of the energy produced by fuel is used to move the vehicle's weight. Therefore, vehicle manufacturers are looking for new ways to make vehicles lighter. Substituting metal parts with equivalent polymer composite materials is one of the most significant opportunities in reducing vehicle weight. In addition to lightweight, the new requirements about the restrictions on collision safety in vehicles are made more stringent by governments. Resistance to side collisions is one of the main requirements for crash-safe car bodies. When the collision occurs from the side of the car, even if the impact energy is low, the level of injury in the passengers is high. It is because of the low distance between the car body and the passenger, and consisting of the body structure, only a few side components that absorb collision energy. One of them is the B-pillar, which located between the front and rear doors of the car. It is an essential component for the safety of passengers and drivers. The B-pillar designs to minimize inward deformation in the event of a collision, as well as to have a high load-bearing capacity and to absorb impact energy highly. In this study, B-pillar of a passenger car was designed as functionally graded using continuous fiber-reinforced thermoplastic composites. The obtained design was validated by using Finite Element Analysis with the properties of continuous filament reinforced thermoplastic composite materials and compared with equivalent steel sheet B-pillar. The results show us by using continuous filament fiber reinforced thermoplastic composite materials and a functionally grading approach, the mass of the obtained B-pillar was less than 50% the equivalent steel part, under the same performance.

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abst. 2264
Repository

Adjacent shallow shells interaction in nonlinear supersonic fluttering panels

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The self-excited aeroelastic instability of thin plates or shells in the supersonic regime is called panel flutter and is capable of causing severe structural failures in aircraft and space vehicles. Supersonic panel flutter is an aeroelastic instability of plates and shells that has regained the attention of researchers during the middle '90s, particularly with the expansion of advanced composites applications. The use of such advanced materials in airplanes may lead to improvements in the control of static and dynamic deformations, thereby allowing aeroelasticity tailoring design of aircraft components. The structural and aerodynamic models to be adopted for flutter instability prediction must be adequate to describe the interaction between the aerodynamic, inertial, and elastic forces of the system. Real aerospace structures operating in external flows are typically made of thin-walled panels restrained to spars and stringers that act as stiffeners. These stringers are usually distributed along the panels' inner surfaces to provide structural stability, especially against shell buckling. Various approaches exist for idealizing the kinematic boundary conditions that the stringers impose on the panel. The most common approach, and also the one used herein, is to consider large panels with simply supported lines uniformly distributed

along the surface. A panel delimited by externally supported boundaries is denoted as a single bay or single panel. For aeroelastic analysis, much of the modeling addresses the flutter problem of single bays with either simply supported or clamped boundary conditions to represent the structural constraints along the edges. Nonetheless, adjacent panels within a multibay arrangement interact under external loading. The interaction between adjacent bays was investigated by a few researchers, mostly in the '60s. Earlier models for multibay supersonic flutter analysis were based on the linear structural behavior of isotropic materials. The finite element method was widely employed, and the flutter prediction was entirely based on eigenvalue solutions. According to the authors' best knowledge, there was a very long gap before the multibay supersonic flutter problem was revisited when the interest in composite materials grew for aerospace applications. Very few investigations on the supersonic flutter onset on multibay composite panels were performed in the early '90s, mostly using a linear finite element model. Since then, no studies have been found in the literature addressing the multibay panel flutter problem. Furthermore, all the works published to this date on the matter have focused solely on predicting the flutter boundary, always employing linear aeroelastic models for mode coalescence analysis. Little or no attention has been given to the nonlinear post-flutter regime, which is critical for the structural design and fatigue life estimation. Given that aeronautical panels are typically composed of large internally reinforced plates and knowing that these reinforcement elements subdivide the panel into several cells capable of structural interaction, this paper proposes the study of a finite element computational model for nonlinear supersonic flutter analysis of reinforced, laminated curved panels. The Marguerre's theory will be used to describe the behavior of the laminated curved panel together with the von K ´arm ´an's strain-displacement relations for geometric nonlinear deformations. For the calculation of the aerodynamic loads of the model, the first-order piston theory, suitable for supersonic flows, will be used, with the presence of a static aerodynamic load term due to the curvature of the panel. Results have shown the significant impact of the nonlinear structural behavior in the flutter mechanism for different multibay geometries and lamination schemes, as well as the curvature dependence on the jump phenomena.

Thermo-mechanical creep behavior of un-cured prepregs

abst. 2525
Virtual Room
Tuesday
September 1
12h00

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The mechanical properties of composite structural components degrade due to void formation. Therefore, it is essential to suppress or evacuate the voids during the consolidation of composites. In particular, aerospace industries demanding low void content of less than 2%. It is difficult to achieve less than 2% using the vacuum bag only (VBO) prepreg process. To control the void content in VBO prepreg process, designing the efficient cure cycle by optimizing the several parameters, most importantly ramp-dwell is important. Thermomechanicl compaction is viscoelastic in nature and an important stage in both autoclave and out-of-autoclave processing. In this study, thermo-mechanical creep compaction studies on uncured prepregs are performed to mimic the ramp-dwell stages of processing. The creep experiments were performed on uncured prepregs specimens of different layers such as 4 and 8 at two different pressure to mimic, ramp-dwell stages in out of autoclave (OoA) and autoclave processes. The microstructure of pristine (before testing) and tested specimens were investigated using the X-ray computed tomography. The distribution and movement of voids in the specimens were analyzed with the increase in the number of layers using the VGStudio Max software. The increase in the %void volume ratio with the increase in the number of layers was observed. The decrease in the size of voids were found in creep tested specimens compared to pristine specimens.

abst. 2115
Virtual Room
Tuesday
September 1
08h45

A repair algorithm for composite laminates to satisfy lay-up design guideline

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In recent decades, composite laminates have been employed in the aerospace industry due to their high strength-to-weight and stiffness-to-weight ratios. In contrast to metals, composite laminates exhibit more complex failure mechanisms, often undesired stiffness couplings, and a large combinatorial design space (because fibre angles usually take a limited number of values, e.g. 0, $\pm$45 and 90°). Hence, the complex task of designing straight-fibre composite laminates is often guided by empirical design guidelines, e.g. balance and 10% rule, which increase confidence in the laminate's long-term structural performance and integrity. Current state-of-the-art algorithms for laminate design are found wanting as they have difficulties finding lay-ups that have satisfactory mechanical properties and simultaneously meet design guidelines. Most computational efforts can, in fact, be spent exploring solutions which do not satisfy aerospace lay-up design guidelines. Hence, elastic tailoring is often not performed efficiently, resulting in sub-optimal/over-designed laminates. The present work focuses on enhancing laminate compliance with said design guidelines during the design procedure to avoid unnecessary and counter-productive trade-offs between design guideline satisfaction and structural performance. At present, the techniques used to enforce design guidelines exhibit many drawbacks. They: (i) are limited to a few guidelines; (ii) do not always guarantee retrieval of laminates complying with the guidelines; (iii) explore a reduced design space; and (iv) are computational expensive. With these drawbacks in mind, repair methods transforming composite laminate lay-ups into feasible stacking sequences appears as the most promising techniques to enforce design guidelines during laminate design. This is because repair methods can be used to force optimisation algorithms to explore only the feasible stacking sequence design space, i.e. only including lay-ups satisfying the design guidelines. To facilitate the straight-fibre composite laminate design process, we propose a deterministic repair method that transforms stacking sequences into lay-ups satisfying the aerospace design guidelines.

abst. 2206
Repository

Experimental and numerical studies of eccentrically compressed composite columns with open cross-sections

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The study investigates short thin-walled open cross-section columns made of a carbon-epoxy laminate. The tested columns were subjected to compression, including an eccentric compressive load relative to the gravity center of the cross-section of the column. The scope of the study involved determining the effect of eccentric load on the structure's stability and load-carrying capacity. At the same time, a numerical analysis by the finite element method was performed using the commercial simulation software Abaqus®. The non-linear numerical analysis of the compressed profiles was performed by the Newton-Raphson method. Failure of the composite material was described using a progressive damage model, wherein damage initiation in the composite material was described based on failure criteria while the evolution of damage was described by the energy-based progressive damage criterion. Results predicted by the numerical model were validated by experimental tests performed on real structures. The results enabled a comprehensive description of the composite material's failure, starting from failure initiation until the total loss of load-carrying capacity of the column. Results presented in the paper was conducted under the project UMO-2015/19/B/ST8/02800 financed by the National Science Centre Poland.

Dependence of temperature fluctuations on randomized material properties in two-component periodic laminate

abst. 2412
Repository

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The purpose of this investigation is to study extremal values of temperature fluctuations occurring on interfaces in two-component periodic laminate, caused by unidirectional heat flow during steady state. It is well known that for a heat flow problem, perpendicular to the laminae, the averaged temperature depends only on boundary conditions. The temperature oscillations are more complex function, since they depend also on material properties, or theirs ratio, to be precise. If we consider this ratio as random variable then function values of temperature fluctuation occur to be random variable as well. Knowing the relative error (coefficient of variation) in determination of conductivities ratio and its expected value, an interesting would be as well the value of relative error of studied function, and whether is it smaller value or not. We shall conduct numerical experiments by Monte-Carlo method in order to answer that question.

Reliability-based design optimization of 3D orthogonal woven composite automobile shock tower

abst. 2191
Repository

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Three-dimensional orthogonal woven composites own excellent mechanical properties and delamination resistance, which have broad prospects in automotive lightweight applications. The multi-scale characteristics and inherent uncertainty of design variables introduce great challenges to the optimization procedure for 3D orthogonal woven composite structures. This paper proposes a reliability-based design optimization method to guide the lightweight design of 3D orthogonal woven composite automobile shock tower, which includes design variables from material and structure. An analytical model was established to predict the elastic and strength properties of composites. Then, an optimization procedure was established to conduct the multi-scale reliability optimization design of composite shock tower, which combines Monte Carlo reliability analysis method, Kriging surrogate model and Particle Swarm Optimization algorithm. The results show that the optimized shock tower meets the requirements of structural performance and reliability, while achieving a weight reduction of 37.83%.

Influence Of Application Of Mullite Additive On Change Of Thermal Protection Properties Of Powder Composite

abst. 2254
Repository

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The authors have conducted research into the heat resistance of a composite material subjected to a stream of hot combustion gases - ablative investigations. Ablation is a self-regulating heat and mass transfer process, which, due to physical and chemical reactions, leads to irreversible structural and chemical changes of a material combined with simultaneous heat absorption. This process is initiated and sustained by a high temperature heat source. Ablation is a process which takes place due to an influence of fire. It consists in cooling the composite surface by evaporation or sublimation of materials which are part of the composite. It contributes to changes in energy balance on the surface of the material. Changing the energy balance leads to a delayed ignition of the material. The authors analysed an impact of the applied additive of mullite powder in the composite matrix base on the ablative properties of a powder polymer composite. In order to determine the impact, five batches of the manufactured samples (three samples per batch) of the composite material were examined. The batches differed only in the percentage share of the filler. The authors used epoxy resin CES R70 with CES H72 hardener, modified with a changing amount of the mullite additive (between 0 to 6,6% volume share). The composite measuring approximately 35 mm in diameter and approximately 10 mm in thickness was subjected to an impact of a mixture of combustible gases at a temperature of approximately 1,000 °C. The examinations of a temperature rise on the rear surface of the sample, exposed to a hot stream of flammable gases, were carried out for 120 seconds. In order to measure the rear temperature, temperature sensors in the form of thermocouples, J and K type, were used, whereas for the measurement of the surface of ablation, a pyrometer was used. The authors also used a thermal imaging camera to check a uniform distribution of temperature on the rear surface of the tested material. Conducting experimental research allowed specifying the distribution of temperatures occurring on the rear surface of the samples and determining the ablation weight loss and the ablation rate. On the basis of the conducted examination, it is possible to conclude that the use of a reinforcement in the form of mullite significantly improved thermo-protective properties of the composite. Moreover, reducing the rate of ablation and the ablation weight loss were also confirmed. Owing to using the mullite additive, it became possible to reduce the parameters of ablation with regard to the base material respectively by: The temperature of the rear surface from 60.6 °C to 48°C; An ablation weight loss from 57% to 19%; The rate of ablation from 61m to 26m; Mass ablation rate from 78mg to 25mg.

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abst. 2548
Repository

Imperfection-Insensitive Continuous Tow Sheared Cylinders

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Geometric imperfection sensitivity is the largest influencing factor that limits the design of thin-walled monocoque cylinders. Current generation cylindrical architectures, such as those found in rocket launch vehicles, rely on the use of sandwich structures or blade-stiffened structures to reduce the imperfection sensitivity of the cylinder. Whilst must research has been focused on the creation of new knockdown factors that relate to the modern architectures used, this work focuses on reducing the imperfection sensitivity of a structure from a design perspective. Variable-angle composites offer an opportunity to tailor the load paths of structures, thus reducing the effective area over which imperfections initiate buckling. Continuous Tow Shearing (CTS) is one such variable-angle manufacturing technique. CTS does not cause common in-process manufacturing defects associated with Automated Fibre Placement such as fibre wrinkling or fibre buckling. In addition, CTS features a fibre angle-thickness coupling that results in a local thickness build-up, which, whilst increasing the mass of the structure, enables embedded stiffeners or hoops to be created by shearing the tow. This design feature is highly desirable in cylinders, as stiffeners are known to reduce the imperfection sensitivity of the structure. Here we show that the mass of a CTS cylinder is invariant of the number of embedded stringers or hoops created by the shearing process. Nonlinear finite element models with seeded imperfections are used to calculate a knockdown factor (KDF), a measure of imperfection sensitivity. The CTS cylinders behaviour was measured using two criteria: KDF and imperfect, specific buckling load. Of the 2320 layups that were in the initial pool of possible architectures, 90 were considered for a nonlinear buckling analysis as they had a similar axial stiffness and compression buckling load to a QI cylinder on a mass-specific basis.

Many cylinders were found to have a KDF 20 to 30% higher than a QI cylinder. It was found that, in general, the fewer the number times the lamina was sheared, the higher the KDF. However, it was found that the higher the number of stiffening elements, the higher the specific, imperfect buckling load. The stiffening elements did not act as panel breakers as the EI contribution was not large enough, instead acting as load attractors. Layups that used the maximum amount (70 degrees) of shearing had a lower KDF when compared to a layup that used a medium degree (30 – 40 degrees) of shearing. The cylinders that had the highest KDF had a localised buckling mode, indicating that the shearing had caused a trapping of the buckling mode. The cylinders that had the lowest KDF had a global buckling mode. It was found that there is a relationship between the difference in pre-buckling strain field (between a perfect and imperfect cylinder) and the knockdown factor. This novel relationship is strong when the KDF is high, showing that a linear analysis can provide a first-order approximation of the imperfection sensitivity of a cylinder.

Physics-Informed Neural Networks for the Analysis of Composite Structures

abst. 2573
Virtual Room
Tuesday
September 1
14h30

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The growing use of composite materials and the increasing complexity of modern composite structures - see, e.g., variable-stiffness (VS) configurations [1] - make advanced analysis tools more and more important. In this context, different methods [2-4] have been proposed to effectively analyze the mechanical response of VS composite structures. In the present work, a new method is presented for the analysis of VS configurations based on Artificial Neural Networks (ANNs). Due to their universal approximation properties, ANNs have been widely used as metamodels for design and analysis purposes. However, standard NN architectures are commonly used as a 'black-box', where training relies solely on the set of available data and without considering the intrinsic physics of the problem. One crucial aspect is the amount of data to train the network, which, in many practical problems, can be scarce as resulting from costly analysis or experiments. Recent advances in machine learning have introduced a new class of ANNs, known as Physics-Informed Neural Networks (PINN) [5]. In this new kind of neural networks, the information content of available training data is enriched by considering a physics-based loss function, which embeds the underlying physics of the problem. This knowledge is not exploited in conventional ANNs. In this work, presented is an application of PINNs for the analysis of advanced composite structures with emphasis on static elasticity problems. Results are generated by training PINNs with Gradient-Based Learning (GBL) algorithms. Among the different optimization techniques available in literature, the Adam optimization rule [6] is used here. Results show that PINNs can predict accurately the solution, even when trained with limited and noisy data. A second strategy, alternative to GBL algorithms, is proposed in the present work. The approach refers to the so-called Extreme Learning Machine (ELM) [7]. Differently from GBL, where all parameters of the network are tuned iteratively, only the outer layers weights are trained in ELM; the inner parameters are chosen randomly. The comparison with GBL shows that even better generalization performance, at a much lower training time, is obtained for ELM. Although the following results are still preliminary, the proposed framework is promising and can be applied for solving a wide range of problems ranging from structural analysis to optimization problems. Acknowledgments: The research leading to these results has been funded by Ministero dell'Istruzione, dell'Università e della Ricerca, PRIN 2017. References [1] Z. Gurdal, R. Olmedo. Composite laminates with spatially varying fiber orientations: Variable stiffness panel concept. Structural Dynamics and Materials Conference, 2472, 1992. [2] R. Vescovini, L. Dozio. A Variable-kinematic model for variable stiffness plates: vibration and buckling analysis. Composite Structures, 142, pp. 15-26, 2016. [3] G. Raju, Z. Wu, P.M. Weaver. Postbuckling analysis of variable angle tow plates using differential quadrature method. Composite Structures, 106, pp. 74-84, 2013. [4] P. Ribeiro, H. Akhavan. Non-linear vibrations of variable stiffness composite laminated plates. Composite Structures, 94(8), pp. 2424-2432, 2012. [5] M. Raissi, P. Perdikaris, G.E. Karniadakis. Physics-informed neural networks: A deep learning framework for solving forward and inverse problems involving nonlinear partial differential equations. Journal of Computational Physics, 378, pp. 686-707, 2019. [6] D.P. Kingma, J.L. Ba. Adam: a method for stochastic optimization. International Conference

on Learning Representations, pp. 1-13, 2015. [7] G.B. Huang, Q.Y. Zhu, C.K. Siew. Extreme learning machine: theory and applications. Neurocomputing, 70(1-3), 489-501, 2006.

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abst. 2554
Virtual Room
Tuesday
September 1
14h15

A 3D SHELL MODEL FOR THE THERMAL AND HYGROSCOPIC STRESS ANALYSIS OF COMPOSITE AND SANDWICH STRUCTURES

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A general 3D exact shell solution for the thermo-hygro-elastic analysis of a heterogeneous group of multi-layered composite and sandwich structures is proposed. The 3D equilibrium equations are written in orthogonal mixed curvilinear coordinates, they are valid for spherical shells and they automatically degenerate in those for simpler geometries. The elastic part of the proposed model is based on a layer-wise exact solution where the exponential matrix method allows to solve the differential equations through the thickness direction. Simply-supported boundary conditions and harmonic forms for each variable are employed. The temperature and moisture content amplitudes are imposed at the external surfaces in steady-state conditions. Therefore, the related profiles can be evaluated through the thickness direction in three different ways: - calculation of temperature and moisture content profiles using 3D Fourier heat conduction and 3D Fick diffusion equations, respectively; - evaluation of temperature and moisture content profiles using 1D version of Fourier heat conduction and Fick diffusion equations, respectively; - a priori assumed linear temperature and moisture content profiles through the thickness direction. After the definition of the temperature and moisture content profiles, they can be considered as known terms in the 3D differential equilibrium equations. A set of non-homogeneous second order differential equilibrium equations are obtained. After a reduction to a first order differential equation system, the exponential matrix method is used for both the general and the particular solutions. The effects of the temperature and moisture content fields on the static response of plates and shells are investigated for different thickness ratios, geometries, lamination schemes, materials and temperature/moisture content values. Results will demonstrate the importance in the 3D shell model of both the correct definition of the elastic part and the appropriate evaluation of the temperature and moisture content profiles through the thickness of the structures.

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abst. 2641
Repository

Compressive proprieties of different nanoparticles reinforced epikote 828 nanocomposite (CB/epoxy , CNT/epoxy , GNP/epoxy nanocomposite)

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The effect of adding several nanoparticles as carbon nanotube CNT, carbon black CB and graphene GNP on the compressive proprieties of Epikote 828 epoxy was studied. A series of epoxy-based nanocomposite with 1-4wt% CNT, 1-5 wt% GNP and 1-2 wt% CB was prepared. static uniaxial compression tests were conducted to study the effect of CNT, CB and GNP on the compressive stress-strain behavior of the Epikote 828 polymer. It's as found that the compressive proprieties depend on the nature, mass fraction of nanoparticles reinforcement and its interaction with the epoxy. Reduction in compressive strength for 4wt% CNT and 5wt% GNP were recorded, which due to the intercalated structure way and the high density of CNT, GNP addition in the polymer that creates in its turn a high localized stress in the matrix during compression that leads to premature failure. However, adding carbon black shows enhancement in the compressive mechanical performance of the epoxy even with high mass fraction it didn't present a decrease in the strength structure which confirm the good interaction with matrix epoxy.

Predication of the in-plane mechanical properties of continuous carbon fibre reinforced 3D printed polymer composites using classical laminated-plate theory

abst. 2222
Virtual Room
Tuesday
September 1
09h00

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In this study in-plane mechanical properties of continuous carbon fibre reinforced thermoplastic composite manufactured using a Markforged Two 3D printing system was evaluated and compared against predicted values from classical laminated-plate theory. Strength, stiffness and Poisson's ratio of the composite specimens were measured using tensile testing both in longitudinal and transverse direction and the shear properties were also measured. The influence of fibre orientation on mechanical properties was investigated and were compared with that of non-reinforced nylon samples and known material property values from literature. It was determined that the modulus of elasticity and tensile strength values were significantly improved as compare to unreinforced nylon specimens. Furthermore, cross-sectional micrographs of specimens are analysed to observe the microstructure and fracture mechanism of the 3D printed composite. Experimentally determined values were used to predict the behaviour of the materials in different orientation using classical laminated-plate theory on the commercially available LAP (Laminated Analysis programme) software programme. The model developed will allow the designers to predict the elastic (mechanical) properties of 3D printed parts reinforced with fibre for components which require specific mechanical properties.

Experimental investigation and Artificial Intelligence Modelling of the Residual Impact Damage Effect on the Crashworthiness of Braided Carbon/Kevlar Tubes

abst. 2220
Repository

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Fiber reinforced plastic composites are promising candidates for building the next generation of automotive and aircraft structures. However, these materials are sensitive to any potential impact, which may cause matrix micro-cracking or internal inter-laminar delamination damages. This study provides insights into the sensitivity of braided Carbon/Kevlar round tubes to external damages and neural network-based models that can predict the consequences of damages on the crush-behavior (load-bearing) capability. This was investigated by subjecting the tube to transverse low-velocity impacts at different energy levels and locations. Then, those pre-damaged tubes were crushed under a quasi-static compression test. The results indicate that the pre-impact energy levels have a significant effect on the deterioration of both the structure strength and crush behavior. The location of the damages is mainly responsible for altering the collapsing behavior of the structure rather than its performance. The crush force efficiency is not significantly affected by the pre-impact energy levels, rather, it is highly dependent on the pre-impact/damage locations. The undamaged tubes were collapsed in a progressive manner, whereas splitting and crack propagation were the dominant failure modes in the tubes with residual damages. The path of those cracks was governed by the location of the damage. The neural network-based models successfully provided a relatively quick and accurate assessment at any given compression stroke step. A two-layer network (35 nodes, 35 nodes) in each layer yielded the best prediction accuracy with an MSE of 0.000191 KN

Experimental investigation and AI-based modeling of fiber-reinforced and sandwich laminated polymer composites pipes

abst. 2408
Repository

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Pipes are used for water supply, heating, clean drinking water, sewage disposal and transportation pipelines. Fiber-reinforced and sandwich laminated polymer composites currently play an important role in industry due to their low cost, corrosion resistance and high strength to weight ratio. Thus, this paper investigates the effect of the woven and filament wound fiberglass composites and their combination scenarios on the strength of polymer pipes. Also, a sandwich-structured composite formed from two fiberglass composite layers and a steel layer is proposed, evaluated and compared with the other scenarios. The best performing scenario is tested to identify its ability to provide high load-carrying capacity at large deformations (crash behavior). All tests were carried out using the 4 points bending test. Moreover, Scanning Electron Microscope (SEM) analysis is carried out to investigate the structure of the laminates. The microstructures clearly indicate the fractured surface. A number of neural-network based models are developed, evaluated using the MSE performance measure and compared with the object to provide an accurate AI-based model for the prediction of the load carrying capacity of the best performing composite structure.

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abst. 2647
Repository

Experimental investigation of the crashworthiness behavior of fiber and fiber/metal reinforced composites pipes

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Crashworthiness plays a key role in vehicles accidents. The energy absorption capacity of laminated composite materials are heavily investigated in industry due to their low cost, corrosion resistance and high strength to weight ratio. Thus, this paper experimentally investigates the effect of woven fiber laminates and fiber metal sandwich laminates on the strength and energy absorption capacity of polymer pipes. The sandwich-structured composite is formed from two glass-fiber composite layers with a steel layer in between. Four normal and hybrid reinforcement configurations are proposed and evaluated. The crashworthiness characteristics of the reinforced composite pipes were identified using quasi-static axial compression tests. The crushing parameters, in terms of load-displacement response, load carrying capacity, Specific Energy (SE) absorption capability and Crush Force Efficiency (CFE) were determined for each sample. Moreover, Scanning Electron Microscope (SEM) analysis was carried out to investigate the microstructures, which clearly indicate the fractured surface. The results show that the pipe reinforced with a 1mm steel layer sandwiched between 2 layers and 4 layers of woven glass-fiber has the best SE and CFE of 14 J/g and 0.91, respectively, while the pipe reinforced with 7 layers of glass fiber only has the best Initial Peak Load (IPF) of 139.36 KN.

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abst. 2122
Repository

Finite Element Modelling of GFRP Reinforced Timber Beams

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abst. 2664
Virtual Room
Tuesday
September 1
11h00

Metastable Chaotic Vibrations of Bistable Asymmetric Composite Laminated Square Shallow Shell under Foundation Excitation

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We point out the metastable chaotic vibrations in the vibration experiment of the bistable asymmetric composite laminated square shallow shell under the foundation excitation. In the vibration experiments, the testing object of the vibration experiments is a bistable asymmetric composite laminated square shallow shell with clamped at the center and free at four edges. Based on the experiment results, we not only find there exist the upper-mode and lower-mode chaotic vibrations, and the dynamic snap-through phenomena, but we also find that there are small vibrations around the unstable zero position between the upper-mode chaos and lower-mode chaos. This confirms the metastable chaotic vibrations exist in the bistable asymmetric composite laminated square shallow shell.

Propagation of uncertainty from constituents to structural assessments in composite strength modelling

abst. 2400
Repository

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In-service safety and reliable lifetime assessments are key challenges for high performance load-bearing applications and require great care to be taken during their design. The design of composite material structures can be assisted by computational models. Many complex computational models have been developed for predicting the failure and lifetime analysis of structures. Critical structures such as high pressure composite cylinders require very accurate computational models, to understand the stochastic nature of the predicted structural response. The following issues limit the use of composite strength models for making reliable structural predictions: • The complex interaction between the fibres and matrix which governs the failure mechanism has not been accurately incorporated in composite strength models. • Lack of reliable constituent properties which are used as input for the models. There are several studies aimed at improving the state-of-the-art models. However, accurate constituent properties to be used as input for these models are rarely available. Authors usually do not comment on the uncertainty of the constituent properties reported, which is of major importance for stochastic simulations. Since fibres are the principal load bearing constituents of unidirectional composites, Islam et al. have quantified the uncertainty in the parameters of the fibre strength Weibull distribution arising during to the characterisation process, using a Monte-Carlo approach to capture the stochastic nature of the fibre strength behaviour. Strength of T700 carbon fibres, popularly used in composite pressure vessels, is used as reference. In this study, the influence of uncertainty in input fibre strength on model predictions has been evaluated. A composite strength model developed at Mines ParisTech was used. This model considers physical processes such as fibre failure and its interactions with the surrounding matrix. It was first developed in 2005 and has been improved over the years to simulate different loading conditions during service of composite structures such as pressure vessels. The strength and lifetime of a composite structure (coupon) is simulated under two different practical loading conditions (monotonically increasing and sustained loading) to elucidate the sensitivity of different structural responses to the input fibre strength distribution. The calculated uncertainties in the shape (m) and scale (0) parameters of the fibre strength Weibull distribution were used as input for the models. The results are listed as follows: Monotonic loading: • The failure stress is seen to be significantly dependent on the scale parameter. The observed variation in the predicted failure stress is about 10% from the mean case, for an uncertainty of 10% in scale parameter. • The sensitivity of the model predictions to the shape parameter was insignificant. Sustained loading: • The time to failure of the composite specimen was also found to be strongly affected by uncertainties in the scale parameter. The calculated uncertainty of 10% in the input scale parameter resulted in a variation in the predicted lifetime of about 15-30%. • The calculated uncertainty of 25% in the shape parameter resulted in a variation of about 16% in the predicted lifetime of the specimen. The structural behaviour predicted by the

model is found to be highly sensitive to the uncertainties in the input fibre strength distribution which arise during characterisation. The understanding of the constituent properties and their characterisation process needs to be improved, in order to improve the reliability of computational model predictions, so that the predictions can be used with confidence in industrial applications. Acknowledgement: This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 722626.

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abst. 2602
Virtual Room
Friday
September 4
12h15

Torsional Behaviour Prediction of Triaxially Braided Composite Tubes Having Different Braiding Angles

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This study provides an estimation for the effect of braiding angle change on torsional strength of 2D trixially braided epoxy matrix carbon fiber composite tubes; produced via HP-RTM process. 2D triaxially braided composite tubes were tested under pure torsion up to failure. Material model of braided composite tubes was constructed via Digimat's FE module by homogenization method of the software. Yarn properties and braid architecture in the model were established according to the manufactured part. Representative volume element was generated for six layers of braided structure which is same as the braided composite tube. To reveal actual yarn properties of the manufactured composite tubes, microstructural characterization was performed by optical microscope. Besides, fiber volume fraction and density of composite tubes were experimentally determined. Analysis results of constructured model exhibited a 0.74 percent relation with experimental results. With this proximity, in case of pure torsion, this model was used to predict shear modulus of composite tubes which are braided at a braiding angle ranging from 25 to 65 degrees. Model predicts that maximum torsional strength can be achieved when the tube is braided with a 50 degree braiding angle.

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abst. 2130
Repository

In-mold dielectric analysis during cure of a polyurethane-based sheet molding compound

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The application of polyurethane resin systems in sheet molding compound promises potential benefits in regards to mechanical performance and recycleability of parts. However, the high reactivity of conventional polyurethane systems renders them unsuitable in such applications. A novel polyurethane system based on internally blocked isocyanate with thermolatent crosslinking is used within this work to produce sheet molding compound. During compression molding, resin cure progression was investigated using a novel in-mold sensor for dielectric analysis. The measured dielectric material response has been correlated with rheological properties using a modified oscillation rheometer setup which allows for simultaneous shear viscosity and dielectric measurements.

Path Planning and Fiber Angle Optimization of Continuous Fiber Composites for Additive Manufacturing

abst. 2591
Virtual Room
Tuesday
September 1
15h45

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This study proposes an optimization framework for 3D printers to integrate the structural and the manufacturing perspectives. The recent developments in Additive Manufacturing (AM) technologies of composite structures led to the emergence of new design techniques to find innovative and more efficient solutions. The main goal of this study is to implement a path planning algorithm and optimize both the printing time and the stiffness of the produced part. A Genetic Algorithm is used as a solver to optimize a multi-objective function including the printing time and the structural performance. In terms of the structural performance, the stress and stiffness are selected as the objective function. The framework is applied for different 2D and 3D cases. The designs are obtained for two types of the continuous fiber path planning, namely straight and curvilinear fibers. The raster filling scheme is developed for the continuous deposition path planning. The results show that the fiber orientations can change significantly based on the objectives. The fiber orientation is tailored around the hole for the shell plate with the hole when the stress objective is considered. The optimal fiber path planning is also dependent to the selection of the weight factors for the printing time and the structural performance objectives. The design parameters for the calculation of the printing time can be updated according to the 3D printer specifications.

Bi-criteria stability evaluation approach of gravity dam with pre-stressed cable reinforcement

abst. 2005
Repository

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The stability with certain safety margin is one of basic requirements for design and operation of gravity dam engineering. The pre-stressed cable reinforcement is often used to enhance and ensure the sliding stability of gravity dam. In this paper, the finite element method (FEM) is introduced to implement the numerical simulation of sliding failure process of gravity dam before and after the pre-stressed cable-based reinforcement practice. According to the FEM calculations, the two criteria on strength and energy are integrated to evaluate the effect of reinforcement measures on stability improvement of gravity dam. Taking this one step further, dam body, dam foundation and pre-stressed cable reinforcement measures are regarded as a gravity dam system. According to the energy evolution process and its relationship with the strength loss and the overall failure of gravity dam system, an energy catastrophe model, with the strength reduction coefficient and the strain energy as control variable and state variable of dam system stability respectively, is built to identify the dam system stability. The appropriate energy criterion is proposed. The energy criterion-based evaluation approach for stability improvement of gravity dam undergoing pre-stressed cable reinforcement is presented. The varying strain energy analysis for gravity dam system during strength reduction and the energy threshold as instability failure criterion make the mechanics and physical evidence of built evaluation model and obtained results be more definite.

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abst. 2588
Virtual Room
Tuesday
September 1
11h30

Numerical investigation of orthogonal machining damage development in CFRPs considering thermal effects

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A coupled thermo-mechanical three dimensional (3D) finite element model (FEM) of mechanical and thermal damage development during orthogonal machining of carbon fiber reinforced polymers (CFRPs) for various fiber orientations is presented. In addition to commonly observed mechanical damage mechanisms like fiber breakage, matrix cracking, fiber pull-outs, delamination etc. [1,2], the variation of laminate elastic, strength and ply interface fracture properties due to in-situ cutting temperature becomes crucial. The material removal process during composite machining is in the form of fractured particles that will carry away heat at it leaves the cutting zone. The primary source of heat generation during composite machining occurs at the workpiece-tool contact region at the clearance face due to high abrasive action between hard reinforcing phase and cutting tool. The inherent anisotropy in composites leads to damage development in a non-uniform manner along the composite which depends on directional thermal properties of the laminate. Regardless of the importance of cutting temperature in orthogonal machining of CFRPs, only few studies are available in literature which includes thermal damage effects in addition to mechanical damage predictions [3-6]. However, in all of the previous research the focus is towards cutting temperature predictions for thermal damage analysis, energy dissipating mechanisms during orthogonal machining and heat partition between workpiece-tool contact region for various fiber orientations with respect to cutting direction. In summary, the effect of in-situ cutting temperature on the laminate elastic, strength and interface fracture properties during orthogonal machining of CFRPs is missing and these considerations are crucial for accurate numerical predictions of thermal and mechanical damage. In the present study, a 3D equivalent homogeneous model (EHM) FE model for orthogonal machining of CFRP for various fiber orientations with respect to cutting direction is presented which addresses all of the shortcomings of the previous work described. The FE mesh for the EHM FE machining model is constructed using C3D8R elements. The cutting tool is assumed to be a rigid solid and is constructed using R3D4 elements, which is constrained to a reference point for prescribing the tool velocity. The in-situ temperature predictions is modeled using heat generation due to frictional interaction (surface contact) at the workpiece-tool interface at the clearance face. The machining process is modeled using element deletion based on continuum damage model [7], developed using a user material subroutine VUMAT in commercial FE software ABAQUS/EXPLICIT [8]. The present FE model successfully predicts sub surface damage along the machined surface, in-situ cutting temperature rise for thermal damage and stress increase during cutting process. References [1] Haddad M., Zitoune R., Bougherara H., Eyma F., B.Castanié B., "Composites Part B", 2014; 57: pp.136–143. [2] Akshay H., Dilpreet S., Sagar K., Dinesh K., Suhasini G., "Composites Part A", 2016; 82: pp.42–52. [3] Xiaoye Y., Johannes R., Mattia B., Yusuf A., Reza V., "Composite Structures", 2019; 220: pp.460–472. [4] Fu-ji W., Jun-wei Y., Jian-wei M., Bin N., "Composite Structures", 2018; 197: pp.28–38. [5] Santiuste C., Dıaz-Alvarez J., Soldani X., Miguelez H., "Journal of Reinforced Plastic and Composites", 2014; 33(8): pp.758–766. [6] Jinyang X., Mohamed M., "IOP Conference Series: Materials Science and Engineering", 2015; 87: 012059. [7] Hashin Z., "Failure criteria for unidirectional fiber composites", Journal of Applied Mechanics, 1980; 47: pp.329–34. [8] Hibbit K., ABAQUS user's manual 6.4-1. Pawtucket, Rhode Island, USA, Sorensen Inc., 2003.

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abst. 2601
Virtual Room
Tuesday
September 1
11h45

Experimental characterization of compressive strength and modes of compressive failure in UD-FRP laminates with wrinkles at varying locations

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At macro length scale, out-of-plane waviness [1] in fiber reinforced plastic (FRP) laminate, defined as wrinkle, is a predominant geometrical defect that occurs during fabrication of laminate accompanied with matrix rich regions. Characterizing wrinkle geometry [2, 3] is an important aspect to determine the degree of wrinkle severity as it has a direct effect on the compressive strength of laminate. The compressive strength of laminate significantly reduces as the degree of wrinkle severity increases as evident from previous studies [4]. Several techniques for artificially producing wrinkle in the laminate have been proposed by researchers in the past [5, 6]. Present study focusses on experimental fabrication of unidirectional Carbon FRP (UD-CFRP) laminate with wrinkle geometry using transverse strip ply method [5], characterization and testing of wrinkled specimens. Four test cases are currently investigated out of which one test case consists of pristine sample without wrinkle and other three test cases with the presence of wrinkle. The test cases containing wrinkle are fabricated with transverse strip ply placed at locations namely, outside of laminate (at the bottom), in the middle of laminate and at the last interface of the laminate. The thickness and width of strip ply are kept constant for all test cases containing wrinkle. Combined loading compression (CLC) fixture [7] is used for testing the fabricated samples. The variation of compressive strength of the laminate in the presence of wrinkle for all the four test cases are investigated. Post mortem studies are also carried out on the tested samples to provide an insight on the modes of compressive failure [8] for the proposed test cases. References [1] K. D. Potter," Understanding the Origins of Defects and Variability in Composites Manufacture," International Conference on Composite Materials, Edinburgh, United Kingdom, July 27-31, 2009. [2] C. S. Yerramalli, T. Miebach, K. Chandrasekar and S. C. Quek, "Fiber waviness induced strength knockdowns in composite materials used in wind turbine blades," European Wind Energy Conference and Exhibition, Warsaw, Poland, April 20-23, 2010. [3] M. P. F. Sutcliffe, S. L. Lemanski and A. E. Scott, "Measurement of fibre waviness in industrial composite components," Composite Science and Technology, Vol. 72, 2012, pp. 2016- 2023. [4] S. Mukhopadhyay and S. R. Hallett, "Compressive failure of laminates containing an embedded wrinkle; experimental and numerical study," Composites: Part A, Vol. 73, 2015, pp. 132-142. [5] J. Wang, K. D. Potter, K. Harza and M. R. Wisnom, "Experimental fabrication and characterization of out-of-plane fiber waviness in continuous fiber-reinforced composites," Journal of Composite Materials, Vol. 46, No. 17, 2012, pp. 2041-2053. [6] D. O. Adams and M. W. Hyer, "Effects of layer waviness on compression strength of thermoplastic composite laminates," Journal of Reinforced Plastics and Composites, Vol. 12, 1993, pp. 414-429. [7] D. Adams and J. Welsh, "The Wyoming Combined Loading Compression (CLC) Test Method," Journal of Composites, Technology and Research, Vol. 19, No. 3, pp. 123-133. [8] N. A. Fleck, "Compressive failure of fiber composites," Advances in Applied Mechanics, Academic Press, Vol. 33, 1997, pp. 43-117.

Carbon fiber-reinforced epoxy-UHMWPE composite material with high strength and radiation shielding capabilities

abst. 2683
Repository

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Carbon fiber-reinforced epoxy (CF/EP) composites have succeeded in replacing metals in both primary and secondary structures of aircrafts (e.g. wings, fins), spacecrafts (e.g. ENVISAT primary structure) and launch vehicles (e.g. interstage and fairing structures, propellant tanks, thrusters). Nonetheless, the poor radiation shielding properties of CF/EP limit their use in long duration space missions and the development of lightweight composite materials with radiation shielding effectiveness is therefore a highly sought-after objective in the space sector. Ultra-high molecular weight polyethylene (UHMWPE) is one of the most effective materials in shielding against space radiation thanks to its high hydrogen content, but it has poor mechanical and thermal properties to be a structural material. In this paper, we used UHMWPE to fabricate carbon fiber-reinforced epoxy-UHMWPE (CF/EP-U) composites, in order to combine the superior mechanical and thermal properties of the carbon fibers and thermosetting polymer with the radiation shielding capabilities of polyethylene. The non-isothermal curing behavior of UHMWPE/epoxy composites at different wt% of UHMWPE was initially investigated by differential scanning calorimetry (DSC). The vacuum outgassing characteristics of the UHMWPE-loaded epoxy systems were also analyzed, with all tested samples showing a total mass loss (TML) lower than 1%. After the assessment of the outgassing properties of the UHMWPE/epoxy composites,

the epoxy/UHMWPE at 1 wt%, 3 wt% and 5 wt% were used to fabricate CF/EP-U laminates through the hand lay-up manufacturing technique. The vacuum outgassing characteristics of the CF/EP-U composites were investigated, with all tested samples that showed a TML lower than 1%. Short beam shear (SBS) tests were performed to evaluate the interlaminar shear strength (ILSS) of laminates before and after the outgassing and the UV exposure tests. Results showed that the ILSS values of CF/EP-U laminates increases at low UHMWPE concentrations with respect to the CF/EP composite, and these values remain higher after both the outgassing and the UV exposure tests. Overall, the results of the mechanical analysis show the promising use of carbon fiber-reinforced epoxy-UHMWPE laminates to protect sensitive spacecrafts equipment from radiation while still providing structural reinforcement.

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abst. 2557
Virtual Room
Tuesday
September 1
10h30

Numerical Analysis of Curing Process-Induced Residual Stress of Composite Laminate

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Residual stress is produced during the curing process of composite materials, which induces the deformation to the final product. Therefore, it is essential to predict curing process-induced residual stress of composite materials, whereby to improve the quality of the final product. In this study, a numerical approach to predict the curing process-induced residual stress for the woven composite laminate is proposed. The elastic modulus of the yarn (unidirectional composite) during the advancement of cure is predicted via the viscoelastic constitutive model. The three-dimensional (3-D) engineering constants of the woven composite are calculated by using the coordinate transformation and the volume averaging method of the crimp yarn. Moreover, the geometric constants of the woven composite are calculated through the geometric model based upon the unit cell. The process-induced residual stress of the yarn and the 3-D engineering constants of the woven composite are compared with the results obtained from the other researches to validate the subroutine developed. Furthermore, the curing process-induced residual stress of the woven composite laminate with several stacking sequences are evaluated by curing process simulation. Acknowledgment. This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (NO. 2019R1A2C4070280).

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abst. 2528
Repository

An improved first-order beam model for the bending and buckling response of thin-walled functionally graded sandwich I-beams resting on the elastic foundation

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This paper proposes an improved first-order beam theory by separation of variables for bending and buckling analysis of thin-walled functionally graded (FG) sandwich I-beams resting on an elastic foundation. By dividing the displacements into bending and shear parts, this model can produce the deflections and buckling loads for both two cases with and without shear effect. Governing equations are established from Lagrange's equations. The new Ritz's approximation functions, which are combined between orthogonal polynomial and exponential functions, are developed to solve the problems. The results of thin-walled FG sandwich I-beams are presented and compared with those available literature to verify the present theory. The effects of material distribution, boundary conditions, length-to-height ratio, shear deformation and foundation parameters on the results are investigated. The proposed beam

model is accurate and straightforward for the static and buckling response of thin-walled functionally graded sandwich I-beams.

Vibration of carbon nanotube reinforced functionally graded beams attached to the inside of a rotating rim

abst. 2015
Repository

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Vibration of carbon nanotube (CNT) reinforced functionally graded beams attached to the inside of a rotating rim has been investigated. Material properties change in the thickness direction. Effective rigidities of the beam have been obtained using modified rule of mixture coupled with molecular dynamics simulations. Ritz method with algebraic polynomials has been utilized in the formulation of the problem. Parametric results have been obtained for different material and geometrical properties.

Effect of architecture on the collapse of non-stochastic metallic cellular lattices

abst. 2301
Repository

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Cellular lattices are a class of materials with high specific mechanical properties that are intended for applications where a high strength/density ratio is desired. When their solid phase is metal-based, they are frequently stochastic and manufactured by foaming or casting. However, recent developments on additive manufacturing and casting techniques allow the fabrication of non-stochastic cellular lattices with tailored geometries and mechanical properties. This study explores the collapse mechanism on different three-dimensional honeycomb-based architectures manufactured by an additive manufacturing assisted investment casting hybrid technique. 4D X-ray CT is performed while samples are compressed to monitor the overall sample and in-situ strut collapse deformations. It is shown that the plastic collapse of these cellular lattices is deeply related with their Poisson's ratio. Lattices with positive Poisson's ratios show diffuse deformations along the sample faces and plastic deformations occurs by a shear sliding diagonal planes. However, in samples with negative Poisson's ratios, plastic deformation accumulates by the generation of local densification and increasing the values of plastic collapse strength. Samples with a zero Poisson's ratio have high specific modulus due to the change from flexure to axial loading in the struts, in which collapse occurs by the subsequent buckling of cell lines. Coupled static structural-eigenbuckling finite element analysis was performed to detail the sample collapse in other architectures and estimate the overall influence of the Poisson's ratio in the collapse mechanism of cellular lattices. It is highlighted that the combination of flexural and axial local deformations in the transition architectures from negative to zero Poisson's ratios are fundamental to obtain cellular lattices with a combination of high specific modulus and plastic collapse strength.

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abst. 2634
Repository

Improvement mechanical properties of Epoxy by adding Nano Al2O3 and SiC

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The main objective of the present work is to improve the fracture toughness, mechanical and tribological Properties of epoxy by adding nano-Al2O3 and/or nano-SiC. The nanoparticles were infused into epoxy resin with an ultrasonic liquid processor with 0.5, 1 and 1.5 wt.% of epoxy. For nanocomposites, addition of of silica, and alumina nanoparticles improves the tensile strength over neat epoxy. In general, the fracture toughness, mechanical and tribological Properties of epoxy are improved markedly by adding different types of nanoparticles. Pin on ring wear test was also performed to examine wear performance of epoxy Al2O3 and SiC nanocomposite. The two-parameter Weibull distribution function was used to investigate the statistical analysis of the experimental tensile results. Some models for the prediction of the elastic modulus of nano-reinforced composites were evaluated. The measured moduli were compared to theoretical predictions. The Paul model shows the best agreement with the experimental data. The dispersion of nanoparticles was examined using optical micrograph.

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abst. 2072
Repository

Detection of artificial defects in aramid composites by ultrasonic IR thermography

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The paper presents selected results of defect detection in a multi-layer aramid composite structure used in light ballistic armour by ultrasonic infrared thermography. The tests were carried out using samples of the aramid composite with deliberately introduced artificial defects. The effect of changing the generator head size on defect detection was tested. The research were carried out using different test parameters such as: generator power, stimulation time, recording time and ultrasonic frequencies. During tests, the influence of changing the type and method of sample support on the detection of defects was also tested.

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abst. 2586
Repository

Effect of basalt fiber on the mechanical properties and wear resistance of Polyether ether ketone composite

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Polyether ether ketone (PEEK) is a special engineering material with excellent mechanical properties and heat resistance, which is widely used in aerospace, rail transit and other fields. A new kind of material of PEEK with basalt fiber (BF) was produced. The effect of BF on the crystallization behavior of PEEK was studied, and the effect of different contents of BF on the mechanical strength and wear resistance of PEEK composites was discussed. With the content of BF increases to 25wt.%, the tensile strength increases to 140MPa. When the content of BF is 15wt.%, the wear loss of PEEK composites is the lowest 0.08473mm3, which is 72% lower than that of neat PEEK. The modification of peek by basalt fiber can improve the mechanical properties and wear resistance, which further expand the applicable range of PEEK and reduce the cost of fiber-reinforced PEEK composite.

Microscopic damage modeling of unidirectional PMCs with curing residual stresses

abst. 2650
Repository

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Curing residual stresses (CRS) have a non-negligible effect on the mechanical performance and even the damage of polymer matrix composites (PMCs). In this study, a novel numerical method is proposed for capturing CRS in accordance with real curing process of unidirectional PMCs. This methodology develops thermochemical and thermomechanical simulation from macroscale to microscale by means of finite element (FE) modeling. Then, the obtained CRS are combined with the microscale representative volume element (RVE) to compute the transverse tensile damage of PMCs. The predicted results coincide well with the experiments and the microscopic damage distribution with CRS reveals the intrinsic mechanisms of CFRP composites from fabrication to service. Besides, the influence of curing process on the strength performance of PMCs are further investigated using this proposed framework.

AI-based Health Monitoring of Tunnel Structures with CUF Method

abst. 2068
Repository

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AI-based health monitoring, especially the reliable deformation analysis and prediction, is an increasingly important topic in the field civil engineering. In the present paper, terrestrial laser scanning (TLS) technology and finite element analysis (CUF) model are combined, in order to study deformation behavior of tunnel structures. The innovation of this paper is that the geometric model of tunnel structure is constructed directly with surface-oriented TLS measurement, which can be automatically imported into CUF model for deformation analysis and prediction. The higher-order computation is realized simultaneously in real geometric model from TLS data and the CUF model.

Shape optimization design of fabric rubber seal

abst. 2651
Virtual Room
Tuesday
September 1
10h45

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In this paper, the cross-section shape optimization design method of fabric rubber seal is proposed. First, the cross-section shape optimization design method is introduced based on the structural features of fabric rubber seal. Then, according to the key performance of fabric rubber seal, the optimization constraints, optimization objective and corresponding calculation methods are determined. Finally, the optimal cross section shapes of fabric rubber seal are obtained under different gas pressure differences and temperatures. The shape optimization design method and the optimal cross section shapes of the fabric rubber seal have important guiding significance for the design and manufacture of the fabric rubber seal. Key words: cross section shape optimization; fabric rubber seal; gas pressure difference; temperature

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Strength improvement of composite single-lap joint reinforced with I-fiber stitching process

abst. 2710
Repository

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Composite lap joints have been extensively used in recent years owing to their excellent properties and the demand for light structures. However, composites exhibit weak mechanical properties in the direction of their thickness, which may cause failure in composite lap joints. To overcome this problem, various reinforcement methods that delay fracture by dispersing stress concentration have been discussed, such as Z-pinning and conventional stitching. The I-fiber stitching process is a promising technology that combines the advantages of both z-pinning and the conventional stitching process. In this paper, the reinforcing effect of the I-fiber stitching process was verified by fabricating composite single-lap joint specimens with different thicknesses, number of I-fibers, and stitching angles, and evaluating their lap shear strengths. The stress distributions of the single-lap joints were determined by finite element analyses, and the results were compared with the experimental results.

Composite structures in civil engineering

Experimental investigation of deformation behaviour of stress-ribbon bridge prototype under sustained load

abst. 2357
Virtual Room
Wednesday
September 2
15h00

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Stress-ribbon bridges are the most slender and flexible structures. A structural system of such elegant bridges consists of load-bearing cables or strips and a deck slab that is placed directly to the ribbons distributing the applied load. Although this structural system is simple, the deformability of stress-ribbon bridges under a point loading or an asymmetrical load distribution causes a severe design problem: kinematic displacement of the slender structure can exceed static deformation component several times. The increasing flexural stiffness of the bridge deck is an efficient way of restriction of the kinematic movements. This study is a part of the ongoing project, which aims to develop an innovative stress-ribbon bridge structure that comprises fibre reinforced concrete (FRC) deck adhesively joined to the ribbon bands. The assessment of the deformation behaviour of the adhesively bonded bridge system under a sustained load is the focus of the research. A stress-ribbon bridge prototype subjected to symmetric and asymmetric loading is considered. The punching-shear resistance of the FRC deck segments (produced without a conventional bar reinforcement) is also the research subject. Two 5 m long stress-ribbon systems were constructed and tested. The reference prototype represents a stress-ribbon system with simply supported deck slabs. The deck segments adhesively bonded to the ribbons comprised the alternative bridge system. The bridge prototype with adhesively bonded FRC segments demonstrated 8% lower deflection for symmetric and 30% for asymmetric loading, considering the bridge prototype with simply supported deck segments as the reference. The tests were carried out at 30, 130 and 155 days after the formation of the joint connection to investigate the deformation behaviour of the adhesive bond under a sustained load. The test results indicated that the kinematic displacements of the bridge prototype increased by 20% at the 130 testing day. The further stabilisation of the deformations puts forward the effects related to the concrete cracking and shrinkage for the design of the stress-ribbon systems.

Application of seeds of the C-S-H phase to improve the performance of concrete composites containing fly ash

abst. 2152
Repository

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One of the most frequently used additions to concrete are the siliceous fly ashes (FA). They are a by-product of a coal combustion in power plants. Fly ashes precipitate in electrostatic precipitators during the exhaust gas cleaning process. A big problem is to manage this waste in such a way that it does not have a negative impact on the environment, which is why its use, apart from the economic aspect, also has an ecological aspect. Numerous studies confirm that it is possible to use the FA additive in concrete. They have a positive impact on its mechanical and physical properties. However, the problem with the use of FA is a significant reduction in the concrete parameters in the early stages of curing The use of FA significantly delays: the hydration processes, the setting time and hardening

of the concrete mix. This results in limiting the possibility of using this type of concrete compo-sites e.g., in prefabricated structures. The paper presents the results of studies presenting the acceleration of binding process of the concrete containing FA, by using the chemical admixture of the C-S-H (CSH) nanoparticles. This admixture is an aqueous suspension of the crystallization seeds. Thanks to the nucleation, the growth of crystals of hydrated calcium silicates is significantly accelerated. The use of the CSH seeds, as activators, leads to the development of microstructure of concrete composites with improved physical and mechanical properties. The tests were carried out for mixtures with FA and the CSH nano-admixture. Four concrete mixtures were prepared, i.e. two reference and two with the CSH nanoadmixture. The first two reference mixtures are a mixture without the FA and a mixture with 20% of the FA (in relation to the weight of cement). The 20% addition of FA results from the most measurable benefits for the concretes modified with this additive, which is confirmed by common earlier studies. Other modified mixtures are mixture without FA, with the use of 4% of the CSH nanoadmixture (in relation to the weight of the binder), and a mixture with 20% addition of FA and 4% of the CSH nanoadmixture. The application of the nanoadmixture in the amount of 4% results from both the manufacturer's recommendations and previous experimental studies. The paper presents research on the compressive strength (fcm) and tensile strength (fctm) of the concretes after: 4, 8, 12, 24 and 72 hours and 7 days. In addition, the SEM microstructure and XRD phase composition studies were carried out for the cement matrix. Acceleration of setting time may also affect rheological processes associated with shrinkage, therefore the authors of the paper additionally performed shrinkage tests of the cement matrix. Mechanical strength tests have confirmed the positive impact of the CSH nanoadmixture on the parameters of concrete composites. In the first hours of mixture curing and hardening, a significant increase in the concrete strength was noted. After 4 hours, the increase in fcm and fctm was over 4 times, after 8 hours nearly 3 times, and after 12 hours about 2 times. After 24 hours, the influence of the CSH nano-admixture was small. During the period of up to 7 days, no deterioration of mechanical properties caused by concrete nanomodification was noted. Then detailed cement matrix tests were carried out for each of the peri-ods. A detailed microstructure examination and a phase composition study was performed using the SEM and XRD analyzes. Based on the research, the positive effect of the nanoadmixture on the hydration process and development the structure of concrete in all periods examined was con-firmed. In addition, due to the accelerated rate of setting time and hardening of the mixture, the authors of the paper conducted shrinkage tests for cement matrices modified with the addition of FA and the nanoadmixture (in proportions identical to those for the concretes). Based on the conducted research, no negative effect on the rheological contraction was found, what is more, for concretes with the addition of FA, this effect was positive. The conducted research confirmed the possibility of modifying the micro-structure of concretes with the addition of FA using the CSH nanoparticles. The application of the nanoadmixture has a positive effect not only on the mechanical parameters of the concrete composite, in early curing periods, but also on its microstructure. Application of the CSH seeds and accelera-tion of setting time does not negatively influence the rheological processes such as the shrinkage, and in the case of the concrete composites with FA this property is even improved.

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abst. 2217
Repository

Stability of thin micro-periodic cylindrical shells; extended tolerance modelling

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The aim of this contribution is to formulate and discuss a new averaged mathematical non-asymptotic model of stability problems for thin linearly elastic Kirchhoff-Love-type circular cylindrical

shells with a periodically micro-heterogeneous structure in circumferential direction (uniperiodic shells). By periodic inhomogeneity we shall mean here periodically variable shell thickness and/or periodically variable inertial and elastic properties of the shell material As examples we can mention cylindrical shells made of composite materials or reinforced by periodically spaced families of stiffeners. At the same time the shells have constant structure in axial direction. This so-called general tolerance model is derived by applying a certain extended version of the known tolerance modelling technique. This version, presented in [Tomczyk B, Woźniak C. Tolerance models in elastodynamics of certain reinforced thin-walled structures. Kołakowski Z, Kowal-Michalska K, editors. Statics, dynamics and stability of structural elements and systems, vol. 2. Poland, Lodz: University of Technology Press; 2012. p. 123-153], is based on a new notion of weakly slowly-varying functions. Contrary to the starting exact shell equations with highly oscillating, non-continuous and periodic coefficients, governing equations of the proposed model have constant coefficients depending also on a period of inhomogeneity. Hence, the model makes it possible to investigate the effect of a cell size on the global shell stability (the length-scale effect). The differences between the general tolerance model proposed here and the corresponding known standard tolerance model derived by means of the more restrictive concept of slowly-varying functions are discussed. Moreover, a certain asymptotic model being independent of a microstructure size will be presented. As an example, there are analysed critical forces in a shell strip composed of two homogeneous materials densely and periodically distributed along the circumferential direction. In order to evaluate the length-scale effect in the stability problem under consideration, the cell-dependent critical forces obtained in the framework of both the general and standard tolerance models are compared with the cell-independent critical forces derived from the asymptotic model.

Design and Evaluation of Curved and Non-uniform High-Strength Fibre Cementitious Composite Truss Structures

abst. 2024
Repository

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In the current research, curved and non-uniform truss structures were designed and manufactured by using high-strength and high ductile fibre cementitious composites. The fibre cementitious composite mixed with steel fibres has a uniaxial compressive strength of 120-130 MPa, a direct tensile strength of 10-12 MPa with an ultimate tensile strain of 6.0-9.0 %, and a slump flow of 720-740 mm. In order to manufacture curved and non-uniform fibre cementitious composite truss structures, special formwork systems were developed using fibre-reinforced plastic with clay sculpture method. In truss structures, the truss members were determined from the reinforced concrete beam with solid rectangular cross-section by using the Strut-Tie approach. The designed and developed truss structures were evaluated from a set of loading test.

Efficacy of Textile-Reinforced Mortar for Masonry Panel Strengthening

abst. 2004
Repository

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The search for materials alternative to traditional ones is not easy, given the risk of losing the effectiveness of the work being done, especially when it is aimed at increasing certain mechanical properties such as the strength of materials not having tensile strength, such as masonry. For these it is proposed to find innovative solutions that make it possible to strengthen existing buildings effectively,

but in a reversible and minimally invasive way. Fiber textile are used for this purpose because they are easy to apply and, above all, they have the advantage of providing considerable tensile strength without increasing the weight of the original structure. This research investigated the adhesion of textile-reinforced mortar applied on masonry panels obtaining the strengthening of masonry walls. More specifically, single lap shear tests were performed on masonry samples to which five different types of fabric, such as basalt, steel, stainless steel and two type of glass, were applied. All fabrics were impregnated with the same type of lime-based mortar. The results obtained from the experimental tests were used in the mechanical behavior analysis of the reinforcement-masonry system and for calibrating an analytical model able to describe the shear stress-displacement interface law. The stress development along the fibers follows a trilinear behavior and after reaching the peak, friction is generated that allows the transfer of stresses until rupture.

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abst. 2280
Repository

Effect of BFRP Ties on the Compressive Response of BFRP RC Columns

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Several studies have investigated the use of Fiber-Reinforced Polymers (FRP) rebars in reinforced concrete (RC) flexural members. However, not enough depth of understanding is currently available with regards to their use in compression members. This research aims at investigating the effect of using BFRP ties on the structural performance of square concrete columns longitudinally-reinforced with Basalt FRP (BFRP) bars. The use of BFRP ties as a replacement to steel transverse reinforcement in BFRP RC columns is discussed. A total of 6 short columns with a cross-section of 180mm $\times$ 180mm are cast and tested under concentric loading. Three columns were transversely-reinforced with BFRP ties while the other similar 3 specimens were reinforced with steel ties. The effects of the test parameters on the overall response of FRP RC columns including axial load capacity, failure modes, confinement efficiency (EC), ductility, strength contribution of longitudinal rebars, and deformation capacities will be discussed during the presentation. The results showed comparable performance in terms of capacity and ductility between BFRP and steel ties. Furthermore, replacing the steel ties with BFRP ties slightly decreased the ductility and the ultimate capacity of BFRP RC columns. The main failure mode of all columns was compression-controlled attributed to concrete crushing at strains close to 0.003.

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abst. 2405
Virtual Room
Wednesday
September 2
15h15

Nonlinear dynamic analysis of base isolated structures under strong seismic events

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In the present work an innovative seismic isolator named high damping hybrid seismic isolator is illustrated. The high damping hybrid seismic isolator is realized by assembling in series a lead rubber bearing isolator and a friction slider isolator which is characterized by a high friction coefficient. The base isolation system is designed according to the European seismic codes EC2 and EC8. The objective of the base isolation system is to provide the passive control of structures and ensure the base isolation for the earthquake resistance of reinforced concrete buildings. The seismic behavior of a multi-storey reinforced concrete building base isolated by the proposed isolation system is studied and analyzed by comparing it with the seismic behavior of the same structure base isolated by a traditional lead rubber bearing isolation system. The base isolated multi-storey reinforced concrete structure is investigated by performing a nonlinear dynamic analysis. In the investigation different extreme seismic events have been considered. The considered strong seismic events are characterized by extreme values of peak ground acceleration and high energetic values at low frequency. The investigated strong seismic events are therefore characterized by anomalous values of intensity and frequency content. The performed nonlinear dynamic analysis describes the behavior of multi-storey reinforced concrete buildings base isolated by the adopted high damping hybrid seismic isolation system. The time history of the base

shear and the time history of the base displacement of the superstructure are derived for the multi-storey reinforced concrete building subject to the considered extreme seismic events. Consequently, the properties of the considered high damping hybrid base isolation system are illustrated for the seismic protection of multi-storey reinforced concrete buildings under extreme seismic events.

Repairs of high pressure gas pipelines with two different types of composite sleeves and evaluation of their effectiveness

abst. 2398
Repository

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In service, high pressure pipelines are exposed to surface corrosion. Two types of damage to pipelines occur quite frequently, namely (i) surface corrosion resulting in corrosion pits and reduced wall thickness and (ii) stress corrosion cracking, a complicated dangerous damage mechanism occurring as a superposition of corrosion mechanisms and static or dynamic stresses, resulting in an occurrence of different types of stress corrosion cracks. High-pressure pipeline operators have to ensure safe and reliable service and so to consider effective remedy measures, if any section of a pipeline is damaged. There are special standard codes, which serve as a basis for and evaluation, whether the damaged section can be further operated or has to be replaced by a new pipe segment. Replacing pipe sections is enormously expensive not only due to the labour and material costs, but also due to huge financial looses occurring for the period, when the pipeline has to be taken from the operation and gas transport has to be stopped. Therefore, several repair methods were designed already in the past and have been used. One of the oldest methods is use of steel sleeves to cover the damaged areas. This method, though quite simple, is surprisingly effective, but has disadvantages and its possibilities are limited. More progressive are composite sleeves, having been recently frequently used. Composite sleeves usually use fibre fabrics, usually either glass or carbon, wound circumferentially around the pipe and wet by a suitable resin, usually epoxy. Though the E-modulus of the composite material of the sleeves is lower, the strengthening effect and reduction of stresses in the pipe wall is sometimes sufficient, particularly if a sufficient number of layers are applied, even more than 30. That is why this method is very time consuming and expensive. Another advanced type of sleeve has been recently designed, a combination of steel and composite materials, where a suitable gap between the inner surface of the covering sleeve steel material and the pipe damaged surface is filled in with small glass balls in closest packing and filled with epoxy resin. An experimental programme with the aim to evaluated and compare effectiveness of two types of repairing sleeves, namely composite sleeve with carbon fabrics and the innovative steel/composite sleeve with the small balls and epoxy resin was performed. Artificial area defects on the tested pipe section, reducing the wall thickness by 50% and 80%, were manufactured. The sleeves were applied to the damaged areas along with the same sleeves covering sections without any damage. Special methods were developed to make experimental stress-strain analysis under the sleeves. The results of the experimental programme confirmed that both types of sleeves were effective, at least partially. However, the combined steel/composite sleeve with the glass balls and epoxy resin reduced the stress in the pipe wall much more significantly, 3-tiems in average, than the sleeve with the carbon fabrics, when the stress reduction was only up to 40% of the stress without a sleeve. The strengthening effect of the combined steel/composite sleeve is so significant that such sleeve can be considered even for repairs of pipes damaged by cracking, which has not been allowed by standards by the present-days.

FRP beam-to-column hybrid joints subjected to monotonic and cyclic loading

abst. 2623
Virtual Room
Wednesday
September 2
15h45

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Joints in FRP structures use bolting, adhesive bonding or combination of both (hybrid). Hybrid joints results in less stress concentrations around bolts and superior fire and fatigue performance. Lack of ductility and brittle failure make the use FRPs in seismic regions uncertain. Static monotonic behaviour of bolted FRP joints is somewhat well-known. This paper provides an insight into cyclic behaviour of bolted and hybrid FRP joints. Cyclic response from five full-scale exterior FRP beam-to-column joint subassemblies is presented. First two specimens use bolted and hybrid joints with steel web and flange cleats. Next two consist of bolted and hybrid joints with flange cleats only. Last one has bolted joint with FRP web and flange cleats. Cyclic performance is assessed through hysteresis moment-rotation curves in the form of dissipated energy. Companion monotonic tests are also conducted to compare reference skeleton moment-rotation curves with cyclic hysteresis behaviour. Tests with FRP cleats showed the worst overall cyclic performance with least dissipated energy. Hybrid joints exhibited improved hysteresis response with better accumulated energy dissipation. Cyclic performance of web and flange cleated, and flange cleated joints was almost similar. In general, skeleton curves from monotonic testing showed higher moments and rotations than hysteresis curves from cyclic testing. More research is needed to assess seismic worthiness of FRP structures.

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abst. 2547
Repository

Behavior of FRP Ring-Confined CFST Columns under Axial Compression

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Concrete-filled steel tube (CFST) columns are widely used in applications, while they suffer deterioration due to various reasons. On the other hand, the concrete in CFST columns is subjected to tension at its elastic range because the elastic Poisson's ratio of concrete is smaller than that of the steel. To this end, fiber-reinforced polymer (FRP) rings are proposed to strengthen the CFST columns in the present study. By strengthening CFST columns with FRP rings, it is expected that their nominal yield strength is increased and they exhibit a monotonic ascending load-strain behavior under compression. In the present study, an experimental study on axial compressive behavior of FRP ring-confined CFST columns is carried and the effects of the FRP type (carbon FRP (CFRP), PET FRP (polyethylene terephthalate FRP)), the FRP thickness (0, 2, 3, 4 layers) and the ring clear spacing (40, 80, 120mm) on the axial compressive behavior (including failure mode, load-strain curve, hoop strain-axial strain curve and confined concrete stress-strain curve) are investigated. The strain distribution (including the axial compression strain distribution and the hoop strain distribution) along the height of specimens are presented based on the particle image velocimetry (PIV) strain measurement technique. The experimental results show that FRP rings substantially enhance the ultimate load capacity and slightly enhance the nominal yield strength of CFST columns. The ultimate axial strain of PET FRP ring-confined specimens is much better than that of CFRP ring-confined specimens due to the large ultimate tensile strain of PET FRP. The ultimate axial stress and ultimate axial strain of concrete in CFST specimens are obtained and compared with those provided by existing stress-strain models to examine their accuracy and capability.

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abst. 2423
Repository

Study on concrete-filled pultruded GFRP tube columns after freeze-thaw cycles

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This paper presents a study on the mechanical properties of concrete-filled pultruded GFRP tube (CFGT) column after freeze-thaw cycles. A total of 72 (36 circular columns and 36 square columns) CFGT columns were tested. The number of freeze-thaw cycles (0, 20, 40 and 60 times, from -17.6[U+2103] to +8[U+2103]), height, concrete compressive strength and section type were considered

as the parameter. The failure modes, ultimate capacity, initial stiffness and load-displacement curves were obtained and analyzed. The results showed that, with the number of freeze-thaw cycles increasing, the ultimate capacity of CFGT columns decreases evidently and the maximum decreased percentage of ultimate capacity of the circular and square specimen after freeze-thaw cycles are 67.84% and 70.70%. The initial stiffness of the CFGT columns reduces evidently when the number of freeze-thaw cycles increases, the maximum decreased percentage of the initial stiffness of the circular and square CFGT columns after freeze-thaw cycles are 65.57% and 73.21%. The result also indicates that when the concrete compressive strength is 30MPa, the ultimate capacity of CFGT columns is lower than that of columns with the concrete compressive strength of 20MPa and40MPa. Furthermore, the simplified formula which was based on the test data for the ultimate capacity of CFGT columns after freeze-thaw cycles was proposed.

Experimental study on compressive behavior of concrete-filled GFRP tubular stub columns after being subjected to acid corrosion

abst. 2453
Repository

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This paper presents the results of axial compression tests of concrete-filled GFRP tubular (CFGT) stub columns after being subjected to acid corrosion. Fifty-four specimens subjected to acid corrosion and nine specimens untreated with acid solutions are axially tested. The variables of the specimens are wall thickness of GFRP tube (3.5 mm, 5.0 mm, and 6.0 mm), concrete strength (C20, C30, and C40), PH value (4, 5, and 6) and immersion duration (0 days, 20 days, and 40 days). The failure modes, load-strain curves, load-displacement curves, and ultimate strength of the specimens are obtained and analyzed. Experimental results show that the CFGT stub columns after being subjected to acid corrosion are all failed with the fracturing of GFRP tube and crushing of core concrete. The immersion duration has the largest influence on the percentage decrease in ultimate strength for the acid corroded CFGT stub columns, followed by the PH value of acid solution. However, the effects of the wall thickness of GFRP tube and concrete strength on the percentage decrease in ultimate strength can be neglected. Based on the experimental results, the computational formulas are proposed to calculate the reduction coefficient and ultimate strength for the acid corroded CFGT stub columns. Additionally, the finite element models are also developed for the acid corroded CFGT stub columns by the ABAQUS software and are verified with the experimental results.

Test on pultruded concrete-filled GFRP tubular stub columns externally strengthened with CFRP sheets

abst. 2506
Repository

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This paper investigates the effect of layers of CFRP sheets (zero, one, two, three, four), concrete strength (C20, C30, C40), and column height (150 mm, 200 mm, 250 mm, and 300 mm) on the behavior of pultruded concrete-filled GFRP tubular (CFGT) stub columns. Sixty specimens were tested to investigate failure modes, the ultimate load-bearing capacity, load-strain curves, load versus displacement curves and the initial stiffness at elastic stage and ductility of the specimens. Test results indicated that, in general, the CFGT stub columns wrapped with CFRP sheets showed a better mechanical behavior than those without CFRP sheets wrapping. Furthermore, the more the layers of CFRP sheets are, the higher the ultimate strength and initial stiffness of the CFGT stub columns are. Based on the regression of the test data, the simplified formulae for ultimate strength of concrete-filled GFRP tubular stub columns externally strengthened with CFRP sheets was proposed. Accuracy of the formulae was evaluated by comparison between the calculated and experimental results.

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abst. 2507
Repository

Experimental investigation of pultruded concrete-filled GFRP tubular stub columns after elevated temperatures

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The behavior of pultruded concrete-filled GFRP tubular (CFGT) stub columns after elevated temperatures under axial compression is presented in this paper. A total of 117 specimens were tested, including 108 CFGT stub columns after elevated temperatures and 9 CFGT stub columns at ambient temperature, of which 12 CFGT stub columns were carried out load-strain tests. The main parameters involved in the test include the wall thickness of square GFRP tubes (3.5mm, 5.0mm, 6.0mm), concrete strength (C20, C30, C40), temperature (150 °C, 200 °C, 250 °C, 300 °C) and temperature duration (60 min, 90 min, 120 min). This paper presents the failure modes, ultimate load-bearing capacity, load-strain curves, load versus displacement curves, and initial stiffness at the elastic stage and ductility of the specimens. It was found that high temperature has the greatest influence on the ultimate load-bearing capacity of the columns. As the elevated temperature specimens subjected increased, the percentage decrease in load-bearing capacity had an obvious increase, the ductility became worse and the initial compressive stiffness slightly decreased. The crack resistance of the specimens improved after elevated temperature. The axial deformation versus load curves had an obvious elastic-plastic stage as the elevated temperature duration increased to 120 min. Based on the experimental result, a formula was proposed to calculate the ultimate load-bearing capacity of CFGT stub columns after elevated temperatures.

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abst. 2297
Repository

An Ultra-Lightweight CFRP Composite Beam String Structure

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In this work, a non-full-scale beam string structure (BSS) made of all-carbon fiber-reinforced polymer (CFRP) composites was designed, optimized and fabricated. Proposed CFRP BSS consisted of compression box-beams, tension strings, connecting braces and structs. In particular, PMI foam was installed inside of the box-beams to enhance their local buckling strength. ANSYS parametric design language was employed to optimize the structural components of BSS to obtain the minimum mass of the structure. Moreover, finite element analysis was conducted to evaluate the influence of the prestressed tension string, and an improved stress distribution of the compression beams was observed. Multiple thermo-curing and compression modeling processing technologies were adopted to fabricate the CFRP BSS. Additionally, a four-point bending test was conducted to investigate the flexural behavior of the proposed CFRP BSS. A good load-carrying capacity as well as an extremely light weight were achieved, indicating an excellent structural efficiency. Proposed CFRP BSS, as the first-of-type, has a great potential to be widely adopted in practical applications in the future when high strength-to-weight ratio is required in design.

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abst. 2283
Repository

Experimental Identification of the Fractional Parameter for Rubber Concrete and Fiber-Reinforced Rubber Concrete

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In all classic engineering research and in the majority of scientific papers concrete has always been considered as a purely elastic material. However, this assumption at early ages may not always describe the real behavior of the material. In fact, concrete is a viscoelastic material, especially at early ages. Fresh concrete is a viscous mixture of cement, water and aggregates in a basic composition. After setting concrete increases its elastic performance and reduces viscosity. This process continues during all the period of the concrete hardening. Therefore, concrete with aging transforms from a viscoelastic material to an elastic-like material. In order to describe this transformation, internal friction, as a ratio of the imaginary part of the complex Young's modulus to its real part, could be applied [1]. Since real part of the complex elastic modulus is related to elastic behavior of the material and the imaginary part describes its viscous properties, then internal friction or damping is an important parameter to understand the properties and behavior of the material. There exist different models to describe the viscoelastic properties of materials, among them the models involving derivatives of fractional order, the survey of which is presented in [2], wherein it is noted that such models provide a good agreement of analytical calculations with experimental results. The order of the fractional derivative, or so called Fractional Parameter, is an important material characteristic which describes the microstructural changes in the material due to different internal or external conditions. When the fractional parameter is known, fractional derivative models can be applied to predict the behavior of the material under certain conditions, as well as dynamic response of structures made of such materials. The fractional parameter for concrete was identified in [1] by using the Resonant Frequency and Damping Analyzer (RFDA) to measure internal friction. The device is based on Impulse Excitation Technique. A small impact is applied to a simply supported sample of a special shape and dimensions in order to initiate the vibrations of the specimen. The signal is received by a special microphone and is transmitted to a PC. Special software RFDA receives the signal and calculates resonant frequencies, dynamic moduli and damping. When all the data are obtained, the vector diagrams could be constructed. The fractional parameter has been measured as a tangent slope in the corresponding points of the diagrams [3]. In this paper, such an assumption is generalized for the case of polymer concretes, namely, rubber concrete and fiber-reinforced rubber concrete. It is remarkable that both of the materials are based on caoutchouc binder. These materials were invented and investigated at the Voronezh State Technical University, Russia [4,5]. Such materials have received a wide application in industrial buildings subjected to chemically aggressive environments. However, the fractional parameter of rubber concrete and fiber-reinforced rubber concrete has never been identified previously. This paper presents the results of the pioneering experimental studies for such materials. The results obtained could be utilized for the analysis of dynamic response of beams and other structural elements made of fiber-reinforced rubber concrete. Acknowledgements. This research has been supported by the Russian Foundation for Basic Research, Project No. 20-38-70143-Stability. References 1. Popov I.I., Chang T.P., Rossikhin Yu.A., Shitikova M.V. (2016) Application of impulse excitation technique to investigation of concrete damping and its changes at early ages. DEStech Trans Eng Technology Res, 339-343, DOI:10.12783/dtetr/imea2016/9362 2. Rossikhin Yu.A., Shitikova M.V. (2019) Fractional calculus models in dynamic problems of viscoelasticity. Handbook of Fractional Calculus with Applications. Vol 7 (D. Baleanu, A.M. Lopes, Eds.), pp 139-158, De Gruyter, DOI: 10.1515/9783110571905-008 3. Popov I.I., Rossikhin Yu.A., Shitikova M.V. (2020) Experimental identification of the fractional parameter for a viscoelastic model of concrete at different ages based on the impulse excitation technique. Proc 13th Int Conf on Vibration Problems, 29 Nov – 2 Dec 2017, Guwahati, India, Springer 4. Potapov Yu.B. (1998) Highly effective composites based on liquid caoutchoucs (in Russian). Proc Int Conf Actual Problems of Construction Material Science, Penza, Russia, pp 16-17 5. Potapov Yu.B. (2000) Rubber concrete: a new type of corrosion-resistant construction materials (in Russian) Stroitel'nye materialy XXI veka No 9, pp 9-10

The use of composite materials in reducing noise emissions from refrigeration compressor units

abst. 2603
Repository

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The article presents the results of research on the reduction of noise emited by high-performance compressor chillers used in commercial facilities. The operation of compressors located inside the

technical premises of large-format stores and often in the immediate vicinity of residential premises may cause acoustic discomfort as well as the permissible sound levels in buildings as well as increased levels of noise emissions to the external environment. The material in the article contains a description of the entire process of work undertaken to reduce this adverse phenomenon, i.e. 1. Before applying sound-absorbing and sound-proof insulation: results of acoustic measurements inside the store's premises, results of external environmental measurements, sound levels in a residential premises located above a commercial facility, location of the main sources of noise, analysis of obtained test results. 2. Design process: selection of absorbent and sound-absorbing materials, short description of the technical design, process of construction and assembly of the designed acoustic chamber. 3. After the partition assembly: acoustic analysis of the recorded control measurements containing the values of sound pressure levels after silencing the aggregates in all previously mentioned locations. The described solution uses K-Flex sound absorbing composite materials based on non-foamed high-density rubber and polyester fibers Two class A sound analyzers were used for sound measurements made in accordance with applicable acoustic standards: Brűel & Kjaer 2260 Investigator and Norsonic Nor 140. Acoustic tests, construction and assembly works were carried out in 2019 and 2020 at the commercial building of the "Biedronka" network in Żywiec Poland, whose owner and principal of the analysis was Jeronimo Martins Polska S.A. Company. Based on the registered data and analysis of the results, we can formulate the following conclusions: - compressor chillers can cause significant acoustic discomfort due to excessive noise emissions, - insulation and sound absorbing materials must be precisely selected for the range of sound waves emitted and sound pressure levels, - proper use of composite materials with proper construction of the acoustic barrier results in a significant reduction of sound levels inside buildings.

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abst. 2003
Repository

Efficiency of steel, polypropylene and glass fibres on flexure-shear behaviour of high-performance concrete beams

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In general, fibre reinforced concrete (FRC) contains a single type of fibre. The utilize of several fibre types in FRC in an appropriate combination and proportion can improve both the properties of concrete and the synergy of their performance. Such a fibres mixture is usually called as hybrid fibres. Good interaction between various types of fibres can surpass the action of single fibre in FRC. The fibres should be selected so as to counteract the development of cracks and ensure continuity of stress transfer in the full strain range. The first type of fibres should be shorter to bridge microcracks and control their growth. The remaining fibres types should have increased length and strength to smoothly arrest the propagation of macrocracks. In recent years, a lot of investigations have been carried out to assess the flexure-shear strength of concrete beams containing mainly steel fibres. On the other hand, there is little research on the flexure-shear strength of hybrid fibre-reinforced high-performance concrete (HPC) beams. The addition of fibres to the HPC is particularly attractive as its brittleness may be limited. Despite the increase in the HPC cost, the application of hybrid fibres can be justified to provide a structural alternative to the stirrups in reinforced concrete beams. This study is aimed at investigating the possibility of replacing conventional shear reinforcement with hybrid fibre reinforcement in high performance concrete under flexural loading. Therefore, nineteen HPC beam specimens reinforced with tensile longitudinal steel deformed rebars were constructed and tested. Glass fibres, polypropylene fibres and steel fibres were used as reinforcing discrete hybrid fibres of varying fibre volume fractions 0%, 0.5%, 0.75%, 1%, 1.25%, 1.5%, 1.75%, 2%, 2.25% and 2.5%, as well as with two different proportions 1:1:1 and 0.25:1.25:1.5. An investigation was performed on the influence of the addition of hybrid fibres on the cracking response, load-carrying capacity, and ductility of the HPC beams. The addition of fibres increased the first-cracking load, ultimate shear strength, ductility, and mitigated the crack width of the steel rebars-reinforced HPC beams. The results of this study show that it is possible to replace stirrups with hybrid fibres.

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abst. 2032
Virtual Room
Wednesday
September 2
15h30

Influence of high cycle fatigue on the bond behavior of FRCM - concrete joints

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A large number of reinforced concrete (RC) structural elements employed in existing structures and infrastructures is subjected to repeated and oscillatory actions during the service life. Constructions like viaducts and railway bridges, as an example, undergo prolonged high cycle fatigue actions due to vehicular traffic. Under these circumstances, RC structural elements experience crack propagation, resulting, over the years, in a significant decrease of their durability. Externally bonded (EB) fiber reinforced composites have proven to be an effective solution for increasing the fatigue life of structural elements because they allow for stress re-distribution from the internal rebars in the RC element to the fiber reinforcement. In this category, fiber reinforced composites comprising high strength fiber textiles embedded within a cement-based matrix, generally referred to as fiber reinforced cementitious matrix composites (FRCM), are increasingly gaining attention due to their good compatibility with substrates and relatively good behaviour at high temperature. Failure of RC elements strengthened with one layer of textile generally occurs due to debonding at the matrix-fiber interface, with relative slippage of the fibers with respect to the embedding matrix. Accordingly, one of the main parameters governing the effectiveness of the EB FRCM reinforcements is their bond behavior. Limited studies are currently available regarding the influence of high cycle fatigue on the bond behavior of FRCM-concrete joints. This study aims first at presenting a state of the art on the fatigue and post-fatigue behavior of FRCM composites. Furthermore, some preliminary results of an ongoing experimental campaign on FRCM–concrete joints subjected to high cycle fatigue loading are presented and discussed.

Analysis of Damaged RC beams strengthened with NSM FRP

abst. 2159
Repository

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Near surface mounted (NSM) technique of strengthening with FRP rods inserted in grooves on the concrete cover of damaged RC beams has been increased in recent years although the study of bond request again deeply theoretical and experimental studies. Aim of this paper is the static and dynamic behaviour of undamaged and damaged reinforced concrete (RC) beams with free-free ends. RC beams strengthened with NSM glass and carbon fiber reinforced polymers (G-CFRP) rods have been experimentally analysed. Damage of RC beam model has been obtained by cracking of concrete under bending tests. Detection of damage and monitoring of RC beams with and without strengthening has been carried out by vibration tests assuming free-free ends at different degree of damage. Envelope diagrams of Frequency Response Functions (FRFs) obtained by the dynamic experimental tests are shown and the changes of natural frequency values are correlated to the damage degree of beam elements. Finally modelling of RC beams by Finite Element Method (FEM) has been developed for the undamaged beam and for beam damaged by notches. Experimental results are below discussed and comparison between experimental results and theoretical and numerical data is shown.

Experimental study on RC beams with an FRP-strengthened web opening

abst. 2515
Repository

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In order to achieve good seismic performance of reinforced concrete (RC) frames, the strong column-weak beam design philosophy has been widely adopted in the seismic design of RC frames. However, a large number of existing RC frames designed according to old-version design codes violate the strong column-weak beam hierarchy, due to the inadequate consideration/stipulations on such hierarchy. Against the above background, a novel seismic retrofit method for RC frames where the strong column-weak beam requirement is not satisfied was proposed based on the concept of Beam-end Weakening in combination with fiber-reinforced polymer (FRP) Strengthening (referred to as BWFS method for simplicity). The beam opening (BO) technique, which involves the creation of a web opening in the beam and the shear strengthening of opening area using FRP, is one of the techniques to implement the BWFS method. The creation of a web opening in the beam aims at reducing the sum of the positive and negative flexural capacities (referred to as SFC for simplicity) of a T-section beam to that of the corresponding rectangular beam, i.e., to offset the contribution of cast-in-place floor slab to the flexural capacity of the beam. To compensate the shear loss of the beam caused by the creation of web opening, the shear strengthening is applied around the opening using FRP. The previous experimental study on RC T-section beams with a web opening of relatively large sizes showed that the SFC of the beam was much over-weakened. In the present study, six large scale T-section beams with a web opening were tested to further investigate the effectiveness of the BO technique. Out of the six beams, two had a web opening of medium size and four had a web opening of small size. The test results showed that the two beams with an un-strengthened web opening failed in shear due to the formation of diagonal cracks in the web chord, while all four beams with an FRP-strengthened web opening failed in flexure due to the formation of plastic hinges at the two ends of the web and flange chords, indicating that the adopted FRP strengthening system can effectively compensate the shear loss of the beam caused by the creation of web opening and thus ensure a ductile behaviour of the beam. Moreover, the test and analysis results showed that the BO technique was very effective in reducing the SFC of the beam, and a web opening between the medium size and small size examined in this experimental study could be capable of reducing the SFC of the T-section beam to the desired value (i.e., the SFC of the corresponding rectangular beam).

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abst. 2517
Repository

Shear strengthening of RC beams using NSM FRP method: analysis of the test results and comparison of strength models

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Fiber-reinforced polymer (FRP) composites have attractive extensive investigation as a strengthening material for existing structures. Among various strengthening methods, the shear strengthening of reinforced concrete (RC) beams using near-surface mounted (NSM) FRP method has become one of the mainstreams. Compared with the externally bonded (EB) FRP strengthening method, NSM method is featured as higher bond strength on FRP-to-concrete interface and better protection to the NSM FRP reinforcement in aggressive environments. This paper presents an analysis of the existing test results and comparison of the existing strength models. A test database of more than 160 RC beams strengthened in shear with NSM FRP was collected from publications. Based on the test database, the failure modes observed in existing tests were categorized and an analysis was carried out to clarify the influences of key parameters (including inclination angle and percentage ratio of NSM FRP, concrete compressive strength; the ratio of longitudinal and transverse steel reinforcement) on the performance of strengthened beams. Furthermore, ten existing models for predicting the strength of RC beams strengthened in shear with NSM FRP were collected and studied. Although these models were all proposed for the failure mode of FRP debonding or concrete cover separation from the side of the beam, they were based on different mechanisms. The performance of the existing strength models was investigated by comparing their predictions with the collected test results, based on which discussions were made. The present study could not only provide useful information on shear strengthening of RC beams with NSM FRP to potential readers but also offer a basis for the selection of strength model for the development of design provisions.

RC Beams with an FRP-strengthened web opening: strength model

abst. 2645
Repository

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Web openings often need to be created in existing reinforced concrete (RC) beams for the passage of utility ducts and/or pipes. Such web openings lead to significant decreases in the load-carrying capacities of the beams due to the reduced cross-sectional area and/or severing of some of the existing stirrups. Therefore, an externally bonded fiber-reinforced polymer (FRP) strengthening system is often applied around the web opening to ensure the safety of the weakened beam. A number of existing experimental and numerical studies have provided useful information on the structural behavior of RC beams with an FRP-strengthened web opening. However, it is desirable to develop a simple strength model for RC beams with an FRP-strengthened web opening, if only the strength of such beams is of concern. In the present study, a strength model for RC beams with an FRP-strengthened web opening is proposed for engineering use. Test results are compared with the predicted results using the proposed strength model to verify the accuracy of the model. A good agreement between the predicted and test results is obtained and therefore the proposed strength model is recommended for engineering use.

Preparation and Corrosion Properties of Wollastonite based-Chemically Bonded Phosphate Ceramics Coating

abst. 2571
Repository

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An inorganic anticorrosive coating, merging wollastonite into chemically bonded phosphate ceramic (CBPC) binder, was prepared to protect rebar from corrosion. The different of wollastonite based-chemically bonded phosphate ceramic (Wo-CBPC) coatings was identified by using XRD, TG and SEM/EDS techniques. The micromorphology results showed that wollastonite dissolved in the amorphous phosphate matrix, which can tailor the composition and optimize property of the coatings by introducing new species. An electrochemical performance was put forward to evaluate the corrosive behavior of the inorganic coating. The experiment results showed that the corrosion potential (Ecorr) increased and the corrosion current density (Icorr) reduced the addition of the wollastonite to a certain degree. Moreover, the resistance of the Wo-CBPC coating (Rc) values were much higher than that of CBPC when the wollastonite was added. The best anticorrosion profile of the coating was observed when the content of wollastonite was 15%. The addition of the wollastonite in CBPC coating cannot only provide excellent microstructure but protect rebar from further corrosion.

Composites in Innovative Applications (chaired by L. Solazzi)

abst. 2059
Repository

Design and Optimization of CFRP-SPCC Hybrid Laminates for Structural Applications

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Carbon Fiber Reinforced Polymers (CFRP) gain huge interest from researchers around the world due to its superior properties with strength-to-weight ratio, excellent results in static and fatigue tests, and have excellent in corrosion resistances. Several applications such as Aerospace, Structures, and Automotive reported using CFRP as main structures or combined with other material such as metal and specialized conductive polymers. In modern structures like automobiles and buildings, CFRP mixed with conventional material to create hybrid material that has beyond properties compared to CFRP. Metal-based material that used in automotive and structural applications have relatively low-tension stress compared to CFRP. In this study, Steel Plate Cold Commercial (SPCC) is used and combined with CFRP. SPCC is reportedly used in the automotive structure as outer structures. Superior mechanical properties and affordable cost are the advantages of SPCC compared to other metal that used as main structures in automotive. Combine CFRP and SPCC into hybrid material can ensure better properties and can save the cost. Moreover, this combination is a future technology that can be applied in core structures of automotive industries. The present study used CFRP-SPCC as hybrid material for automotive and structural applications. Designing material properties of CFRP-SPCC hybrid material using Classical Lamination Theory (CLT) and FEA software shows that the optimization can be obtained. The composition of the fiber angle between longitudinal and transverse is presented. Properties comparison between CFRP and SPCC also observed to obtain the best combinations. The results reported that hybrid laminate [SPCC/[0]n]S strength increased more than 100% from 1000 MPa (0.5 mm) thickness compared with 2 mm of CFRP thickness with 2000 MPa. The experimental results show good agreement with simulation results. The other trends of optimization show that the by adjusting the volume fraction of hybrid laminates, the strength can increase from below 500MPa to more than 3000MPa with a minimum changed in strain performance. The study used a total volume fraction of [[SPCC]n/[0]m]S hybrid laminate that fixed with 2.612 mm, thermal effect induced during simulation, and temperature difference is set with 105°C. In other results, the effect of temperature differences during manufacturing process is investigated. [SPCC/±45/0]S is used in this study as a representative specimen with temperature difference are varying from 0 to 300°C. The results show that laminate strength does not change so much, even though 0°-layer of CFRP facing residual compressive stress during fabrication process, the strength is not change drastically. The analysis based on real applications related to operational temperature that used present material combinations also evaluated. The set of temperature is varying from as hot as 45°C to as cold as -45°C. The results show that the range of maximum strain of laminate from 45°C to -45°C can up to 0.1% of strain. The further analysis show that the highest differences occurred at [SPCC/0]S hybrid laminate compared with other combinations. Additionally, comparison is based on the room temperature (25°C). Further analysis with comparison regarding angle effect of hybrid laminates with residual compressive stress and curing temperature also evaluated. The waviness trend shows higher when the temperature is set higher, and vice versa. Moreover, the analysis based on raw material cost also included where the optimization depends on the budget and based on the applications that researcher and designer decided.

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abst. 2137
Repository

Excavator lightweight by using composite material

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The present research concerns the lightening of an excavator using composite materials and aluminum alloy instead of the classic constructional steel. This operation took place by first evaluating the load conditions to which the machine is subjected. They depend on the excavator's work area / diagram. In particular, on the position of the bucket and the load amount present in the bucket itself. In addition to these loading conditions, a further action was assumed i.e. the excavator rotation with the bucket moving transversely, for example for moving a marble block. These actions were verified, through specific experimental tests carried out in the field by the implementation a series of accelerometers placed on the excavator. This activity has allowed to estimate the dynamic effects induced by the load movement. As known, these effects increase the actions (forces and moments) which act on the machine. The magnitude evaluation of these actions made it possible to carry out a first check of the excavator in its original configuration in terms of both geometry and material. A series of experimental surveys are made for building the correct machine geometry, subsequently the machine solid model was built. It was assumed that the machine was built with a classic construction steel. By finite element method, it was evaluate the mechanical behaviour (stresses and strains) of the machine. The results obtained in terms of safety coefficient, maximum displacements, stiffness, etc., have been taken as parameters for the development of the new geometries by adopting different materials. The materials chosen were aluminium alloy (Al 6063 UNI EN 573-3) and composite material (carbon fiber and epoxidic resin). Regarding the geometry of the arms, by adopting aluminum instead of the classic construction steel, the arms section remained rectangular. While adopting the composite material, the sections were modified to make the solution itself feasible (assuming the filament winding technique for the construction), the arms sections were changed from a rectangular to an elliptical section. For fixing, the arms and the relative actuators (hydraulic cylinders specific details made of aluminium alloy) were adopted. In the first step, the structural optimization in weight was performed for arms, hydraulic cylinders, and pins; these components were designed considering steel, aluminium and composite materials. Indicatively, for these components, the weight for steel solution is near 6000 kg, for aluminium alloy is about 3300 kg, while adopting composite material, the weight is about 2000 kg. The next phase regards the excavator chassis design. In this case, aluminum alloy was adopted instead of steel. The composite material wasn't assumed because the surface of this component is exposed to impacts such as the projection of stones that would have increased the danger of failure of the frame. The successive step regards the counterweight, present on the back of the excavator's cab, in order to balance the overturning moment generated by the load moved, by the weight of the arms, hydraulic cylinders and pins with the moment stabilized. The numerical results, carried out on the excavator made with composite materials (both the arms, the hydraulic cylinders and the pins) and the chassis in aluminium alloy, show the whole weight about 42.6 t with the comparable mechanical behaviour with the machine made of steel material (safety coefficients, displacements, etc.). The weight in the original configuration is about 57.8 t. The reduction is near 27%. The lightening of the overall system of the arms, by adopting composite materials, allows both to increase the capacity of the bucket and to reduce the force generated by the hydraulic cylinders to move both the load and the arms. The research is still in progress in order to study the whole increase performance for excavator made of composite material.

Influence on the stresses values in hydraulic cylinder made of composite material due to the variability of geometrical and materials properties

abst. 2514
Repository

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Axial-symmetric components find applications in various structural and non-structural areas. Some of these are the pressure vessels (in general they are subject to internal pressure), the pipes for the transport of fluids which can also be subject to external pressure if placed on the bottom of the sea, for example. The aircraft fuselages are subjected to a pressure variation between the inside and the outside, that can lead to the failure of the components. This load condition occurs also for submarine structures whose greatest danger, due to external pressure, is the instability phenomenon. With a view to a continuous lightening of the structures, they are designed by adopting increasingly performing materials, or rather materials whose relationship between the fundamental characteristics for the application is more positive. An example is the ratio between the breaking load of the material and its density. Hence

the greater will be this value and the greater will be the reduction in weight of the component with respect to the classical solution made using conventional materials such as steel. In this perspective, composite materials are among the best performing materials. The axial-symmetric components design process can be performed by adopting two different theories. The first one considers the component as a small thickness (Thin). In this case the circumferential stress value does not changes along the depth of the component itself. The second one considers the component as a high thickness (Thick). In this case, unlike the first theory, the stress value changes in the depth of the component and its variation increase with the ratio between R (internal radius of the pressure vessel) and its thickness. The two theories lead to the determination of the maximum (circumferential) or equivalent stress according to the strength theory assumed (maximum shear stress or maximum value of the octahedral stress), whose expression includes the obvious term of pressure, diameter and thickness of the component itself. The aim of this research is to study the variation of the maximum stresses and therefore the safety coefficient, in a hydraulic cylinder subjected to high internal pressures. For the development of this research, the two theories described above were adopted and elaborated for the applications to a hydraulic cylinder made as a single body in which the internal layer is a thin aluminium tube while the external component is made of composite material. In this case, the maximum stresses formula depends on numerous variables. These variables are geometrical and correlated to the rigidity of the materials. In this research it was assumed six variables. The adoption of a composite component made of a multilayer component (a cylindrical aluminium thin tube and a composite material coating), provides that the analytical formulation of the maximum or equivalent stress, according to a specific theory, considers a series of variables like internal and external aluminium tube diameter, the external composite tube diameter and Young's modulus both for aluminium and for the composite material. The analytical formulation, in order to determine the variation of the maximum or equivalent stresses, in relation to the variation of the values of the variables that define the stress function, takes place through the use of partial derivatives. They have been determined analytically and implemented in the Mathcad calculation program software for their solution. The procedure was carried out considering the pressure vessel, in our case hydraulic cylinder, both the one made entirely of steel (adopting the two theories both small and thick thickness) and the solution in multilayer aluminium and composite cylinders. The standard deviation of each variables was assumed from the normal and usual technological operations carried out for the construction of the component, such as for example the tolerance on the internal and external diameter of the component. The results show that, by adopting the two theories for axial-axisymmetric problems (small and high thickness), the maximum and/or equivalent stresses standard deviation is similar. By adopting a multilayer cylinder component, in which the external one is made of composite material, the standard deviation of the maximum stress is considerably higher. This result has several implications. The most important is that, if we want to make a component by adopting the same reliability value as the component made of steel, the safety factor assessed in a deterministic way must be significantly higher since by adopting the composite material, the variability in the stress values is considerably higher.

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abst. 2156
Virtual Room
Thursday
September 3
12h15

Carbon Fiber-Reinforced Textiles Enhanced with Carbon Nanotubes

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The present work investigates the behavior of fiber-reinforced composites where during the production process the carbon fiber is enhanced with Carbon NanoTubes (CNTs). The main raw materials derive from virgin (T200 and T630) and recycled (T300) carbon fibers which improves the Life-Cycle Assessment (LCA) of the whole production process. The mechanical behavior of composite materials depends on several factors, the most important of which is the interatomic bond of the constitutive material and lack of defects in the crystal structure. CNTs belongs to the nanoscale where interatomic bonds are relevant. These bonds are able to generate the highest forces known in nature, therefore CNTs have a very high mechanical strength. Theoretically speaking, a single fiber made of CNTs might have an elastic modulus of 4 TPa with a traction strength of 220 GPa (100 more than steel). The

present raw material has a cost of 9EUR/m2 which is more than 3 times cheaper (32EUR/m2) than the virgin product. The technical specifications of the prepreg textile with CNTs, employed in this study, are better than traditional materials with a smaller cost. Carbon Dream SpA did not only produce two new textiles prepreg/cnt but also demonstrated to be able to produce any kind of prepreg textile with CNTs. The others prepreg/cnt available on the market have a very limited application in the industry. On the contrary, the present innovative production process is able to create a very large number of textiles with a variable quantity of epoxy. This technology allows to apply CNTs to the 97% of composite products. The laboratory testing presented on T200, T630 and T300 recycled show the increment in the mechanical properties of the composites when the CNT are used to improve the bonding properties of the composites. Testing refer to bending and peeling testing which will be validated through numerical modelling via standard finite element implementations. Acknowledgements: Regione Toscana Bandi RSI - POR FESR 2014-2020. Codice Domanda: CUPST:3389.30072014.068000248.

Additive manufacturing of temperature sensitive actuators manufactured from NiTi shape memory wires embedded in polymer structures

abst. 2109
Virtual Room
Thursday
September 3
12h00

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Additive manufacturing allows the integration of shape memory wires into polymer matrices. Actuators produced in this way offer a wide range of shapes and wire integration appropriate to external loads is realisable. Prestrained NiTi wires and a polymer matrix are co-deposited simultaneously using an ARBURG plastic freeformer. Actuation of the shape memory alloy is possible using conductive heating. Amorphous thermoplastics with high glass transformation temperature and high tensile strain at yield are preferred matrix materials. Material selection based on Ashby maps implied that ABS, PC and PA are the most promising matrix materials processible with the ARBURG freeformer. Mechanical characterisation revealed the best matrix material for this purpose. Adhesion between NiTi wire and the matrix material are investigated and mechanical- and thermal properties of the composite are analysed. Based on the results an analytical material model of the composite will be developed which maps the mechanical properties as a function of temperature.

A FEASIBILITY STUDY ON ADDITIVE MANUFACTURED HYBRID METAL/COMPOSITE SHOCK ABSORBER PANELS

abst. 2509
Repository

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In recent years, metallic lattice structures produced by means of the Selective Laser Melting (SLM) process have attracted a growing interest in the scientific community for their valuable stiffness/weight ratio and, consequently, wide range of possible applications. Indeed, additive manufacturing techniques are inherently capable to produce structural configuration with any geometric complexity fulfilling any topological optimization requirement, if compared to the common subtractive production techniques.

There are many application fields for lattice structures, such as recoverable lattices, plate lattices or hierarchical lattice structures for applications ranging from heat exchangers, medical implants or acoustic dampers. In many applications, metal lightweight lattice structures are joined with carbon fibers reinforced polymers in order to improve the overall mechanical performances and decrease the weight of structural components. The research activity presented here is focused on the investigation of the feasibility and the effectiveness of hybrid metal/composite lattice structures shock absorbers manufactured by additive techniques. Firstly, an extensive modelling and analysis activity has been carried out focused on the assessment of different configurations of Unit Cells within the commercial FEM code Abaqus, by adopting a simplified Fem model with beam and shell elements formulation. The Unit Cells, has been designed as a solid base model, represented by a metallic lattice Repetitive Volume Element and composite skins. Different configurations of metallic lattice structures with and without composite skins have been investigated in order to evaluate their energy absorbing capability under a 6J impact analysis. Once selected the best configuration in terms of energy absorption capability, a refined numerical model with 3D elements formulation and by discretising the composite at ply level has been defined. The mechanical behaviour under impact and the energy absorbing capability have been assessed in order to evaluate the applicability of this hybrid composite panels as multipurpose shock absorber.

Delamination and fracture

The effect of staggered matrix crack induced delamination growth on the thermomechanical properties of cross-ply laminates

abst. 2327
Repository

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Matrix cracking in composite laminates is a common phenomenon that might occur during the manufacturing process or due to loading. The presence of matrix cracking inevitably results in the formation of delamination which is called matrix crack induced delamination (MCID). While induced delamination is a prevailing damage mechanism in laminated composite materials, it is also a critical aspect of damage that needs careful considerations. In the most performed researches induced delamination due to symmetric matrix cracking is studied; however, in this study, cross-ply laminates with the stacking sequence of [90n/0m/90]s including matrix cracking with a staggered pattern is investigated analytically for the first time. It should be noted that in the present study, the effects of induced delamination formation on the thermomechanical properties and consequent strain energy in cross-ply composite laminates are discussed and compared with finite element analysis (FEA). To obtain the analytical model for the aforementioned laminate, the generalized plane strain assumption is considered along with the classical lamination theory in different zones of pristine and damaged laminate. In this regard, a new stiffness matrix for the damaged laminate as well as strain energy release rate due to delamination formation are acquired using the equilibrium equations and the crack closure technique. Then after, the effect of different delamination length on the stiffness of the laminate and energy release rate (ERR) is investigated. The obtained results are verified with FEA which confirms the accuracy of the proposed analytical method.

Stiffness degradation due to matrix cracking and induced delamination evolution in laminated composite subjected to bending loads

abst. 2342
Repository

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Matrix cracking and induced delamination are two of the most important failure modes, which can be formed due to bending load in composite laminates with different layups. Physically, at the primary stages of loading, matrix cracking is formed in the transverse direction of loading in different plies. Then the stress concentration at the tips of matrix cracking leads to the initiation of delamination through the interface of composite laminate. In this research, the variation of flexural properties of symmetrical laminates in presence of matrix cracking and delamination is investigated using an analytical approach based on a crack density based model. To this purpose, an analytical approach based on the linear elasticity theory is proposed and applied to estimate flexural material properties and the critical load of damage initiation and propagation. Then, employing developed relationships, strain energy release rate (SERR) of composite laminate with matrix cracking and induced delamination is calculated. Finally, to validate the performance of the model, the variation of crack density and delamination length as a function of applied load in cross ply composite laminates subjected to 4 point bending test is calculated and compared with available experimental results. Moreover, a finite element model is used to verify the accuracy of the developed model on predicting the flexural stiffness reduction. To this purpose, the stiffness reduction due to matrix cracking and induced delamination as a function of crack density extracted from FE model for Carbon/Epoxy composite laminate with different layups is compared with results of the developed model. Favorable agreement between obtained results of the developed model with numerical model and available experimental results shows that the presented model is capable of predicting material properties of composite laminates in the presence of matrix cracking and induced delamination.

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abst. 2011
Repository

Interlaminar toughness and electrical conductivities of CFRPs interleaved with MWCNT- and graphene nanoplatelet-doped thermoplastic veils

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Thermoplastic veils doped with MWCNTs and graphene nanoplatelets (GNPs) were used as interleaves of a carbon fibre/epoxy composite, aiming to study its effects on the interlaminar toughness and electrical conductivities. It was found that interlaying original thermoplastic veils significantly increased the Mode-I fracture energy (GIC) and Mode-II fracture energy (GIIC) of the CFRPs. However, it also caused a significant drop in the electrical conductivities, that increased the risk of damage against lightning strikes, and hence limited the applications in airplanes and wind turbine blades. Fortunately, the addition of a small amount of MWCNTs on the thermoplastic veils considerably increased the electrical conductivities, especially in the through-thickness direction. It was also found that the adhesion between the thermoplastic fibre was increased for doping MWCNTs on the veils. This further improved the fracture toughness of the laminates at a relatively low content of MWCNTs. In contrast, the incorporation of GNPs on the veils decreased the PPS fibre/epoxy adhesion, resulting in detrimental effects on the fracture performance.

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abst. 2215
Repository

Mechanical Properties of 3D Woven Composites With Large Repeat Unit Cells

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This paper presents in-plane shear, open-hole and mode 1 fracture toughness data for carbon fibre 3D woven angle interlock carbon fibre composites. The in-plane shear moduli of 3D woven angle interlock composites was measured using 4 different test methods. In previous work the in-plane shear modulus (Gxy) was determined via the plate twist test and the results compared with the Gxy determined via the V-notched beam Iosipescu (ASTM D5379) and V-notched rail shear (ASTM D7078) methods. In this paper the results are compared with measurements taken by tensile test of a $\pm$ 45 3D woven composite (ASTM D3518). Furthermore, open-hole tension tests and mode 1 fracture toughness tests were conducted on the 3D woven composite. The results indicate that both the plate twist and tensile test of a $\pm$ 45 3D woven composite methods are suitable for the measurement of in-plane shear modulus for 3D weave architectures with large repeat unit cells and that the measurement is more representative of the global material response. A weave style was developed to manufacture Double Cantilever Beam (DCB) specimens for testing and a significant increase in the Mode 1 fracture toughness Propagation, GIC was observed. Impact and through thickness tension tests also showed improved properties compared to a 2D laminate.

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abst. 2276
Repository

On the Damage Tolerance of C/C-Sic Composite Hot Structures

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Thanks to their excellent structural performance at high temperature, the Ceramic [U+2010] Matrix Composites (CMCs) are good candidates for light [U+2010] weight structures in high temperature applications, such as applications to re-entry vehicles. Beyond the well-known high temperature resistance, the CMCs do also show good damage tolerance properties, making them suitable for applications to large primary structures. Unfortunately, the production at the industrial level is currently at an embryonic stage due to the criticalities in the involved manufacturing processes which do not allow to produce defects free components. During the design phase, the presence of these manufacturing related defects are taken into account by introducing knock-down factors reducing the mechanical properties. However, this approach can be highly conservative and can strongly limit the intrinsic advantages of using such materials. Moreover, even if suitable non-destructive techniques (such as tomography) can be adopted to identify the manufacturing defects, still uncertainties exist about these defects evolution and, above all, about their influence on the structural performance (in term of stiffness and strength) of real components. The adoption of suitable material and fracture mechanics numerical models could help to correctly predict the stiffness and strength characteristics of CMCs at coupon and subcomponent level. Which such advanced numerical models the manufacturing defects and their influence on the structural performance could be taken into account leading to a strong reduction of the currently adopted knock-down factors. The present work aims to investigate the damage tolerance of a C/C-SiC hot structure acting as aerodynamic control surface of a reusable re-entry vehicle. These vehicles are exposed to severe environmental conditions when re-entering Earth atmosphere. Indeed, the highest loaded areas such as nose, leading edges and control surfaces can experience temperatures up to 1650°C. Since the structural integrity of a re-entry vehicle needs to be guaranteed during all the mission phases and for multiple missions, a damage tolerant reliable design is required. Starting from the validation at coupon level of the material and fracture mechanics numerical models, by means of experimental data available in literature, a full parametric Finite Element model has been developed. The proposed parametric model is able to consider any delamination in any planar and thickness location all along the body flap domain. In order to reduce the computational costs, the entire body flap was modelled by means of layered shell elements, while layered solid elements have been used in the delaminated area. Hence, to connect the global coarse model and the local refined model, a global-local approach has been implemented. Finally, a sensitivity analysis has been performed finalised to assess the influence of location (in plane and trough the thickness) and dimension (radius) of a circular delamination on the damage tolerance of the investigated structure.

Towards rain erosion delamination damage prediction in Wind Turbine Blades: Interface modelling approach

abst. 2440
Virtual Room
Thursday
September 3
11h30

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Wind Turbine Blade design trends to improve efficiency based on increasing the rotor diameters to capture more energy. When considering the impact force of rain droplets on the blade frontward facing leading edge, the tip speed (scaled accordingly with the rotor diameter) is a key contributor to erosion damage on the top coated surface which is a maintenance cost concern predominantly significant on offshore locations. The leading edge protection system (LEP) of the wind turbine blades are identified as an area where a solution may be obtained through its polymer-based multilayer material optimization in order to protect the underlying structural composite laminate. The coating layers adhesion and erosion are affected by the shock wave caused by the collapsing water droplet on impact. The stress waves are reflected and transmitted to the laminate substrate through the thickness of the LEP system. It is necessary to optimize the contact adhesion resistance of the multi-layered system interface boundaries in order to avoid failure by delamination [1]. The investigation has been directed into the interphase adhesion modelling based on its failure energy characterization, which was assessed by pull-off testing and peeling-adhesion testing. The work considers distinctive coating configurations as study cases that ponders the inclusion of a primer layer and a filler layer on a LEP configuration system. A numerical model is used to relate delamination lifetime prediction and to identify suitable coating and composite

substrate combinations. A proper definition of the Cohesive Zone Modelling (CZM) allowed one to account for the interface adhesion and hence to estimate delamination caused by the interface stress-strain behavior. In the research work, an experimental investigation into various coating application cases have been undertaken and related with the rain erosion durability factors by means of rain erosion accelerated testing technique (RET) used as the experimental key metric in an effort to assess the response of the material with the numerical procedure.

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abst. 2483
Repository

ANALYSIS OF SMART POLYMER COMPOSITE DELAMINATION USING GRATING OPTIC FIBER SENSORS.

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Polymer composite materials have numerous applications in aircraft construction, in industry, in manufacturing parts of the mechanical structures and parts such as pipes used in chemistry, in agriculture and in medical devices. In all these kinds of applications the failure caused by delamination is an important issue to be considered for an improved design of reliable mechanical parts made of polymer composite materials. The main purpose of the paper consists of presenting simulation results obtained with a finite element method (FEM) analysis of smart composite materials based on a grating optic fiber sensor embedded in the polymer matrix of such composite, composite which are used for construction of mechanical structures and parts. The composite material is transformed into a smart one by using the grating optic fiber sensor signal as input into a feedback loop of an automation system. There were analyzed the short period diffraction grating (Fiber Bragg Grating - FBG) and the long period grating (LPG) versions of the optic fiber sensor. Both grating versions are induced into a single mode (SM) optic fiber by various methods which are briefly characterized. The composite de-lamination process is analyzed using the cohesive zone model (CZM). CZM implies the traction-separation law that describes the softening in the cohesive zone near the de-lamination point, zone. In the performed analysis a bi-linear traction-separation law in a laminated composite using the layered shell interface (LSI) was used for description of mixed-mode softening and de-lamination propagation. The simulations were performed considering a composite material plate of 1.5 mm thickness with PVC or PDMS matrix. The grating optic fiber sensor is analyzed as embedded in the polymer matrix being used as stress detector.

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abst. 2449
Repository

A Multi Phase Field-Cohesive Zone Model(MPF-CZ) for fiber reinforced composites relying on Puck failure criteria

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In this investigation, a novel numerical framework endowing a multi-Phase Field model, relying on the phenomenological Puck failure criteria, in combination with Cohesive Zone (CZ) formulation is

developed for the comprehensive understanding of fracture in long fibre reinforced composites (LFRC) involving interfaces and their surrogates. With regard to intra-laminar cracking, in a comprehensive analysis, a mathematical model encompassing two independent non-local phase-fields in continuum anisotropic media are used in order to distinguish between the different physical failure mechanism that arises in the LFRC, namely fibre failure and inter-fibre failure (matrix dominated failure). Moreover, matrix dominated deformation states are incorporated with plastic effects via an invariant based plasticity model. From the formulation standpoint, an additive decomposition scheme is recalled to account for the bulk energies stemming from the fiber-failure and inter-fiber failure and the dissipated energies created due to debonding along prescribed interfaces at laminate level interface. Therefore, the total internal energy functional is modelled as an amalgamation of (i) total elastic energy constituting from fiber and inter-fibers incorporating Puck failure criteria and plasticity for inter-fiber failure, (ii) Surface energy (Crack energy) stemming from fiber and inter-fiber failure, (iii) the cohesive interface energy obeying linear Traction-Separation law. The emphasis is further made on the evaluation of the corresponding thermodynamic consistency, and the variational formalism leading to the non-linear partially coupled equations equipped with different driving forces. These coupled equations are numerically solved using finite element methods emphasizing on the implementation by utilizing the user-defined capability UMAT and UEL of ABAQUS. Specifically, a three-layer structure corresponding to displacement and two-phase fields, and an interface layer employing traction separation law is defined. Here, each layer shares the same nodes but has different stiffness and degree of freedoms. A user defined UMAT is written for the solution of equilibrium equations for displacement field, UEL is defined for the solution of the phase fields, and in-build CZM is exploited along the interface. Several representative examples are examined to assess the practicability and reliability of the proposed modeling framework. Special attention is focused on the application of the model to delamination migration in LFRC structures containing cross-ply laminate disposals. Corresponding results are contrasted against experimental results exhibiting a very satisfactory agreement.

Is it possible to effectively reinforce high performance, self-compacting, fibre reinforced concrete with FRP laminates using cement matrix?

abst. 2339
Repository

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Fibre reinforced concrete (FRC) belongs to the group of special concretes which are characterized, apart from strength, by special properties . Self-compacting concrete (SCC) has an increasingly important role in the design of new structural components due to the rheological parameters of fresh concrete mixture, which enables formwork with complicated geometry to be hermetically filled . It is widely known that varied types of concrete reinforced by different Fibre Reinforced Polymer (FRP) materials have been studied many times due to their important applications, such as strengthening purposes or the construction of hybrid elements. When understanding the influence of technological parameters on the effectiveness of CFRP reinforcement, the load capacity of self-compacting high-performance fibre-reinforced concrete (SCHPFRC) can be seen to be critical for its performance. In this research, a few factors that have an influence on the stress-strain characteristic of concrete confined by FRP laminates were examined. The number of CFRP layers and the manner of surface preparation were considered as significant parameters that have a high impact on the behavior of concrete. In the article, attention was focused on the parameters that have an influence on the cooperation of carbon fibres laminates with the concrete surface when cement matrix is used. This paper reports on the analysis of confinement effects that are generated by FRP wraps in concrete cylinders. The obtained results show that the use of cement matrix in FRP composites in the case of SCHPFRC has no influence on the strength of concrete specimens.

Deformation and failure mechanism of 3D printed hybrid continuous fiber reinforced composites

abst. 2228
Repository

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Abstract: The use of continuous fiber as reinforcement is well known to improve the mechanical performance of thermoplastic composites. However, it is difficult to optimize the energy absorption of continuous fiber reinforced composite components, since the inherent conflict between strength and ductility. For this purpose, this study focused on the designed and characterization of continuous fibers reinforced polyamide (PA) - based composites with synergistic enhancement of the strength and ductility. Continuous carbon and Kevlar fibers were used as reinforcements for production of non-hybrid and hybrid composites. Thermogravimetric analysis and quasi-static indentation (QSI) test were conducted to evaluate the thermal and mechanical properties of the continuous fiber reinforced PA composites. The effects of stacking sequence and fiber content on the mechanical properties of 3D printed composites were also analyzed. The results showed that the additions of the continuous carbon and Kevlar fibers with a certain designed improved the toughness (strength and ductility) of the composite, which led to an enhancement of the energy absorption properties. The results also indicated that deformation and failure mechanisms of hybrid continuous fiber reinforced composites highly depended on the fiber stacking sequence and fiber content. Keywords: 3D printing; continuous carbon fiber; continuous Kevlar fiber; stacking sequence; fiber content; quasi-static indentation test

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abst. 2145
Virtual Room
Thursday
September 3
11h00

An iterative semi-analytical method to study the mode I bridging-traction law of multidirectional composite laminates

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Large scale fiber bridging in multidirectional laminates is one of the most common toughing mechanisms, resulting in a significant resistant curve on fracture toughness. To account for the effect of the fiber bridging in delamination simulation, a physically analytical method is presented to express the mode I energy release rate with the applied load and bridging-tractions, a numerical iterative procedure

is adopted to determine the parameters need in bridging-traction law, the results show that the maximum bridging stress and the form of the bridging-tractions are depend on the interface angle, but the maximum crack opening displacement at the end of the bridging zone is independent on the interface angle. The identified bridging-traction law is integrated in a cohesive zone model to simulate the delamination of multidirectional double cantilever beam specimens, and the numerical results corresponds well with the experimental results, indicating the accuracy and applicability of the proposed method. The advantages of the proposed method are the less parameters required to be experimentally measured and the simplicity to implemented in finite element analysis.

Assessment of failure mechanisms of composite laminates with impact damage delamination and repaired with bolts

abst. 2151
Repository

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Low-velocity impacts usually induce extended damage in terms of delamination within composite laminates and cause a significant reduction of the compressive strength. Both experimental and numerical studies are carried out in this paper to investigate the interactive deformation and failure mechanisms including local bucking/delamination propagation and global bucking of composite laminates with delamination, as well as the effectiveness of repair solution with field bolts. Typical compression after impact (CAI) tests are used to determine the compressive strength of the composite laminates with either artificial delamination or real low-velocity impact damage delamination. Numerical models with cohesive elements in the delamination area is developed to simulate the CAI test to identify the failure mechanisms. The experimental and numerical results are in good agreement and it is revealed that the degradation of the load capacity in terms of compressive strength of composite structures with delamination and impact damage is mainly attributed the combined local buckling/delamination propagation effects. Consequently, the field-bolt repair can effectively restore CAI strength of composite laminates with delamination and impact damage by primarily hindering the local buckling (out-of-plane separation of sub-laminate) and then preventing the propagation of the delamination

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Correlation analysis of statistical void-related characteristics and fatigue Mode I interlaminar fracture toughness of CFRP composites

abst. 2214
Virtual Room
Thursday
September 3
11h45

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This study is pointed to correlation analysis of void-related characteristics and fatigue Mode I fracture toughness of carbon fiber reinforced polymer (CFRP) composites. The unidirectional carbon/epoxy specimens were manufactured by vacuum infusion with the averaged void volume fractions 0.5, 2.5 and 5%. The void volume fractions were characterized utilizing laser-ultrasonic imaging, scanning electron microscopy and chemical etching. The statistical distributions of shapes, orientations, sizes and accumulations of voids were calculated by processing of micro-CT data extracted at vicinity of the initial crack tip. Experimental plots of fatigue Mode I interlaminar fracture toughness were obtained according to ASTM D6115. As a result, the correlations between statistical void-related characteristics and Mode I interlaminar fracture toughness were obtained for static and fatigue regimes.

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abst. 2074
Virtual Room
Thursday
September 3
11h15

Comparison of delamination onset and propagation in curved composite laminates with different lay-ups

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In curved composite laminates, the importance of a three-dimensional stress state cannot be neglected to realistically predict laminate strength. In particular, thick L-shaped laminates subject to bending fail typically by delamination induced by high interlaminar tensile stress, which arises in the curved zones [1, 2]. However, considering multi-directional lay-ups, in-plane stress components may lead to intralaminar damages, which can have different consequences on the failure of the composite laminate. In the results presented in [3], matrix cracking was induced on 90 degree oriented plies on the tensed side, and this promoted delamination between plies close to the lower surface of curved specimens, with remarkable influence on the qualitative and quantitative response. In this paper, tests on L-shaped thick specimens made of AS4/8552 are presented, considering both unidirectional and cross-ply lay-ups. Failure modes and loads are compared and the stress states are analyzed by using detailed finite element models, which take into account the geometrical non-linearity related to deflections and are used also to estimate approximately the distortion and the state of stress induced by the cooling phase of the manufacturing process. The test results and the analysis of unidirectional curved laminates provide an estimation of the nominal interlaminar strength of the material, which is confirmed by other results published in the literature for a material with the same resin system [4]. A comparison of failure loads and failure modes suggests that intralaminar damage phenomena may play a fundamental role in the failure of cross-ply laminates. Moreover, stress analyses indicate that failures occurred at interlaminar tensile stress levels which were lower than those leading to the failure of unidirectional specimens. The estimation of in-plane stress in 90 degree oriented plies provides not negligible values in the zones of delamination onset, in particular, if thermal residual stress states are considered. Overall, the results provide a clear indication that, for materials with high interlaminar tensile strength, predictions considering only delamination and interlaminar tensile strength may overestimate the strength of curved composite laminates. References: [1] Sun CT, Kelly SR, Failure in composite angle structures part I: initial failure, J Reinf Plast Compos, 1998;7:220-32; [2] Wimmer G, Kitzmuller W, Pinter G, et al., Computational and experimental investigation of delamination in L-shaped laminated composite components, Eng Fract Mech, 2009;76:2810-20; [3] Dongfeng Cao, Haixiao Hu, Qingfeng Duan, Peihao Song, Shuxin Li, Experimental and three-dimensional numerical investigation of matrix cracking and delamination interaction with edge effect of curved composite laminates, J Compos Struct, 2019;225; [4] Makeev A, Seon G, Nikishkov Y, Lee E, Methods for assessment of interlaminar tensile strength of composite materials, J Compos Mat, 2014;49:783-94

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abst. 2671
Repository

Comparison of some higher-order models for doubly-curved delaminated composite shells

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The modelling of delaminated doubly-curved composite shells is carried out in this work using the first-, second- and third-order theories. In the first step the displacement field is deduced based on the system of exact kinematic conditions and by introducing the displacement multiplicator matrices. Using the generalized displacement field and the principle of virtual work the governing partial differential equations of the shells are derived. The delaminated and undelaminated regions are formulated separately. The system of equations are reduced to ordinary differential equations by assuming simply

supported constraints for two opposite edges of the shells. This so-called Lévy-type solution makes it possible to provide an analytical solution for the delaminated composite shells. An important aspect of the problem considered is that the shear moduli of the layers are close to each other, thus shear strain continuity is imposed. The analytical model is applied to four different scenarios depending upon the thicknesswise position of the delamnination. The four different cases are solved by using the developed model and the state space approach providing solution for the mechanical fields, like displacement, strain and stress. Besides, to characterize the fracture mechanical behavior of the shells, the J-integral is calculated too along the delamination front. The J-integral is also decomposed into mode-II and mode-III components, thus the mode separation is relatively easy in these particular cases. The shells are also modeled in ANSYS using 3D SOLID type finite elements. Apart from the usual mechanical fields, the virtual crack closure technique is applied to determine the energy release rate components. The calculations led to the following results. The analytical models show very good agreement with the 3D finite element solution. Even the J-integral is very accurately captured by the shell models. Based on the work performed the second- and third-order models seem to be promising candidates to carry out further developments.

Crack twisting as a means to increase interlaminar fracture toughness

abst. 2630
Repository

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Layered polymer composites such as carbon fiber reinforced polymer composites offer excellent strength and stiffness-to-weight ratio. Most of the strength and stiffness of the composite is attributed to the reinforcing fibers while the matrix that binds the fibers together is usually weak, making delamination at the interlaminar region one of the most common modes of failure in layered composites. Here, we build upon our previously introduced fabrication method that utilizes filament extrusion 3D printers to precisely deposit polymer patterns. These polymer patterns act as barriers against crack propagation and steer them around the reinforcement to form a wavelike crack path, thereby improving the effective fracture toughness. In this paper, we perform an in-depth analysis of the underlying mechanics contributing to the increased fracture toughness. We relate this increase in fracture toughness to crack tilting and crack twisting around the reinforcing polymer using crack deflection theory (Faber and Evans, 1983). In a previous study, we have shown an increase in G_IIc up to 76% purely due to crack tilting. Faber and Evans (1983), however, showed that more energy is required for twisting a crack around an inclusion than for tilting around it. Basing upon this, new reinforcement patterns that twist a planar crack around interlaminar reinforcements are developed and tested in mode-I (double cantilever beam – DCB) and mode-II (end notch flexure – ENF). The tested DCB and ENF samples are then analyzed using a combination of optical and scanning electron microscopy as well as micro-CT scanning to obtain the crack angle deviation from a planar crack. Further, a parametric study to optimize the interlaminar reinforcement pattern for maximizing the effective fracture toughness will be performed using an experimentally validated finite element framework.

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abst. 2572
Repository

Numerical stochastic study of damaged composite materials in humid environment

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The present work is devoted to the durability of composite materials used in MRE structures submitted to harsh environments. Many recent works have indeed shown that organic matrices employed to produce composite materials are hydrophilic. It is thus of first importance to study the moisture diffusion process within these materials since it leads to a significant drop of the mechanical properties and to relevant internal mechanical states coming from the hygroscopic swelling of the hydrophilic matrix. This work aims at studying the impact of hygroscopic aging on crack propagation submitted to uncertainties in composite materials. Indeed, water diffusion in composites has already been widely studied by many international research teams which tend to say that its impact is harmful for the material. However, even if experimental results exist, we do not find efficient numerical methods associated to relevant models which allow predicting the behavior of the structure. In this work, we propose an extended finite element method (X-FEM) formulation for the hygro-mechanical problem involving existing crack to study its propagation when moisture diffusion occurs. Based on an implicit representation of the geometry (the crack for instance) with the level-sets technique and on enrichment approximation strategies based on prior physical knowledge, this numerical approach allows using arbitrary finite element meshes and thus avoids remeshings during the computation. Moreover, the complex physic of the problem is submitted to significant uncertainties which should be taken into account when one seeks robust predictions. To achieve this task, we propose an extension of the proposed method to the stochastic framework using spectral approaches such as polynomial chaos approximation. These methods are good candidates in order to get an explicit solution with respect to the basic random variables modeling the diffusion coefficients or the crack length, for instance. They consist in representing the random solution on a suitable approximation basis. Variability related to physical parameters, loadings or geometry can thus be taken into account in the computations. The use of the extended finite element greatly helps dealing with geometrical uncertainties in a parametric/stochastic way since the geometry does not have to be conformed to the finite element mesh. Numerical studies involving homogeneous and heterogeneous materials will allow showing the efficiency of the technique and the impact of cracks on the diffusion behavior.

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abst. 2360
Virtual Room
Wednesday
September 2
09h45

Identification of longitudinal and radial moisture diffusion parameters of flax fibres by means of experimental and numerical analysis

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Thanks to their high specific mechanical properties and low environmental impact, natural fibre reinforced composite materials have attracted a lot of interest in various sectors such as automotive and marine industries. However, the anisotropic nature of natural fibres and their high sensitivity to environmental conditions, especially humidity and temperature, is a major barrier to their wide

development. In order to expand the use of natural fibre-reinforced composites, it is essential to understand their moisture diffusion kinetics and study the various parameters that influence this physical phenomenon at the macroscopic and microscopic scales. Therefore, various research studies have focused on these aspects by considering natural fibre-reinforced composites as homogeneous materials [1,2]. However, only a few studies have analysed the moisture diffusion of this type of materials, highlighting their heterogeneity [3].The aim of this work is to study firstly the hygroscopic behaviour of a unidirectional flax fibre-reinforced epoxy composite and secondly to estimate the longitudinal and radial water diffusion coefficients of the flax fibre. For this purpose, several plates of this material were fabricated by the vacuum infusion process and square specimens were then cut and aged in tap water until saturation. Some of the flax-epoxy samples were sealed with a waterproof paint to force water diffusion along the direction of unidirectional fibres, the transverse direction and the thickness direction. After that, 1D Fick's model was considered to identify the water diffusion parameters of the sealed flax-epoxy samples while 3D Fick's model was used to determine the water diffusion coefficients of the unsealed samples using an optimisation procedure. To estimate the longitudinal and radial diffusion coefficients of the flax fibre, a finite element modelling of water diffusion in the flax-epoxy samples is proposed. It considers the heterogeneous nature of flax-epoxy samples and takes account of the water diffusion properties of the flax fibre and those of the epoxy matrix. To simplify, a plane modelling of water diffusion in the flax-epoxy samples is developed and finite element calculations are carried out using the 3-node hygroscopic triangular element developed by Zouari et al. [3]. In this case, the epoxy resin and the flax fibre diffusivity parameters are needed. The diffusion coefficient of the epoxy resin was deduced from its experimental water uptake curve by minimising the quadratic error between 1D Fick's model solution and the experimental points. For the flax fibre, its longitudinal and radial diffusivity parameters are also needed. Since these coefficients are relatively difficult to obtain experimentally, they are estimated by an inverse approach exploiting the finite element simulations and the experimental water absorption results. The obtained results firstly show that the water diffusion parameter in the direction of flax fibres is greater than that of the transverse direction and largely exceeds the diffusion coefficient along the thickness direction. Secondly, the inverse approach based on the experimental results and the finite element simulations allows to find an estimation of the longitudinal water diffusion coefficient of the flax fibre which is 210 times greater than the radial coefficient. References [1] Chilali A, Assarar M, Zouari W, Kebir H, Ayad R. Effect of geometric dimensions and fibre orientation on 3D moisture diffusion in flax fibre reinforced thermoplastic and thermosetting composites. Compos Part A Appl Sci Manuf 2017; 95:75–86. [2] Regazzi A, Corn S, Ienny P, Bergeret A. Coupled hydro-mechanical aging of short flax fiber reinforced composites. Polym Degrad Stab 2016; 130:300–6. [3] Zouari W, Assarar M, Chilali A, Ayad R, Kebir H. Numerical Modelling of the Transient Hygroscopic Behavior of Flax-Epoxy Composite. J Renew Mater 2019; 7:839–53.

Durablity of epoxy adhesives for civil engineering applications under hygrothermal ageing

abst. 2092
Virtual Room
Wednesday
September 2
14h00

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This paper presents the first results of a huge experimental program about the durability of two commercial epoxy adhesives exposed to different hygrothermal environments for up 15 months: tap water and sea water at 30°C and tap water only at 60°C. After specific exposure periods several changes of the physical and mechanical properties of the resins were assessed: water uptake, flexural and in plane shear behaviour, glass transition temperature and the fracture energy in mode II. Differential Scanning Calorimetry (DSC) analysis following ASTM E1356 Standard was developed in order to understand the influence of curing and post-curing of the resins on their mechanical properties. It was found that in typical environmental conditions for civil engineering applications it is not possible to reach the complete (100%) cure of the resin. The temperature of the water could be responsible of a post-curing phase that contribute to increase the mechanical properties of the resins in general and the fracture energy in particular. The latter was evaluated by End Notch Failure Tests and the relative R-Curves showing a different behaviour between adhesives: elastic-brittle behaviour and elasto-plastic behaviour.

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abst. 2527
Repository

A novel micro-scale characterisation approach on the mechanical property degradation of bulk adhesive in hot-wet environment

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Previous researches have been reported addressing the measurement of adhesive mechanical performance after exposure to hygrothermal environment using macro-scale testing methods, e.g. gravimetric method, bulk adhesive tensile testing, etc. This work presented a novel micro scale approach characterising the influence of water intake on the local mechanical property under elevated temperature (50 oC). Rectangular bulk adhesive samples (80 mm*30 mm) with 1.5 mm thickness were fabricated and cured with a PTFE mould. Gravimetric study was previously conducted on bulk adhesive immersed in deionised and 5% NaCl water, respectively, showing a Fickian diffusion was conformed in the selected adhesive specimen. Necessary water diffusion coefficient and saturation moisture content data can be provided, and the total saturation time in this work can then be estimated considering moisture diffusion in the thickness direction. The immersed samples were periodically removed from the hot-wet environment and cut with a precise cutting machine across the width direction to expose the sample cross section which was then tested with nanoindentation for mechanical property determination, including reduced modulus and surface hardness. Experimental results revealed that water intake in the thickness direction of the bulk adhesive caused significant local (in micro scale) degradation in the material mechanical parameters, both in terms of stiffness and strength, i.e. reduced modulus and hardness in nanoindentation testing. Furthermore, increased local normalised moisture concentration led to further reduction in material property, and immersion in deionised water caused larger decrease in reduced modulus and hardness in bulk adhesive, possibly due to the fact that higher saturation moisture uptake was observed from gravimetric study compared to salt water immersion. The presented work established a micro scale characterisation approach to provide local material degradation data of adhesive exposed to long-term hygrothermal environment.

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abst. 2597
Repository

Experimental characterisation of damage in glass-fibre reinforced polyamide 6 under hygrothermal environment

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Thermoplastic polyamide-based composite materials are remarkable for their sensibility to diverse environmental conditions, particularly to humidity and in-service temperature. An extensive experimental and numerical analysis was carried on such material within the framework of research on the design of composite bolted joints [1]. As a result, it was shown and validated that the matrix-related quasi-static mechanical response of Glass-Fibre reinforced PolyAmide 6 (PA6 GF) significantly alters from one hygro-thermal condition to the other. Similar variations of composite material properties are demonstrated by other researches [2], [3]. The increase or reduction of the yield and ultimate stresses under static loading was associated with the changing matrix glass transition temperature [1], [4]. However, the material examination was restrained to the elastic properties because of its use in the bolted joints. In the present work, we provide a more extensive analysis of the thermoplastic composite, in particular, the evolution of damages and irreversible strains under the hygro-thermo-mechanical

conditions. The main objective is not only to verify the sensitivity of these quantities to the temperature and relative humidity level but also to determine relations to predict the damages and irreversible strains for any hygro-thermal conditions. It may eventually contribute to the enhancement in the design of bolted composite joints as well as in the design of components where the elastic or other properties are required. Besides, to the authors' knowledge, such a detailed environmental impact on the damage and plastic behaviour of the composite material has not yet been proposed. The mechanical impact is represented by the cyclic quasi-static loading of 45° fibre-oriented specimens. Five testing temperatures and three levels of Relative Humidity (RH) stand for the hygrothermal conditions. The desiccation and saturation of specimens at given RH are carried according to the developed protocol presented in the research work [1]. Such changeable atmosphere along with 5-6 loading cycles enables the damage and plasticity characterisation of the composite material for each pair "temperature – RH". Hence, the damage parameters d12 and damage-associated thermodynamical force Y12 are computed for each hysteresis loop [5]. Likewise, the evolution of material plastic hardening and of cumulated plastic deformation is proposed for the given environmental conditions. The damage evolution law, as well as the function of hardening evolution, are consequently suggested as a function of moisture content and temperature. [1] I. Pivdiablyk, "Durability of mechanical performance of prestressed bolted composite joints in a hygro-thermo-mechanical environment," Ecole Centrale de Nantes, 2019. [2] H. Obeid, "Durabilité de composites à matrice thermoplastique sous chargement hygro-mécanique: étude multi-physique et multi-échell des relations microstructure -propriétés-états mécaniques," Université de Nantes, 2016. [3] M. Arhant, "Thermoplastic composites for underwater applications," Ecole Centrale de Nantes, 2016. [4] A.-T. Dau, "Elaboration d'un outil numérique reliant les échelles micro/méso d'un composite thermoplastique sensible à l'humidité et à la température en quasi-statique," Ecole Centrale de Nantes, 2019. [5] Patrick Rozycki, "Contribution au développement de lois de comportement pour matériaux composites soumis à l'impact," Université de Valenciennes et du Hainaut-Cambresis, 2000.

Bond behaviour of NSM strengthening systems on concrete elements under sustained load and cyclic service temperature

abst. 2098
Repository

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The use of Fibre-reinforced polymers (FRP) materials as a strengthening system for reinforced concrete structures has been widely studied during the last decades. Long-term performance and durability in real-world applications may be affected by the combination of several influencing conditions such as sustained load and temperature, which cause creep on the bonded joint and a loss of properties, mainly when it is close to the glass transition temperature (Tg). Therefore, bonded joints must be designed taking into account that they are likely to support harmful conditions. A number of studies combining the effects of temperature and sustained load on concrete elements strengthened with Externally Bonded Reinforcements (EBR) can be found in the literature. However, fewer studies focus on the Near Surface Mounted (NSM) FRP technique. Hence, there is still a lack of data and knowledge in this field. The main objective of this work is to experimentally study the effect of variable service conditions in NSM strengthened concrete elements. Eight pull-out specimens have been loaded under a sustained load and a cyclic temperature during 40 days. To simulate day and night conditions during a relatively warm season, temperature cycles vary between 20°C and 40°C every 24 hours. To study service conditions, the sustained load levels applied to the NSM specimens have been set between 15% and 30% of the ultimate monotonic load. Additionally, the groove thickness and bonded length have been included as parameters of the experimental campaign to study its influence on the bond-slip performance. The NSM specimens have been designed to have two bonded lengths (150 mm and 225 mm) and two groove thicknesses (7.5 mm and 10 mm). A lever arm with a multiplying factor of 10 applies the sustained load to the NSM specimens. The instrumentation of each concrete element consists in one LVDT located in the loaded end, to capture the relative displacement between the FRP and the concrete, and one strain gauge placed in the FRP, to measure the load during time. The experimental results show that

the slip increases significantly during the time. Furthermore, environmental conditions and the level of sustained load have a relevant effect on the bonded joint response. Acknowledgements: The authors acknowledge the support provided by the Spanish Government (MINECO), Project Ref. BIA2017-84975-C2-2-P. The first author acknowledges the University of Girona for conceding the IFUdG grant (IFUDG2018). The third author also acknowledges the support from the Generalitat de Catalunya, under the Grant 2019FI_B 00054.

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abst. 2484
Repository

Effects of mild hygrothermal treatment on the physical and vibrational properties of spruce wood

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Spruce wood specimens were treated under mild temperatures 130°C and 150°C and different relative humidity from 0% to 25%. EMC reduced significantly for all the treatments. Weight loss (WL) increased insignificantly while the colour parameter, L*, decreased dramatically. Tan reduced significantly while the E/d has increased. After reconditioning, the partially reversibility has been achieved for EMC, tan and E/d. But, still an irreversible changes remains, which suggested being due to the chemical changes in wood polymers. While reversible changes has been resulted from the annealing of amorphous polymers. Since, the mild hygrothermal treatment applied to the specimens coincided with no significant WL, there was no obvious damage in wood structure while the irreversible changes present an improvement in vibrational properties by decrease in damping (tan), which could be due to the intermediate relative humidity of the treatment.

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abst. 2546
Repository

An intelligent model for the prediction of depth of wear of cementitious composites modified with high-calcium fly ash

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Although the applications of cementitious composites with high-calcium fly ash is popular trend, no research has been reported on the prediction of its depth of wear. With the current knowledge examining this property involves destructive and costly laboratory tests using special devices (e. g. the rotating-cutter method). Thus, in this investigations an intelligent model for the prediction of depth of wear of cementitious composites modified with high-calcium fly ash was developed. The model based on the relationships between depth of wear and mixture constituents/proportions. The experimental results showed also that partial replacement of cement with fly ash gives depth of wear similar to reference composite without fly ash. Authors presented the possibility of usage artificial intelligence in order to predict the depth of wear by applying artificial neural network with suitable architecture and a learning algorithm. Results showed satisfied precision of new intelligent model for the prediction of the depth of wear with high accuracy compared to the rotating-cutter method. The developed model can potentially assist in the design of high-calcium fly ash cementitious composites with increased durability.

Corrosion resistance of Fiber Metal Laminates based on aluminium and titanium alloys with carbon and glass fibers

abst. 2639
Repository

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For designers and engineers in the field of material engineering, the correct selection of materials becomes important, considering fatigue characteristics, impact resistance, corrosion and understanding of complex mechanisms of destruction of the structure of not only metals but also polymers. Moreover, combining these two components together poses new challenges in determining these properties. Currently, materials combining the features of both metal and fibre reinforced composite material are FML hybrid materials (Fibre Metal Laminates). They constitute alternating layers of metal and fibre reinforced polymer composite. The most common are GLARE laminates based on aluminium and high-strength glass fibres. Due to the growing interest of the aviation and automotive industries in hybrid laminates, new solutions emerge that contain layers of e.g. titanium, magnesium in combination with composites containing carbon fibres. In this regard, the galvanic corrosion, which may seriously reduce the strength of materials during the serving period if a valid protection is not provided for metallic alloys, begins to appear. Surface preparation is also an important factor in the connection between the metal and the polymer layer. This factor is crucial for the permanent connection between two different components. The analysis of literature indicates that there is a need to expand knowledge on corrosion phenomena in Fibre Metal Laminates, in terms of comparing the type and the thickness of metallic layers, surface preparation and a kind of applied fibres. This thesis presents an analysis of changes taking place in Fibre Metal Laminates on the surface of aluminium and titanium as a result of the corrosive environment. The degree of laminate degradation was determined depending on different thickness of metallic layers. Corrosion rates (mass changes) were analysed depending on the time and the type of corrosion changes with the degree of surface degradation were determined. Parameters characterising the phenomenon of corrosion were marked. It has been shown that the dominant type of corrosion occurring on the surface of aluminium layers is pitting and intergranular corrosion. In the case of laminates containing carbon fibres, galvanic corrosion also occurs. Corrosion appears regardless of the thickness of the aluminium layers, but accelerated growth is observed when using 0.3 mm thick aluminium layers regardless of the fibres used. The use of the 3/2 system only promotes degradation of the outer layers of aluminium. The polymer layer protects against perforation into the inner layers of aluminium. Laminates with layers of titanium do not undergo any corrosive changes regardless of the fibres used. Keywords: Fibre Metal Laminates, corrosion, glass fibers, carbon fibers

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A Novel Protocol for Rapid Identification of the Diffusion Properties of Polymer-Matrix Composite Materials with Complex Texture

abst. 2091
Virtual Room
Wednesday
September 2
13h45

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The present work presents a novel protocol for rapid identification of the three-dimensional (3D) diffusion properties of polymer-matrix composite materials with complex texture, based on the exploitation of short time gravimetric tests. According to the Thermodynamics of Irreversible Processes, the diffusion behaviour of materials can be isotropic or orthotropic: for many materials, due to the complexity of the microscopic texture, the principal directions of orthotropy are not known a priori and enter the identification issue. The paper proposes an experimental protocol and an identification algorithm for the full 3D diffusion case, aiming at establishing the 3 coefficients of diffusion along the principal directions of orthotropy and the orientation of the orthotropic reference frame with respect to the sample frame. The identification of the physical properties is done through the minimization of a distance in the space

of the physical parameters. The problem being non-convex, the numerical strategy used for the search of the global minimum is a Particle Swarm Optimization - PSO, the code ALE-PSO (Adaptive Local Evolution-PSO) with adaptive coefficients. The procedure is validated against an experimental case involving carbon-epoxy composite materials for aircraft applications. Acknowledgements: The present work was partially funded by the French Government program "Investissements d'Avenir" (LABEX INTERACTIFS, reference ANR-11-LABX-0017-01; EQUIPEX GAP, reference ANR-11-EQPX-0018).

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abst. 2393
Repository

DESIGN FOR DURABILITY OF COMPOSITE PULTRUDED PROFILES

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Fibre reinforced polymers (FRP) for structures is becoming more relevant in construction and rehabilitation of existing structures. The fabrication of normalized beams in FRP is the consequence of the properties that this family of materials present: lightweight, noncorrosive, high specific strength and stiffness, ease of construction and tailoring capability to satisfy requirements. Another important characteristic of the FRP is the long lasting properties. The lightweight that is intrinsic to a FRP allows for global cost effective construction solutions [1]. In the case of emergencies, rapid availability and reliability is key. Composite structures made of GFRP profiles are especially suitable due to their characteristic manoeuvrability, lightweight and the well-known manufacturing pultrusion process [2]. The use of GFRP pultruded profiles in structures subjected to harsh environments is one of the most important application of those composite systems as traditional materials often are sensitive to conditions such as frequent freezing cycles and salts [3]. Despite the advantages of using FRPs, the fact that these present low ductility, low shear strength, vulnerability to extreme temperatures and possible degradation of mechanical properties when exposed to alkaline environments, UV radiation, temperature cycles and fluctuating hydrothermal conditions can pose some obstacles to the use of these materials in civil construction [3]. Temperature and time-dependent behaviour of the matrix influence lifetime of composite structural elements [4]: • Low temperature may cause brittleness, inducing cracking and propensity to fracture • Elevated temperatures may result in degradation of mechanical properties, cracking, chalking and flaking • Cyclic exposure can cause interfacial debonding and matrix cracking • Time-dependent behaviour of the composite as polymeric-based composite materials are viscoelastic in nature. Stress relaxation and creep will occur when a viscoelastic material is exposed to quasi-static loading and load changes [4]. The pultrusion process can produce these profiles. Due to the process of fabrication, a FRP presents a high environmental impact. Such fact is the main reason why one cannot consider FRP a sustainable material [Lee and Jain, 2009]. Hence, it is relevant to design FRP for durability and predict the products life. In this work, using short-term creep tests and accelerated testing, we will analyse the durability issues, the performance in construction and suggest life prediction strategies. Glass fibre reinforced polymers made by pultrusion are widely employed given their relatively low cost and desirable characteristics. Moreover, UV radiation and water vapour condensation cycles may not affect significantly the tensile elastic modulus [5]. The paper overviews the durability issues of pultruded profiles. The analysis has an emphasis on the approach to increase the durability of a FRP pultruded structure. A brief overview of short creep tests with composites is given. As a starting point for life conditions of pultruded profiles we used finite elements simulation and compare with experimental test. The tests used a constant load in different environmental conditions to study the influence in creep behaviour. REFERENCES 1. Lee, L. S. and Jain, R. (2009). The role of FRP composites in a sustainable world. Clean Technologies and Environmental Policy, 11(3):247–249. 2. Cavaleri, L., Paola, M. D., Ferrotto, M., Scalici, T., and Valenza, A. (2019). Structural performances of pultruded GFRP emergency structures – part 1: Experimental characterization of materials and substructure. Composite Structures, 214:325 –334. 3. Jafari, A., Ashrafi, H., Bazli, M., and Ozbakkaloglu, T. (2019). Effect of thermal cycles on mechanical response of pultruded glass fibre reinforced polymer profiles of different geometries. Composite Structures, 223:110959. 4. Yang, Z., Wang, H., Ma, X., Shang, F., Ma, Y., Shao, Z., and Hou, D. (2018). Flexural creep tests and long-term mechanical behaviour of

fibre-reinforced polymeric composite tubes. Composite Structures, 193:154 – 164 5. Bazli, M., Jafari, A., Ashrafi, H., Zhao, X.-L., Bai, Y., and Raman, R. S. (2020). Effects of UV radiation, moisture and elevated temperature on mechanical proper-ties of GFRP pultruded profiles. Construction and Building Materials, 231:117137

Chemical ageing in filament-wound GFRP - a multi stage modelling and simulation strategy for weak zones

abst. 2212
Repository

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Filament winding is a method for producing tubular, rotationally symmetric composites products with a high [U+FB01]bre volume fraction. They are typically composed of glass [U+FB01]bre reinforced polymers (GFRP). Their applications have a high presence in the chemistry industry and are based on various pipes, storage tanks and vessels that often need to seal pressurized gas or liquid. Operational conditions in[U+FB02]uence the onset of changes in the micro-structure of the material even at low levels of deformations. The main e[U+FB00]ects are based on reductions in [U+FB01]bre strength and [U+FB01]bre-matrix interfacial properties [1, 2]. This work presents a multi-scale approach that is supported by two mechanical experiments to analysis the strength sensitivity of conditioned cross-plied GFRP. The ageing condition was based on a sulphuric acid solution immersion under pressure (5% H2SO4 solution, 95 °C, 15 bar). Two vinyl ester resins were employed as matrix component in order to compare experimentally their performance in experiments. After 0.5, 1, 1.5 and 2 years of conditioning, the GFRP samples were subject to tensile test without the barrier-corrosion layers. The same conditioning for 1-year was applied to the neat resins as homogenous samples in order to collect experimental parameters at matrix component level. The numerical approach with finite element (FE) modelling of manufacture-related weak zones. The approach was developed by means of two routines where the material was defined and the virtual conditioning over stiffness and strength properties was applied. The [U+FB01]rst numerical routine determined a multi-scalar de[U+FB01]nition of the specimen material. The second routine focused on the survey of the strength properties of the GFRP model with the material de[U+FB01]nition and a virtual conditioning application by using a sampling function (Latin hypercube method). The 'conditioned parameter values' were input into the FE model that included an implementation of the Hashin 3D failure criterion [3]. Naturally, the second routine required the 1-year aged elastic constants and the stress [U+FB01]eld generated due to the tensile case. The results show the importance of shear strength values on the ply level and, respectively, the importance of interfacial and matrix properties on the component level. REFERENCES [1] B. F. Oliveira and G.J. Creus, "An analytical-numerical framework for the study of ageing in fibre reinforced polymer composites", Composite Structure, vol. 65, no. 3-4, pp. 443-457, 2004. [2] M. Kanerva, J. Jokinen, E. Sarlin, T. Pärnänen, M. Lindgren, M. Järventausta, and J. Vuorinen," Lower stiffness of GFRP after sulfuric acid-solution aging is due to degradation of fibre-matrix interfaces?", Composite Structure, vol. 212, pp. 524-534, 2019. [3] Z. Hashin, "Failure Criteria for Unidirectional Fiber Composites", Journal of Applied Mechanics, vol. 47, no 2, pp. 329-334, 1980.

Study of the hygro-mechanical coupling in composite materials

abst. 2560
Virtual Room
Wednesday
September 2
14h15

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Composite materials are excellent candidates for marine structures such as MRE (marine renewable energy) or naval structures due to their interesting weight/strength properties ratio and their resistance to corrosion, especially in severe environments (humid air or water immersion). However, these materials are subjected to continuous mechanical loading as well as humid conditions that may reduce their lifetime. These two physical factors and their interaction need to be taken into account to well assess the material behaviour. Even though the uncoupled phenomena are overall well understood, the interaction between water diffusion and mechanical behaviour of composites needs further investigation. Three types of materials have been chosen for this study: neat resin (LY556) to highlight the influence of the matrix in the hygro-mechanical coupling, together with carbon and glass epoxy composites with different stacking sequences to have a better understanding of the overall composite behaviour. The studied layups in this project (for both type of composite) are [+/-45]6 to emphasize the role of the resin especially in the composite's aging and quasi-isotropic [+/-45/0/+/-45]s to represent a more realistic configuration. A large experimental campaign covers the diffusive, mechanical and long-term behaviour of the studied materials both immersed in water and in humid air. First, diffusive and swelling properties will be identified to understand how water molecules can penetrate into the polymeric matrix. In a second step, mechanical properties will be determined at different aged conditions to highlight the influence of water absorption on the mechanical state of carbon or glass fiber reinforced epoxy composites. Then, time-dependent properties are being studied through long-time creep tests and Dynamic Mechanical Analyses (DMA) during aging. This is allowing a better understanding of the evolution of viscoelastic properties during the process of water diffusion. Finally, coupled creep tests have been performed in specific environments (water immersion and humid air) to quantify the damage evolution due to these conditions. In parallel with these experiments, hygro-mechanical models have been developed to try to predict the uncoupled and coupled phenomena. These first are based on determining the uncoupled properties linking a physiochemical or mechanical behaviour with a state of aging, then simulating long-term in-situ experiments where both water diffusion and mechanical loading interact.

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abst. 2354
Repository

Thermal damage of Carbon Fibre Reinforced Polymers (CFRP) with respect to mechanical properties and degradation phenomena

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Carbon Fiber Reinforced Polymers (CFRP) are widely applied in light weight applications e.g. in aerospace because of their high strength to weight ratio compared to e.g. metal structures. However, due to the polymer matrix, CFRP show lower thermal stability. Therefore a quantification of thermal damage is indispensable. A non-destructive evaluation method for moderate thermal damage is Attenuated Total Reflection Fourier Transform Infrared Spectroscopy (ATR-FTIR). The focus of this method is to characterize the surface damage. However, for a more detailed comprehension of thermal damage it is also necessary to gain a deep insight into the bulk material. For this purpose, mechanical, chemical and tomographic investigations were considered through the profile of the CFRP with respect to matrix degradation and occurring delaminations. For this study a frequently used CFRP (HexPly® 8552/IM7) with unidirectional fiber orientation was analyzed. All samples were thermally irradiated at one side with heat fluxes between 15 kW/m^2 and 50 kW/m^2 over various time intervals i.e. every sample suffered from a temperature profile through its depth which is recorded with thermocouples embedded in different depths of every sample. The measured temperature profile over the time through the CFRP sample gives detailed information about the thermal loading inside the sample. ATR-FTIR spectroscopy along a ground incline plane through a CFRP specimen allows a chemical characterization of the thermal damage into the depth. The intensity ratio of characteristic IR bands of the thermally less stable epoxy resin (1510 cm-1) compared to the thermoplastic polyethersulfone (1486 cm-1) decreases with

increasing thermal degradation. Another non-destructive evaluation method is X-Ray Microtomography (μCT). Occurring delaminations can be observed with a resolution of 7μm. Beside the determination of the delamination depth, a grey value analysis allows the calculation of the percentage of delaminations inside the sample. The mechanical behavior after thermal damage of CFRP is determined by tensile, compressive and Interlaminar Shear Strength tests (ILSS). These tests were performed at specimens taken at different depth from irradiated samples with a thickness of 4 mm. The correlation of chemical and tomographic data shows, that delaminations occur beyond a certain degree of matrix degradation. The mechanical investigations show a strong influence of thermal damage on ILSS and compressive strength depending on occurring delaminations and nearly no loss of tensile strength.

Effects of alkali treatment on moisture absorption and mechanical properties of flax/polypropylene composites

abst. 2617
Virtual Room
Wednesday
September 2
13h30

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Surface treatment of flax fiber via chemical reaction is important measures to reduce its moisture absorption and enhance bonding between fiber and matrix. A comprehensive experimental study is conducted to reveal the effects of NaOH concentrations in the treating solution on the efficiency of chemical treatment. The microstructure changes of flax fiber and its composites before and after alkali treatment were compared. Alkali treatment reduced the diameter of flax fiber and made the fiber surface smoother. It turns out that 5wt. % of NaOH in the treating solution brought about optimum tensile and flexural properties of flax/polypropylene composites. Upon chemical alkali treatment, flax/polypropylene composites were subjected to hygrothermal ageing. Alkali treatment reduces moisture absorption in flax/polypropylene composites. 5 wt. % concentration of NaOH was found to be most effective in terms of inhibiting moisture absorption. The results of the current study clearly showed that proper control of treating time and the concentration of NaOH in the treating solution could simultaneously improve the mechanical properties of flax/polypropylene composites and reduce moisture absorption.

Development of a Multiphysics Model of Synergistic Effects between Environmental Exposure and Damage in Woven Glass Fiber Reinforced Polymeric Composites

abst. 2504
Repository

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Glass Fiber-reinforced polymer composites (GFRPs) are made by combining polymer with reinforcement glass fiber yarns to produce new materials that offer lightweight yet strong, durable, corrosion resistance. Its application is emerging in aerospace, the automotive and solar panel industry. Although decades of application have proved composite as a viable, permanent structural material, a reliable, experimentally validated model for the predictive performance for the composite under the expected environment is needed before this material can be used as a massive construction material. This study is to build a physics-based model to predict mechanical, thermal, weather and aging performance of the composite in the short- and long-term. A multiscale modeling technique is used to upscale the usage of material model prediction into structural and system levels. In the multiscale computational model, there are two levels: materials level, structure level. The material level model has the smallest length scale. It consists of woven microstructure, periodic boundary conditions, and coupled multi-physical processes (radiation heat transfer, moisture condensation, polymer deterioration, and solid material behavior), which ultimately affect the mechanical performance of the material. These mechanisms will be computationally modeled using COMSOL® multi-physics modeling software. Specifically, a computational model of the SFMOMA façade panels will be constructed, including all of deterioration mechanisms applied simultaneously. The material model will be used to generate an equivalent

homogenized model that can be used at the structural level efficiently while maintaining the same accuracy. The model is validated by UV/ moisture exposure and mechanical experiment. Results of this study indicate that the synergistic effect of combined UV and moisture exposure on composite material degradation is more severe than simple linear superposition of each exposure's damage. A comparison and analysis of UV and moisture exposure degradation mechanisms indicate that these environmental exposures caused material degradation by weakening the polymer matrix, along with weakening the interface between the polymer matrix and fiber reinforcing yarns. The weakening of the polymer matrix causes surface discoloration and chalking, and effects local matrix material properties. The weakening of the fiber-matrix interface, which is more critical, weakens the bond between fiber-ply and matrix, reduces the energy absorption capacity of the composite, and contributes to global damage and failure of the composite element. In the long term, the models developed in this study will be combined with life cycle assessment (LCA) tools to better support sustainability focused design of new material, thus reducing costs and environmental impacts of the built environment.

Experimental methods

Notched response and compressive fracture toughness of hybrid spread-tow, thin-ply woven and non-crimp fabrics

abst. 2363
Repository

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Ply-level hybridisation, where thin and thick plies are combined, has been proved as an effective technique to achieve the best compromise between strength and toughness of spread-tow reinforcements. However, studies so far are restricted to the tensile case. This study aims at characterising experimentally the notched response and compressive fracture toughness of hybrid spread-tow woven and non-crimp fabrics obtained by uniform (along all ply orientations) and selective (0-degree) ply-level hybridisation. Unnotched and open-hole compression tests were performed on coupons of multidirectional laminates, with thicknesses ranging from 1.8 to 2.2 mm. Notched coupons with different hole sizes were considered to assess the hole size effect in compression. The compression fracture toughness of the laminates was determined using the size effect law obtained from double edge-notched compression (DENC) tests on geometrically similar coupons (i.e. coupons of different sizes with constant width-to-notch length ratio). Since thin laminates were tested, a new test configuration, based on the ASTM D6484 test standard, with an anti-buckling device, was used in all tests. The tests show that this is an appropriate alternative to the original end-loading setup proposed for the DENC tests used in the past to determine the compression fracture toughness of composite laminates, only suitable for sufficiently thick laminates (in order to avoid premature buckling). Based on the compressive crack resistance curves and compressive notched strengths, it is shown that thick spread-tow woven fabrics have higher apparent fracture toughness and improved notched response than the thinner counterparts. Hybrid spread-tow woven fabrics with uniform ply-level hybridisation, as expected, exhibit an intermediate fracture toughness and notched response. In the case of spread-tow non-crimp fabrics, thick (blocked)-ply and thin (dispersed)-ply laminates exhibit the same compression fracture toughness, clearly showing that the compression fracture toughness is not ply thickness dependent, as recently demonstrated for the tensile case. However, selective ply-level hybridisation of the hybrid spread-tow non-crimp fabrics, where 0-degree plies are blocked together to effectively increase the thickness of the layers parallel to the loading direction, leads to a remarkably different notched response, showing that ply-level hybridisation can also be used to enhance the behaviour of advanced composite laminates in the presence of stress concentrations in compression, without compromising the intrinsically high plain compressive strength of thin-ply laminates.

Bending potential on stress strain diagram influenced by the composition of the wood based layered material

abst. 2707
Repository

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abst. 2551
Repository

Nanoanalysis of composite materials: Monte Carlo SEM-EDS strategy to avoid qualitative and quantitative analytical errors

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A correct determination of chemical and mineral compositions down to the nanoscale is nowadays of utmost interest to answer questions regarding composite materials properties. Therefore, different analytical techniques are widely used in this context, and scanning electron microscopy (SEM) combined with energy dispersive X-ray spectrometry (EDS) is one of the most suited and used. However, because of both complex architecture and reduced size features (micro-to-nano) in many composites, it is necessary to consider several effects related to the generation and transport of electrons and X-rays, which in turn are dependent on the SEM-EDS setup, to avoid serious mistakes and quantification errors. In the present work, a Monte Carlo SEM-EDS simulation strategy is proposed and applied to selected micro-nano sized architectures usually found in composites. Recently, Monte Carlo simulation was effectively proposed and applied by the authors to the study of asbestos fibres and bundles [1]. Here, the purpose is to study the effect of both micro-nanometric dimensions (in the 100 nm to 10 micrometre range) and basic geometrical shapes of embedded features in the sample matrix (for instance, prismatic and spherical) in qualitative and quantitative SEM-EDS microanalysis, looking at possible sources of mistakes and errors to be considered and avoided. The physics of electron impact and X-ray generation was taken into account by using the following models. The Mott cross section of Czyzewski and co-workers [2], the Mott scattering cross section of Jablonski and co-workers [3] and a basic screened Rutherford model [4] were considered for the elastic scattering. The energy loss was modelled through an empirical modification of the Bethe equation for energy loss (Joy-Luo expression [5]). The expression of Bote and Salvat [6] was employed for the ionization cross-section. The mass absorption coefficients are those of Chantler and co-workers [7], whereas the fluorescence yields are tabulated experimental values [8]. Secondary fluorescence generation was also considered, together with a realistic SEM-EDS setup and EDS X-ray detector. The simulations showed an important contribution of the thickness and shape of the composite features to the intensity of the X-rays measured by the EDS, thereby influencing the analysis and quantification. The critical overview of the results allowed to determine the correct procedure and technical SEM-EDS parameters to be selected in the field of nano-microscaled materials composite. References [1] G. Valdrè, D. Moro, G. Ulian, IOP Conf. Series: Mater. Sci. Eng. 304 (2018) 012019. [2] Z. Czyzewski, D. O. Maccallum, A. Romig, D. C. Joy, J. Appl. Phys. 68 (1990) 3066-72. [3] A. Jablonski, F. Salvat, C. J. Powell, NIST electron elastic-scattering cross-section database, 2016, National Institute of Standards and Technology, Gaithersburg, MD. [4] R. Myklebust, D. Newbury, H. Yakowitz, NBS Monte Carlo Electron Trajectory Calculation Program, in NBS Special Publication (editors: K. Heinrich, H. Yakowitz, D. Newbury), 460, 1976, p. 105, National Bureau of Standards, Washington, DC. [5] D.C. Joy, S. Luo, Scanning, 11 (1989) 176–80. [6] D. Bote, F. Salvat, Phys. Rev. A 77 (2008) 042701. [7] C. T. Chantler, K. Olsen, R. A. Dragoset, J. Chang, A. R. Kishore, S. A. Kotochigova, D. S. Zucker, NIST Standard Reference Database version 2.1, 2005. [8] S.T. Perkins, D.E. Cullen, M.H. Chen, J. Rathkopf, J. Scofield, J.H. Hubbell, Tables and graphs of atomic subshell and relaxation data derived from the LLNL Evaluated Atomic Data Library (EADL), Z = 1–100. Technical Report. Berkley, CA: Lawrence Livermore National Laboratory, 1991.

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abst. 2095
Repository

Using the P, D, or PD controllers to vibration reduction of a thin-walled laminated beam under kinematic excitation

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The present study was supported by statutory resources allowed to the Department of Applied Mechanics, Lublin University of Technology under"The Grant for Young Researchers" no. FNM 30/IM/2019.
A laminated cantilever beam with an embedded piezoelectric actuator under kinematic excitation is considered. In laboratory tests, it is mounted on an electrodynamic shaker. The LMS controller is applied for power control. To measure the beam response, two sensors are applied. The triangular laser sensor measures the absolute motion of the selected beam point and a strain gauge glued on the opposite side of the beam measures the strains, which define the relative beam motion. The main element of the subsystem of the beam vibration control system is the digital signal processor (DSP), which can be coded to realise the procedures for different control algorithms. The harmonic voltage signal from the controller is supplied to the activator. As a result of the conducted tests, the resonance curves for the beam with and without control are determined. Next, the numerical simulations of the active beam using the finite element method are conducted. The Abaqus software is used to perform a dynamic test of this beam with kinematic excitation. The laminated beam made of a glass-epoxy unidirectional prepreg (length, 316 mm; width, 34 mm; thickness, 1.8 mm) is modeled as a continuum shell finite element SC8R with reduced integration. The layup-ply technique is used to define the sequence of the laminate layers [$\pm$45/90]s. Due to the complex structure of the MFC active element, its equivalent model is proposed. The time-domain numerical analysis is carried out using the implicit procedure with the control algorithm. The voltage signal applied to the MFC actuator as electrical boundary conditions is generated based on beam response in the UAMP subroutine. Select methods of vibration reduction, that is, proportional (P), derivative (D), and PD controls, are presented. The properties of the control system are described using the first-order inertial term. The kinematic excitation is defined by boundary conditions. The experimental results are used to identify the time constant and verify the proposed concept. Finally, the possibility of vibration control is demonstrated numerically using the finite element model. The tested control algorithms show the possibility of reducing beam vibrations. Simple control methods are studied, so the stiffness and/or damping of the system can be changed. The obtained results are consistent in numerical and experimental research, so the developed model can be extended in the future.

COLLAPSE OF REAL L-SHAPED THIN-WALLED COLUMNS MADE OF GENERAL LAMINATE REINFORCED BY CARBON FIBERS UNDER UNIFORM SHORTENING

abst. 2610
Repository

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Damage studies on thin-walled laminated structures made of modern laminates can be made using numerical and/or experimental methods. Due to the very complicated laminate production process, it is difficult to achieve high repeatability and accuracy of the thin-walled structures. So, it is difficult to compare the experimental and numerical results, because the specimen in experimental studies is not perfect, whereas the numerical model of the samples is perfect. The solutions obtained by both methods can differ significantly. Not only quantitative differences are observed. Incompatibility of the nature of damage can be found in experimental studies. The present study was supported by statutory resources allowed to the Department of Applied Mechanics, the Lublin University of Technology under "The Grant for Young Researchers" no. FNM 30/IM/2019. The aim of this study is to present the collapse process of real structures using numerical method validation in experimental studies. The model of the real structure will be prepared using a 3D scanner. The 3D Atos core scanner is used. After scanning the object, a point cloud is obtained. Based on the collected points, a solid model is developed, using reverse engineering. Next, collapse analysis of tested samples on a Zwick Z100 static materials testing

machine is performed. The laminate samples are subjected to uniform axial shortening. The tested columns are loaded with the force values from zero to the maximal load, which allowed one to observe the column behavior until its collapse. Laboratory tests are performed at a constant velocity of the cross-bar equal to 1 mm/min. Directly from the testing machine, the force with the corresponding shortening is collected. All analyzed samples are made with carbon-epoxy laminate using the autoclave method. The configurations of laminate layers are: [60,02,-602,603,-602,03,-602,0,602]T, where direction 0 is along the length of the profile. Material parameters of laminate are Young's modulus along the fiber direction: 170GPa and along the fiber transverse direction: 7.6GPa; shear modulus: 3.52GPa; Poisson's ratio: 0.36. The thickness of the column is 0.81mm, the width of the flanges is 40mm and the length of the column is 300 mm. Finally, the experimental damage tests of the real column are compared with the obtained results of numerical simulations for scanned objects. The damage load, buckling load, and shortening plots are discussed.

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abst. 2526
Repository

APPROACHES TO FATIGUE AND DAMAGE-TOLERANCE TEST OF FULL-SCALE METAL-COMPOSITE AIRFRAME

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As the scope of application of composite materials in the main structure of an aircraft necessary to develop new approaches to full-scale fatigue and damage-tolerance test. Fea-tures of composite materials lead to the fact that experimental confirmation the service life characteristics of the metal-composite structure should be based on compliance with the requirements for composite and for metal structures. These tests must show that cata-strophic failure due to fatigue, the influence of the environment, manufacturing defects or accidental damage can be avoided in operating during the lifetime of the aircraft. Analyzed the main features of fracture mechanisms under cyclic loading of metal and composite aircraft structures and developed on the basis of their theoretical foundations of the formation of the load spectrum for reliable confirm service life of aircraft. It is shown, that for a reliable confirm the service life of composite aircraft, test loads are necessary to enhance to ensure the full-scale tests in a reasonable timeframe. It is re-ceived the basic relationships that define the enhance factors. Analyzed the basic relationships that define approaches to the formation of the test spectrum for loading metal-composite aircraft structures. Considered two main approaches to full-scale fatigue test of metal-composite aircraft structures and develop recommendations for their practical use. Supposed the methods of forming quasi-random block of load for full-scale fatigue test taking into account the peculiarities of the mechanisms of failure of metal-composite air-craft structures.

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abst. 2142
Repository

Improved characterisation and analysis of the mechanical behaviour of a structural fabric and a prepreg for high-performance composite structures

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The development of novel characterisation methods is mainly driven by the need to improve the accuracy of data. Likewise, the lack of accuracy in characterisation can be improved by modifying the existing techniques to carefully control the parameters that influence the results. This work investigates the two main experimental techniques applied to characterise the inplane shear and friction properties of structural fabrics and prepregs. The inplane intraply shear property of unidirectional (UD) prepreg has been a debatable topic that is frequently mixed-up with its inplane friction behaviour. This study presents an improved experimental characterisation technique that validates the characterisation results with the theoretical definition of intraply shear of UD fibre-reinforced materials. Further, this work demonstrates a controlled measurement of the frictional behaviour of a non-crimp fabric (NCF) at

industrially-relevant processing conditions of temperature and strain rate. The new characterisation results have been compared with the available results in the literature that clearly demonstrate the improvement with regards to the typically-ignored factors.

Controllable Dynamical Recovery Loading for Investigating Deformation Evolution of Polymer Composites under Uniaxial Compression

abst. 2541
Repository

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Polymer and its matrix composites present highly rate-dependence, that is, their mechanical behaviors are distinctly increasing with the growing loading strain rate. Whereas, the potential intrinsic mechanisms are little reported, which are significant for designing advanced materials, and they link closely with microstructural evolution characteristics during deforming. But traditional investigations are based on deformed specimen remains partly due to absence of controllable dynamical recovery loading technique. Herein, a novel methodology is proposed to perform dynamical loading based on Hopkinson pressure bar technique, with loading and recovery deformation well controllable. Firstly, theoretical analysis is conducted by one-dimensional stress wave theory on both stress wave loading and recovery process, and the formulae are obtained for interpreting experimental raw data. Resultantly, a modified split Hopkinson pressure bar is specially established with a long incident bar and a short transmitted bar selected. And dynamical experiments are performed under various loading strain rates (500 /s and 2500 /s), with controllable series of loading strains and recovery strains. The dynamic mechanical responses are interpreted for the loading and recovery behaviors, and damage evolution characteristics of the investigated polyurea and propellant composite, and they are also assessed with these under quasi-static loading strain rates (0.0005 /s, 0.05 /s). Finally, the damage evolution trends are characterized, meanwhile the strain rate effect is uncoupled from the influence from adiabatic heating effect while analyzing series stress strain curves, and then potential damage mechanisms are proposed which is also verified with numerical simulations based on unit cell modelling.

The transversal profile of an edge flow in radial injection experiments at constant pressure: Theory vs. experiment

abst. 2067
Virtual Room
Thursday
September 3
08h45

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Experimental determination of permeability, which is the key parameter in resin transfer molding of composite preforms, received recently a special attention during International Benchmarks. Nowadays, unsaturated radial flow experiments tend to replace the rectilinear 1D experiments which are prone to the presence of an edge flow along the edges of the mold. However, recently some weak analogue of

an edge flow was observed for the radial flow as well along the surface of a mold. Thereby, a complex front profile (not plane and not perpendicular to mold surfaces) is observed. In the result, the front position in the middle of the preform thickness is delayed in comparison with the impregnation at mold's surface. If permeability values are measured by the observation of the front position at mold's surface, they no longer correspond to the impregnation at preform's mid-plane and need to be corrected. The phenomenon observed is very close to the so-called race-tracking phenomenon for which several theories have been developed. In our study, we compare analytical predictions with experimental results and find that the leading role in the formation of the front profile and, thereby, in the determination of the mid-plane delay for impregnation is played by the transversal (through preform thickness) capillary flow.

Failure of Composites

An assessment of the influence of grain and mass share of Al2O3 in epoxy resin upon the abrasive wear of composites to be used in friction pairs

abst. 2253
Repository

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Modern industries, especially mechanical engineering and automotive, are constantly searching for construction materials, which may, due to their enhanced useful properties and increased durability, replace the materials used so far. The simulations and laboratory tests comprehensively conducted over the manufactured engineering materials result from their later use in components of responsible structures of machinery or devices. Thus, the observed intensification of the development of materials engineering, apart from defining the obtained mechanical properties for a given material, also enforces the need to determine tribological properties, taking into account further possibilities of exploiting these materials in construction solutions, which include friction pairs. The article presents an analysis of findings of tribological examinations and selected examinations of mechanical properties conducted on a polymer composite with a matrix base of epoxy resin L285 cured with H285 hardener and a physical modifier of friction in the form of variable grain alundum and a mass percentage share of an additive. The produced samples were tested in conditions of abrasive wear in a reciprocating motion using the Taber Linear Abraser model 5750 tribotester. The abrasive stone, used in the test stand, was 6.6 mm in diameter. Its grain equalled 200. The friction path was 101.6 mm/cycle and the total load was equal to 1,850 g. After 200, 400, 600, 800 and 1,000 cycles, the sample mass was determined using precision scales. After each measurement, the products of friction were removed in accordance with the manufacturer's recommendations. The abrasive stone and the sample were cleaned. Next, the selected roughness parameters of the abrasive path of friction, covered by an anti-specimen, were measured using the optical profilometer FRT MicroProf 100. The surface wear was observed on the optical microscope OLYMPUS BX53M+. In addition, according to the norm PN-EN ISO 527-2:2012, static tensile testing was carried out. In the further part of the research programme, the samples were measured with regard to hardness using the Shore's method in accordance with the PN-93/C-04206 norm by means of an indenter mentioned in norm PN-93/C-04206. The samples were also exposed to the measurements of microhardness on the basis of the norm PN-EN ISO 6507-1:2018-05 and the norm PN-EN ISO 4516:2004. In addition, for each composite of different grain alundum and its percentage share, the authors determined density by means of the gravimetric method. Due to an introduction of a modifier in the form of alundum to epoxy resin, an increase in the additive mass share led to a considerable increase in Young's modulus, which was simultaneously correlated with an increase in the composite's hardness. Also, the effect of grain on tensile strength of the examined material was observed. It needs to be stressed that the maximum values were reached only for mass shares at a level of 5%. The author also observed a significant decrease in the weight loss of the sample which was affected tribologically. It was found that an addition of alundum improves the examined properties. For this reason, the materials are recommended to be used in machinery designs in friction pairs. Acknowledgements. The scientific work was carried out in the framework of the project "Analysis of the tribological properties of polymer composites used in aviation, exposed to surface layer wear" No. GB / 5/2018/209/2018/DA financed by the Ministry of National Defence in the years 2018-2022

A Computational Cost-effective numerical methodology for the simulation of the fatigue behaviour in composite materials.

abst. 2513
Repository

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Carbon fibre reinforced polymers (CFRPs) are widely employed in aeronautical structural load bearing components, thanks to their properties in terms of strength, stiffness, weight, and corrosion resistance, if compared to the commonly used metallic materials. Among the other failure mechanisms, fatigue is one of the main causes for CFRPs components collapse. Indeed, when subject to cyclic loading, CFRPs exhibit gradual degradation of the mechanical properties as a result of microcracks propagation. In this work, the empirical model, proposed by Shokrieh and Lessard, for the evaluation of the fatigue induced strength and stiffness degradation, has been implemented in the commercial Finite Element Code ANSYS MECHANICAL, by means of Ansys Parametric Design Languages (APDL). A cycle jump strategy, named SMART CYCLE strategy, has been introduced in the numerical model to avoid the simulation of every single cycle and save computational resources. The SMART CYCLE routine is able to predict cycles where fatigue failure criteria are likely to be verified and to limit the numerical simulation to these cycles where damages propagation in terms of fibre and matrix breakage is expected. The proposed numerical approach has been validated on 30° fibre oriented unidirectional coupons subjected to tensile-tensile fatigue loading condition. The numerical results have been compared with experimental data in terms of number of cycles at failure for different percentage of the static strength. Then, the proposed numerical methodology has been used to investigate the fatigue behaviour of a quasi isotropic open hole composite panel under compression-compression fatigue loading conditions.

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abst. 2249
Virtual Room
Wednesday
September 2
11h00

Experimental investigation on the mechanical performance of thermoplastic composites manufactured with automated fibre placement

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Automated fibre placement (AFP) is an advanced manufacturing process with high accuracy, repeatability, saved labour and high-throughput. Automated manufacturing of thermoplastic composites has been growing steadily for its recyclability and ease of processing. Still, manufacturing of thermoplastic composites with AFP is limited because of the manufacturing defects which affects the structural integrity of the final composite parts. In this paper, carbon/PA6 based thermoplastic laminates are manufactured through infrared lamp (IR) assisted AFP, IR provides the necessary heat to melt the prepreg and the melted prepreg are pressed against layer-by-layer to form a laminate. These laminates are prone to manufacturing defects and ultimately failure of laminates due to delamination, which need to be analysed for improving the process. A detailed experimental study on the strength and stiffness of the specimens manufactured with AFP are investigated. The mode of failure of the specimen during each test and the percentage of decrease in the structural performance of laminates are discussed.

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abst. 2399
Repository

INVESTIGATION OF DAMAGE PROGRESSION IN CURVED COMPOSITE LAMINATES UNDER STATIC AND FATIGUE LOADING BY USING DIC METHOD AND HIGH-SPEED CAMERA

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Composite materials are widely used in aerospace and wind energy industry due to their high specific stiffness. Especially main load carrying structures of airplanes and wind turbine are manufactured composite materials. These structures are comprised of complex shaped parts like curved parts and

experience both static and fatigue loading during their life time. High interlaminar tensile and shear stresses develops in curved shape structure due to these loadings, and these interlaminar stresses caused the delamination type failure [1,2]. A lot of research has conducted about the delamination of curved beam under static loading. However, to the best of author knowledges, failure strength of curved beam under fatigue loading was investigated by Martin and Jackson [3] and failure mechanism of that was investigated by Tasdemir and Coker [4]. This paper presents the experimental investigation of damage progression in curved CFRP laminates under static and fatigue loading. Experiments were conducted with specimens having [03/903/03/903/03]s of stacking sequence. ARAMIS DIC software is used to observe the damage in specimen by looking in-situ mises strain field of specimens during experiments. Under static loading DIC photos were taken at 3 Hz frequency while under fatigue loading, these were taken at peak loads of cycles. Static experiments were conducted under displacement control with 1 mm/min test speed. Displacement range applied in the fatigue experiments is determined according to the results of static experiments, and 2-4 mm of displacement range is applied at 2 Hz frequency to specimens in fatigue experiments. Some static experiments were also conducted with Photron high-speed camera for detail investigation of the initiation and propagation of delamination. High-speed pictures were taken at 100.000 fps. Our results show that the failure mechanism and location of specimens under fatigue loading are different than that under static loading. Under static and fatigue loading, failure occurred due to delamination. In fatigue specimens, delamination is driven by the growing microcracks in the second inner 90° grouped plies where radial stress is maximum. On the other hand, in static experiments, delamination is driven by the matrix cracks in the first inner 90° plies where failure index has the highest value according to the Tsai-Wu criteria. REFERENCES: [1] F. Chang and G. S. Springer, "The Strength of Fiber Reinforced Composite Bends," Journal of Composite Materials, vol. 20, no. 1, pp. 30-45, 1986. [2] C.T. Sun and S.R. Kelly, "Failure in Composite Angle Structures Part I: Initial Failure," Journal of Reinforced Plastics and Composites, vol. 7, no. 3, pp. 220-232, 1988 [3] R. H. Martin and W. C. Jackson, "Damage Prediction in Cross-Plied Curved Composite Laminates," Composite Materials: Fatigue and Fracture, vol. 4, pp. 105-126, 1993 [4] B. Tasdemir and D. Coker, "Comparison of Damage Mechanisms in Curved Composite Laminates under Static and Fatigue Loading", Composite Structures, vol. 213, pp. 190-203, 2019

Microstructural characteristics and tensile damage evolution of the plain weave SiC/SiC composites using X-ray computed tomography

abst. 2660
Virtual Room
Wednesday
September 2
10h15

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Damage evolution of textile ceramic matrix composites is very complex, which has always been a challenge for researchers. In this paper, a miniature high-precision in-situ tensile tester has been developed to conduct nano X-ray CT in-situ tensile tests on the third generation SiC fibre toughened plain weave laminated SiC/SiC composites. Through the three-dimensional reconstruction of the CT scan data, the real morphology of the initial microstructures, and the damage evolution of the material under six successive loading levels have been revealed. On this basis, the changes of a series of damages, such as the matrix cracks, with the increase of tensile load have been analysed. Quantitative analysis on damage evolution has also been carried out. It indicates that there are a large amount of initial porosity in the material, including matrix micro-pores and large voids, due to the CVI process preparation and the complexity of weaving. The distribution of porosity has obvious stratification phenomenon: the matrix micro-pores (small in volume and large in quantity) are distributed along the longitudinal directions of fibre tows; while the large voids (large in volume and small in quantity) are mainly distributed in the central cross area of the warp and weft tows in each layer. In the loading process, the initiation and propagation of cracks have a great influence on the number, volume and distribution characteristics of

porosity. In general, the volume of porosity increases, while the number of pores increases first and then decreases. Matrix cracking within fibre tows, caused by the propagation of matrix micro-pores, mainly affects the number of pores, while cracks outside the fibre tows, caused by the propagation of the large voids, mainly affect the volume of porosity. In addition, the porosity in the vicinity of a fracture surface is higher than that of other parts due to the pull-out of the fibres after a tow rupture. The porosity decreases with the increase of the distance from the fracture end. Finally, the damage evolution and the failure mechanism of the plain weave SiC/SiC composites have been summarised.

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abst. 2381
Virtual Room
Wednesday
September 2
10h30

Damage Interaction in Carbon Fibre Reinforced Polymer Laminates under In-Plane Loading

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Carbon fibre composites are critical under various types of loading condition which is widely used in aerospace industry. In this Paper, progressive failure analysis has been presented for the carbon fibre composites laminates with open hole under in-plane loading condition. The open hole specimen has stress concentration near the hole region, thus failure will initiate from this region. Two types of composites laminates has been selected (namely, CCF300/QY8911 & T300/QY8911 with stacking sequence [45/0/-45/90]2s) for the numerical study to compare the residual strength, delamination etc. The CCF300/QY8911 composite has weak interfacial strength compare to T300/QY8911 composite which produces massive delamination, and splitting bond. Based on the failure mechanism analysis, 2-Dimensional and 3-Dimensional finite element modelling techniques (ABAQUS 6.14) were used for simulation, failure interaction and residual strength prediction. In-built Hashin damage criteria has been applied for progressive damage analysis in 2-Dimensional model. Further, in 3-Dimensional model, Interface cohesive elements were inserted to incorporate the matrix cracking and delamination. Matrix cracking initiation in the cohesive elements was based on stress traction separation laws and propagated under mixed-mode loading. Hashin Damage criteria is also, implemented by using VUMAT subroutine. Proposed 3-D model could well simulate the failure interaction and residual strength and compared with the already reported literature. Furthermore, delamination defect around the hole was also investigated.

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abst. 2518
Virtual Room
Wednesday
September 2
10h45

Delamination and Matrix Cracking in Curved shape Randomly oriented Glass Fibre Composite under Pull-out Test

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The load applied to curved shape composites, attempt to unfold the laminate, and prone to delamination failure. Due to the failure, strength and the stiffness of the laminated composite reduces. Further, matrix and fibre cracking are other major failure's mode in a curved composite laminate. Pull-out test is performed to determine the strength and the various failures of the glass fiber composite. Composite laminates are fabricated using randomly oriented glass fiber in curved shapes using hand-layup method and it's curing has been done by keeping 24 hr at room temperature. All the fabricated curved specimens were experimentally tested for pull-out test on UTM by following the ASTM D-6415 standard. The applied load tries to unfold these laminates and various interactions of failures is examined through an optical microscope. The average ultimate load obtained from the experimental pull-out test is 198 N. Further, failures in the laminates are captured from an optical microscope & Nikon DSLR camera (D7000) and and analysed. It is confirmed that firstly, matrix cracks occur and that leads to the delamination failures in the curved laminates. Also, the curved laminate is numerically simulated

by using commercially available Finite Element Method software "ANSYS 19.0". Damage modelling is studied by including Hashin failure criteria for damage initiation and stress-based damage evolution law. Furthermore, the cohesive zone method is selected to check the interlaminar delamination in the model. Average load carrying capacity obtained from the numerical simulation is 192 N. Therefore, numerical results gave a good agreement when compared to experimentally obtained load carrying capacity.

Multiple-criteria failure analysis of top-hat cross-section GLARE composite members subjected to compression. Numerical and experimental study.

abst. 2298
Virtual Room
Wednesday
September 2
11h30

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This study deals with a failure analysis of thin-walled GLARE columns subjected to axial compression. Considered GLARE structure is a hybrid composite that consists of alternating thin layers of aluminium alloy sheets and unidirectional glass fibre-reinforced prepregs. Comparative study was performed for different thin-walled, open cross–section members that included channel, Z-shape and top-hat sections. Main focus of this study was to assess the performance of top-hat-shaped sections which provided the highest strength when subjected to corresponding axial compression. Various 3/2 symmetrical lay-ups were investigated for which 7 stacking sequences were distinguished based on fibres alignment in the composite layer. GLARE composite specimens were manufactured by autoclaving technique which provided the high-quality of multi-layered laminates. The compression failure test was performed in laboratory by a universal electromechanical strength testing machine of Instron upgraded with Zwick/Roel control software. Double column static testing unit had a maximum capacity of 200kN for which applied screw type testing machine provided a displacement control loading of 1 mm/min. Simultaneously, numerical simulations by FEM were performed to predict the damage of the multi-layered GLARE structures in a post-buckling state. Strength analysis of GLARE top-hat-shaped columns was computed by means of various failure criteria applied for aluminium and composite plies separately. Based on these criteria, failure factors (FF) were determined to assess the potential failure initiation in the laminate. Each composite layer was defined separately and therefore failure factors were computed independently throughout the whole structure. FEM computations allowed one to distinguish particular areas of the columns which are greatly exposed to damage. Numerical results were found to be in a good agreement with experimental tests. An attempt has been also performed to determine the relationship between different types of damage in thin-walled FML composite structures and to understand the mechanisms of damage formation and propagation in laminates.

Modelling Composite Failure through Machine Learning

abst. 2333
Virtual Room
Wednesday
September 2
11h15

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Failure in composite materials has been studied for a long time due to their massive industrial applications, which remains a challenging issue to the composite industry. Numerical methods in micromechanics, such as using finite element method (FEM) and discrete element method (DEM), have been applied to investigate damage progression in unidirectional fibre-reinforced polymer (FRP) composites. The existing studies showed that DEM can provide unique insight into crack initiation and propagation of composites and the simulation results agree well with the experimental ones. However, the numerical simulation at micro-scale for failure prediction is time consuming, which is one of the significant computational challenges that must be addressed before applying the method to general composite structures. Works on reducing computing cost without significant reduction in accuracy are therefore urgently required. Currently, data-driven efforts aided by machine learning techniques have achieved unquestionable successes in, e.g., computer vision, telecommunication, molecular science and many other applications. These informatics strategies are beginning to take shape within materials science. Using material design data and advanced computer models, engineers can realistically simulate the behaviour of materials in specific applications and avoid lengthy cycles of building and testing. The new field, computational materials science supported by machine learning techniques, is becoming one of the fastest growing areas within the field of materials science. In this paper, two efficient machine learning (ML) models, i.e., Gaussian Naïve Bayes classifier and Artificial Neural Networks (ANNs), are developed to predict cracks and failure of uniaxial fibre reinforced composites subjected to transverse tension. A 2D DEM model is used to simulate the micro structure including the randomly distributed fibres, the crack development and the failure of the composites. The composite is discretized to discrete elements with their own distinctive geometric features. The ANNs is composed of four fully connected layers with a back-propagation learning algorithm. These sets of elements serve for the learning process of the ML models to predict the final crack states at failure. The machine learning results show that the major crack paths of the composites are satisfactorily predicted by the trained models with lower computational cost while maintaining good accuracy. The results also show that the accuracy of the predictions highly depends on the features that are chosen to represent the microstructures of the composites as well as the size of the pool of the sample data. It can be concluded that the ANNs based ML model is better placed in predicting failure because of its advantages in dealing with complicated continuous feature data.

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abst. 2105
Virtual Room
Wednesday
September 2
12h00

In-situ mechanical testing of an interpenetrating metal matrix composite consisting of a slurry-based ceramic foam and an AlSi10Mg alloy

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Light-weight materials for structural application with thermal load play a key role in nowadays engineering success regarding to reduction of greenhouse gases and environmentally compatible implementations in mobility and transportation. By combining light-weight metals with ceramics, improved mechanical properties, as well as wear resistance of the composite can be achieved and the reached limits of light weight metals can be outperformed. Such metal matrix composites (MMC) were usually produced using reinforcing ceramic particles or fibers. Industrial application like e.g. piston rings, brakes, engine blocks, connecting rods and propeller shafts [1] show the high potential of this material group. Using an interpenetrating phase composite (IPC) instead of particles, fibers or similar discontinuous reinforcements, higher strength, stiffness and hardness, as well as wear resistance and reduced thermal expansion coefficients can be reached [2]. This is due to the hybrid microstructure of IPCs with both phases building up a complex 3D structure with two continuous constituents. By high production costs - mainly of the ceramic preform - these interpenetrating MMCs are not economically for a broad field of application yet, despite their promising mechanical properties. By using a novel production technique, a macroscopically high homogeneous and low-cost ceramic preform can be fabricated by Morgan Advanced Materials Haldenwanger GmbH, which holds a patent on the manufacturing process [3]. The

homogeneity of the preform promises reproducible and representative properties for small geometries of less than a cubic centimeter already, while the low production costs warrant to facilitate the transfer of bench-scale to industrial application. Based on this ceramic preform an innovative MMC is produced via gas-pressure infiltration with a cast aluminum alloy (AlSi10Mg). The already mentioned complex interpenetrating structure makes it difficult to apply a given failure mechanism theory to the composite material. Preliminary investigation of 2D in-situ compression tests on the surface of composite samples show that a complex 3D failure mechanism inside the material is to be expected. To predict the properties and limitations of this material 3D in-situ investigations are necessary. Compression tests with an in-situ X-ray computed tomography are developed and carried out to get an understanding of the material crack growth and crack propagation, as well as its failure mechanisms. References: [1] R. Asthana, A. Kumar und N. B. Dahotre, Materials processing and manufacturing science. Amsterdam, Elsevier, Acad. Press, 2006. [2] A. Mattern et al., „Preparation of interpenetrating ceramic–metal composites“, Journal of the European Ceramic Society, Jg. 24, Nr. 12, S. 3399–3408, 2004. [3] Lavrentyeva, Oksana, Dr., "Verfahren zur Herstellung von aufgeschäumten keramischen Werkstoffen sowie dadurch herstellbarer keramischer Schaum," DE102015202277A, Apr 28, 2016.

Progressive fracture analysis of the open-hole composite laminates: experiment and simulation

abst. 2248
Repository

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A conforming augmented finite element method (C-AFEM) is proposed to predict the failure process in inter-ply of fiber-reinforced composite laminates. Combining with cohesive zone model (CZM) element, the delamination between inter-plies can also be captured. Matrix fracture, fiber fracture and delamination in inter-plies will occur when the composite laminate fracture, which is a complicated process, and the current method appears capable of modelling failure mechanism of composite laminates, which is demonstrated mesh-independent, high-fidelity and robust. Different stacking open-hole composite laminates subject to tension load are tested by electrical measurement and Digital Image Correlation (DIC) system. Then the proposed C-AFEM is applied to model progressive failure of open-hole composite laminates and the results are found to agree with experiments very well.

Analytical and experimental investigation of the effects of out-of-plane fiber waviness on the mechanical properties of composite materials

abst. 2594
Repository

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Out-of-plane fiber waviness is a common effect inherent to various manufacturing processes of fiber-reinforced composite parts. They cannot be completely avoided and therefore have to be tolerated and

be considered as an inherent part of the structure. To this point, there is still no acceptable approach in the aircraft industry to quantitatively support accept/reject/repair-decisions and make a consistent assessment of wavy layers in composites. Fiber misalignments in general are known to have a detrimental effect on the compressive strength of composite materials. The presence of wavy layers in a laminate leads to a complex local stress state, even at simple global load states. Interlaminar shear failure is predicted to be the dominant failure mechanism that is followed by delamination and layer-wise buckling. The associated shear stress 13 is, according to Hsaio and Daniel [1] the most significant stress component for wavy composites under axial compression. This research contributes to a better understanding of the material behavior and its effective mechanical properties for global compressive and tensile loading in longitudinal direction. We extended traditional analytical approaches and validated them with results from experimental tests. Previous developed models have mainly focused on UD laminates, where all layers are oriented in the same direction, and have concentrated on the effect of fiber waviness on the stiffness. The analytical model is based on the work of Hsiao & Daniel [2] and Altmann et al. [3] where the waviness in a unidirectional laminate is mathematically represented as in-phase sine-waves. The developed micromechanical model represents an extension of these models for multidirectional laminates and is implemented in a MATLAB GUI to determine the effective elastic properties as well as the resulting complex stress state. The failure criterion LaRC03 [4] and the well-established Puck criterion [5] are implemented and applied on the calculated stresses to predict local ply failures and determine the strength of the plies consisting of uniform or graded fiber waviness. The analytical model was validated by experimental tests and the results show good agreement. Mechanical tests, i.e. compression and tension, were accompanied by digital image correlation (DIC) with a GOM Aramis 3D 12M system to detect the corresponding strain distributions and to better understand the material behavior of laminates containing fiber waviness. [1] Hsiao HM, Daniel IM. Effect of fiber waviness on stiffness and strength reduction of unidirectional composites under compressive loading. Compos Sci Technol 1996;56:581–93. doi:10.1016/0266-3538(96)00045-0. [2] Hsiao HM, Daniel IM. Elastic properties of composites with fiber waviness. Compos Part A Appl Sci Manuf 1996;27:931–40. doi:10.1016/1359-835X(96)00034-6. [3] Altmann A, Gesell P, Drechsler K. Strength prediction of ply waviness in composite materials considering matrix dominated effects. Compos Struct 2015;127:51–9. doi:10.1016/j.compstruct.2015.02.024. [4] Pinho ST, Dávila CG, Camanho PP, Iannucci L, Robinson P. Failure Models and Criteria for FRP Under In-Plane or Three-Dimensional Stress States Including Shear Non-linearity. Tm-2005-213530 2005:68. doi:NASA/TM-2005-213530. [5] Puck A, Schürmann H. Failure analysis of FRP laminates by means of physically based phenomenological models. Fail. Criteria Fibre-Reinforced-Polymer Compos., 2004. doi:10.1016/B978-008044475-8/50028-7.

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abst. 2489
Repository

Failure assessment of thin-walled, composite columns with a square cross-section including curing prestress

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Residual stresses, formed in the autoclaving process, are the result of thermal shrinkage during curing of the laminate. It is especially visible in the structures having closed cross-section where extra constraints are applied to the system and higher stresses are trapped inside the laminate. These stresses might be responsible for changes in buckling behaviour and damage properties of the structures. This study combines both aspects of the structural performance of composite structures. Under inspection is taken compression of thin-walled, squared cross-section columns with following dimensions: (width $\times$ height $\times$ thickness): 82 mm $\times$ 82 mm $\times$ 2 mm made of 8-layer GFRP prepreg. The length of the tubes is equal to 250 mm. Specimens with six different layups were manufactured using autoclaving technique and experimentally tested. The goal of this study is to numerically evaluate failure loads of considered columns including residual stresses coming from the curing process and compare them with the experiment. The first step of the analysis is to model, in a simplified manner, curing process of the laminate. Obtained in this way, residual stresses distribution is transferred into the model of tubes' compression. In non-linear buckling analysis, the progressive failure mode is turned on. This enables to reduce stiffness in the elements in which failure criteria are exceeded. To evaluate the structural

capacity of the columns Hashin criterion is employed. The results of FEM analyses are compared with the experiment.

Material model for plain weave fabric composites under compression load

abst. 2302
Repository

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In composite aircraft structures, woven carbon-fiber reinforced composites are used as elements of the boxes to mitigate damage during crash events and provide a measure of protection for the passengers against abrupt decelerations. Due to their multiscale damage effects and complex coupling between failure mechanisms, despite years of extensive works of researchers around the world, a complete and validated methodology for predicting crushing behavior of woven composite structures has not yet been achieved. The aim here is thus to present, for the best of our knowledge, a new material model developed to predict the crush behavior of CFRP plain weave composite hat-shape cross section coupon. Quasi-static crush tests for plain weave fabric composite coupons CMO are performed and detailed numerical investigations are proposed. Eight layers of stacked solid elements model was used with saw teeth-type and 45°chamfer-type triggering mechanisms to ensure a continuous stable crushing mode of failure. The elementary failure mechanisms involved in the crushing of specimens are analyzed. A computational model, which accounts for intralaminar damage, implemented as a user subroutine VUMAT in Abaqus/Explicit was developed and used. A comparison between experimental and numerical results confirms the computational tool's accuracy in predicting the energy absorption and damage mechanisms of Hat-Shape specimens. The developed approach could significantly reduce the cost of physical testing required in the development of crashworthy structures and help provide a predictive tool to estimate the energy absorption.

Experimental testing and of modelling of gradual degradation of Al2O3/ZrO2 ceramic composite under slow and high strain rates

abst. 2496
Repository

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Gradual degradation of brittle composites exhibits different mechanical response under uniaxial tension and uniaxial compression. In this paper we analysed cracking processes and failure under quasi-static loading of 2 phase ceramic material made of Al2O3 and ZrO2 mixture, subjected to tension and compression. Constitutive modelling of two phase ceramic composites obeys description of: (1) elastic deformations of initially porous material, (2) limited plasticity and (3) cracks initiation and propagation. Modelling of polycrystalline ceramics at mesoscopic level under mechanical loading is related to analysis of a set of grains, i.e. Representative Volume Element (RVE). The basic elements of the defect structure inside polycrystal are: micro- and meso-cracks, kinked and wing cracks. To get macroscopic response of the material one can calculate averaged values of stress and strain over the RSE with application of analytical approach. High strain rate degradation process was illustrated for Al2O3/ZrO2 composite, which was subjected to short compressive impulse. The pulse duration was 10-7s. In the proposed more advanced finite elements formulation it was necessary to take into account the following data and phenomena appearing inside of the RVE: (1) spatial distribution of the composite constituents, (2) system of grain boundaries/binder interfaces modelled by interface elements, (3) rotation of brittle grains. The numerical model of gradual degradation of the Al2O3//ZrO2 composite response due to pulse compressive loading presents correctness and capability of the proposed FEM approach.

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abst. 2466
Virtual Room
Wednesday
September 2
11h45

Residual stress measurement in a metal/FRP hybrid structure

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Lightweight materials contribute to an efficient decrease of fuel consumptions in automotive and aircraft industries. Hybrid structures made up by metal and fibre reinforced plastics (FRP) have a high potential in lightweight applications due to their high specific strength and stiffness. For cost and time effective processing of hybrid materials, new processes such as the prepreg-press-technology have been developed, in which the bonding between a metallic material and a fibre compound is exclusively realized by adhesive forces. However, upon processing of these hybrid structures at high temperature, the free or restricted warpage of the component induced by cooling leads to the formation of residual stresses. It is well known that these residual stresses are relevant for the mechanical performance of the material and have a significant impact on the durability of the hybrid structure. The objective of this work is to accurately measure the residual stresses in the hybrid material through incremental hole drilling method, employing a novel formalism to evaluate the residual stresses based on the released strains during drilling. The work tries to cover distribution of residual stresses across the thickness of the hybrid structure with focus on the transition zone between metal and FRP. Methods used for measuring the residual stress, i.e. nondestructive and destructive methods, are compared in terms of applicability and reliability.

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abst. 2497
Repository

Duality between surface texturing and static and fatigue tensile behaviour of 3D woven composite specimens milled with abrasive water jet for repair application

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In a context of environmental awareness, the aviation industry has to reduce the fuel consumption of their aircrafts. To address this regulation, 3D woven Carbon Fibre Reinforced Polymer (CFRP) composite materials, having great strength to weight ratio, have been introduced in the aircrafts' inner and outer structures. In the last case, parts are exposed to several types of damage (e.g. erosion or impact in flight) which can reduce their service life. For obvious financial motives, their maintenance consists in repair of the damaged zone on every possible occasion. This kind of operation is mainly performed by conventional machining process. However, machining CFRP by conventional means creates thermal (matrix degradation) and mechanical (fibre breakage) defects and may be dangerous for the operators due to carbon dust emission [1]. To overcome these issues, non-conventional Abrasive Water Jet (AWJ) machining technique has proven to be a suitable alternative method. Indeed, the machined structures being in a water pool, the spread of dust and the elevation of temperature are greatly reduced. Though used on various materials (from titanium alloy to CFRP laminates), AWJ machining has been scarcely studied on 3D woven CFRP composites [2]. As for every machining process, AWJ machining technique induces defects and damage which can lead to a drop of the parts' mechanical performances. Many researches have proven that the changes in mechanical behaviour are linked to the surface quality of the machined structures. In case of CFRP, Hejjaji et al. [3,4] proposed a new quality indicator called "crater volume" (Cv) which better correlates with the tensile ultimate strength and endurance limit of AWJ milled laminates made of unidirectional plies than the traditional Ra criterion. From the authors knowledge, no similar studies have been carried out on AWJ milled 3D woven composite. The goal of this work is then to analyse the link between the AWJ machining induced surface quality of 3D woven composite specimens and their static and fatigue tensile behaviour. Three

different surface qualities have been produced on dog-bone specimens. After the texturing phase, these qualities have been quantified by the "crater volume" (Cv) criterion. The machined specimens of each quality have then been subjected to static tensile test until failure in order to obtain their ultimate tensile strength. Thanks to this data, tension-tension fatigue tests have been performed (stress ratio R = 0.1, frequency of 8 Hz) to estimate the endurance limit of the textured specimens using the temperature stabilization method. Multi-instrumentation has been set-up for both kind of mechanical tests (viz. extensometer, acoustic sensor, Digital Image Correlation and thermal camera) in order to follow the damage scenario. It has been shown that there is a correlation between Cv and the changes in ultimate tensile strength (UTS) of the AWJ textured specimens. Indeed, an increase in Cv (i.e. a decrease in surface quality) by a factor 2 leads to a drop in UTS by 16%. However, there seems to have no clear effect of Cv neither on the stiffness of the specimens, nor on their tension-tension endurance limit. [1] Haddad et al. Study of the surface defects and dust generated during trimming of CFRP: Influence of tool geometry, machining parameters and cutting speed range. Comp Part A Appl Sci Manuf 2014. [2] Sourd et al. M. New model for the prediction of the machining depth during milling of 3D woven composite using abrasive waterjet process. Comp Struct 2020. [3] Hejjaji et al. Surface and machining induced damage characterization of abrasive water jet milled carbon/epoxy composite specimens and their impact on tensile behavior. Wear 2017. [4] Hejjaji A et al. Influence of controlled depth abrasive water jet milling on the fatigue behavior of carbon/epoxy composites. Comp Part A Appl Sci Manuf 2019.

Numerical and experimental investigation on axial compression performance of multi-impacted braided tube

abst. 2584
Repository

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Tubular braided components are competitive candidates for construction of commercial aircraft fuselage frames [1], automobile and unmanned aerial vehicles (UAV) bodies [2, 3]. As structural components, the composite tubes are susceptible to transverse impact loading events during lifetime, such as dropping of tools or hitting by gravel, hail and debris. In reality, repeated impacts happen even more often than single impact and always occur at different positions [4-6]. The damage induced by single impact may not be observed by naked eye. However, it can easily accumulate and progress in repeated impact and possibly cause significant reduction in structural integrity and residual crashworthiness characteristics. Therefore, it is worthwhile to investigate the effects of pre-impact damages on the damage behaviors and residual crashworthiness of braided tube subjected to compression after repeated impact loading. Due to observation difficulties in experiment, numerical simulation approach is also in demand to understand the dynamic responses and revealing the failure mechanisms of braided tubes. In this study, damage behaviors and residual crashworthiness characteristics of braided composite tube with transverse pre-impact damages subjected to axial compression were investigated. The compression tests were conducted on intact, single impacted and repeated impacted tubes at identical, adjacent and opposite positions to analyze the effects of impact damages. A multi-stepped finite element model considering the progressive damage characteristics was developed in ABAQUS/Explicit to predict the failure behaviors of braided tube. It was found that the damage behavior of braided tube subjected to axial compression was dominated by the propagation of delamination damage induced by impact. The impact damage served as a failure trigger, leading to a decreased residual peak load. Single impact produced limited delamination area and the propagation was also suppressed in compression process, resulting in similar progressive folding damage mode and remained mean load and energy absorption as in intact tube. Its residual CFE value was thus increased. Repeated impacts at different impact positions generated delamination areas which further expanded or had no correlation to that induced by single impact. The rapid propagation of delamination damage caused splitting fracture of the composite layers in compression process, resulting in significantly reduced residual crashworthiness characteristics. The proposed multi-stepped numerical model demonstrated its ability for simulating the damage behaviors of braided tube subjected to compression after repeated impact loading scenario. Reference

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Fiber reinforced cementitious composites (chaired by A. Abrishambaf, M. Pimentel, S. Nunes)

Influence of fibre types on the performance of repair cementitious composites

abst. 2520
Repository

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The major concern associated with the regular repair of our deteriorating infrastructures and the need to improve the sustainability of repair materials has called for a need to develop high-performance composites that are environmentally friendly. Some of the major performance challenges associated with the conventional cementitious composites are their low ductility and high shrinkage. In order to overcome these challenges, short fibres can be incorporated as reinforcement in the composites to enhance its ductility and shrinkage resistance. However, as there are many types of fibres; it is essential to understand how each type of fibre affects the performance of the composite. In this study, high volume fly ash (i.e. 2.2 times Portland cement) which is a waste product was incorporated as the binder component in order to improve the sustainability of the developed cementitious composites. Four types of short fibres were used as reinforcement at a dosage of 2% to produce repair composites with higher flexural capacity and shrinkage resistance. The fibres used are polyvinyl alcohol, polyolefin, polypropylene and basalt. The properties of the repair composites were evaluated in terms of the compressive strength, tensile strength, flexural strength, drying shrinkage, porosity and sorption. The findings from this study showed that the incorporation of the fibres into the composite increased the porosity of the composites. Nonetheless, there was a significant enhancement in the flexural strength, tensile strength and shrinkage resistance with the incorporation of the short fibres.

Multiscale investigation on the tensile response of ultra-high performance fibre-reinforced cementitious composite incorporating Spent Equilibrium Catalyst

abst. 2138
Virtual Room
Thursday
September 3
10h45

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Ultra-high performance fibre-reinforced cement composite (UHPFRC) designates a family of composite materials with superior mechanical properties and durability performance, containing a high amount of binder (cement and silica fume), very low water/binder ratio and a high content of short discrete steel fibres. Spent Equilibrium Catalyst (ECat) is a waste material generated by the oil refinery industry. ECat was shown to act as an internal curing agent and its incorporation as a supplementary cementitious material in ultra-high performance fibre-reinforced cementitious composites (ECat_UHPFRC) allowed reducing the autogenous shrinkage of the composite [1]. In this research, fibre to matrix bond properties and uniaxial tensile behaviour of a UHPFRC mixture incorporating ECat is investigated. The results are compared to a previously developed conventional UHPFRC. Both mixtures have a compressive strength of around 150 MPa. In order to characterize the bond properties, a series of single fibre pullout tests are performed on short and smooth brass-coated steel fibres with a length, lf, of 13 mm and a diameter, df, of 0.2 mm embedded in ECat and conventional ultra-high performance cementitious mixtures, UHPC. The fibres have an embedded length of lf / 2 and fibre orientation angles 0, 30 and 60 degrees. SEM morphology analysis is performed on the surface of the pulled-out fibres from each matrix. At the composite level, uniaxial tensile tests are performed on dog-bone UHPFRC specimens with 3% fibre volume fraction and two fibre orientation profiles: randomly and well-oriented [2]. The number of fibres in the fracture surface is counted to determine the fibre structure parameter as discussed in [2] and correlate this parameter to the tensile fracture parameters. Fibre pullout test

results show a significant improvement in the interfacial bond properties of the inclined fibres (30° and 60°) compare to the align fibres (0°), owing to a snubbing effect that improves the frictional bond between the fibre and matrix. The fibre surface morphology analysis confirms a higher level of damage on the surface of the inclined fibres is observed. For all the inclination angles, both mixtures show a close fibre debonding force. However, a slightly higher maximum force and pullout work are achieved for the fibres embedded in ECat_UHPC. SEM analysis illustrates that, in a fracture surface, some ECat particles are broken or debonded from the matrix. These extra abraded fine particles are squeezed against the surface of the fibre when the fibre moves in its matrix channel, increasing scratching and delamination of the fibre brass coating, and contributing to higher interfacial shear resistance. This fact is also confirmed by the fibre surface morphology analysis which demonstrates slightly higher friction between the fibre and ECat_UHPC. From the uniaxial tensile test results, the tensile behaviour is significantly improved in the case of the well-oriented specimens. For both mixtures, a strong correlation between the fibre structure parameter and tensile fracture parameters is achieved. The tensile stress at crack initiation is slightly reduced in ECat_UHPFRC. In the post-cracking stage, no significant change is observed between the fracture parameters for each matrix which confirms the adequate performance of the new ECat_UHPFRC mixture for structural applications. References: [1] Matos, A.M., Nunes, S., Costa, C., Barroso-Aguiar, J.L. Spent Equilibrium Catalyst as Internal Curing Agent in UHPFRC. Cement and Concrete Composites, 104 (2019) 103362. [2] Abrishambaf, A., Pimentel, M., Nunes, S. A meso-mechanical model to simulate the tensile behaviour of ultra-high performance fibre-reinforced cementitious composites. Composite Structures, 222 (2019) 110911.

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abst. 2564
Repository

Mechanical behaviour of composite sandwich panels with foamed concrete cores reinforced with polypropylene and henequen fibres

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The four-point bending response of composite sandwich panels made of corrugated steel faces and foamed concrete core, developed by the pre-foaming method with a target dry density of 700 kg/m3, is reported. Three different foamed concrete cores were used for the composite sandwich panels, i.e., plain foamed concrete (PFC) core, foamed concrete core reinforced with the natural fibre henequen (Agave fourcroydes Lem.) (HFRFC), and foamed concrete core reinforced with polypropylene fibre (PFRFC), at a fibre volume fraction of 1%. For the sandwich panels with HFRFC, henequen fibres were treated with a 2% (w/v) sodium hydroxide (NaOH) aqueous solution. Quasi-static uniaxial compression and tension tests were performed on the foamed concrete cores. The sandwich panels were manufactured using corrugated steel faces with a nominal thickness of 0.45 mm. The two faces were separated 40 mm using fasteners. A mould containing both faces was manufactured, and the foamed concrete was cast into the mould. The sandwich panels were left for 28 days for curing at room temperature. The compression and tension test results showed that for all fibre-reinforced foamed concrete (FRFC) mixtures, the inclusion of the fibres improved the compressive and tensile strengths and the plastic behaviour when compared to the PFC, which was attributed to the enhanced specimen integrity produced by the fibres. For the PFC, after the peak strength, a sudden failure of the specimens was observed, while for the FRFC specimens, the fibre-reinforcement prevented a sudden failure, allowing the specimens to withstand a percentage of the maximum strength as the displacement increased, which was in contrast to the brittle behaviour of the PFC. The four-point bending tests of sandwich panels showed that fibre-reinforcement

allowed the panels to withstand a greater initial peak failure load, which is attributed to the enhanced strength (both tensile and compressive strengths) of the FRFC cores. After the peak failure load, in all cases, there was an increase in the supported load, which resulted in an apparent strengthening of the panels. This was mainly attributed to the transfer of shear resistance from the core to the fasteners. The reinforcement with polypropylene fibre was the most effective in increasing the maximum load capacity of the panels. For the PFRFC and HFRFC cored panels, there was an increase of 20% and 8% in the maximum load, respectively, when compared to the panels without reinforcement. Finite element simulations were performed to investigate the influence of the face-core bonding on the four-point bending response of the panels. It was found that the face-core bonding plays a very important role in the structural performance of the sandwich panels, which indicates that improvement of the face-core bonding should be addressed when foamed concrete core is used in these types of structures to obtain optimum structural performance. Further experimental and numerical investigations should be performed to assess the performance of these FRFC cored sandwich panels for structural applications. This work was financially supported by CONACYT Problemas Nacionales 2017, grant No. 6718.

Performance of Concrete Columns Strengthened with Fabric Reinforced Cementitious Matrix (FRCM)

abst. 2278
Repository

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Concrete structural elements are in constant exposure to external conditions that have deteriorating effects on their properties. Exposure types include corrosion and seismic loads, which acting solely or combined can cause structural elements to lose a considerable percentage of their strength. Several techniques have been used in the past as a solution to such problems, such as retrofitting concrete elements with epoxy-based fabrics made from Fabric Reinforced Polymers (FRP's). Another recently emerging technique has been using Fiber Reinforced Cementitious Matrix (FRCM) to retrofit damaged structures. FRCM is an inorganic matrix that consists of textile layers sandwiched between cementitious mortar. The textile mesh can be either made of poly-paraphenylene-ben-zobisoxazole (PBO), aramid, carbon or glass. Several studies have been conducted to better understand the behavior of FRCM due to its numerous qualities that include its extremely low weight-to-strength ratio, high tensile strength, compatibility of the binding agent with the original concrete substrate and resistance to high temperatures. The aim of this paper is to study the effects of retrofitting newly constructed short concrete columns with PBO FRCM. A total of 12 columns will be cast with concrete that has a compressive strength of 30 MPa, where all columns will have a reinforcement ratio of 0.02. The effects of varying the type of cross-section, number of FRCM layers and tie spacing will be analyzed and compared. 6 columns will have a rectangular 150x150 mm cross-section and will be reinforced with 4 12 bars. The other 6 columns will have a circular cross-section with a diameter of 170 mm and will be reinforced with 6 10 bars. A standard compression test will be conducted on all specimens where a monotonic load increases incrementally until failure. The investigated parameters will include capacity, ductility and ease of FRCM installation.

Mechanical properties of carbon fiber reinforced concrete (CFRC) after exposure to high temperatures

abst. 2446
Repository

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This paper presents the mechanical properties, residual mechanical properties, and microstructure of carbon fiber reinforced concrete (CFRC) heated at different temperatures. Seven kinds of CFRC with different carbon fiber content (0 wt%, 0.2 wt%, 0.6 wt%, 1.0 wt%, and 1.4 wt%) and carbon fiber length (5 mm, 7 mm, and 10 mm) were prepared. The compressive, flexural, and splitting tensile strength of CFRC at room temperature, 400 °C, 600 °C and 800 °C were tested. The microstructure and carbon fiber failure mode of the fracture surface of CFRC were observed by scanning electron microscopy (SEM). The test results show that the addition of carbon fibers results in a limited improvement in the compressive strength, but a substantial improvement in the flexural strength and splitting tensile strength. The mechanical properties of CFRC are enhanced as the fiber content is increased to a threshold level, but become weakened afterwards. An increase in the carbon fiber length up to 10 mm is found to strengthen the mechanical properties. The residual mechanical properties of carbon fibers blended concrete were more robust against high temperature attack than those of ordinary concrete. The SEM results show that the failure mode of carbon fiber under loading is mainly the breakage and pullout of the carbon fiber.

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abst. 2522
Repository

Utilization of recycled asphalt and crumb rubber as aggregates in FRCC: Crack properties, toughness and absorption evaluation

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The development and application of fibre-reinforced cementitious composites have evolved significantly over the last decade. However, there is a need to find ways to improve the sustainability of the composites. The production and transportation of the major binder (i.e. Portland cement) and aggregates used for FRCC consumes high energy and natural resources. Therefore, finding ways to incorporate recycled materials to replace these conventional components can be used to improve the sustainability of the FRCC. This paper investigates the performance of FRCC made with high volume fly ash as partial replacement of Portland cement, and recycled asphalt/crumb rubber as replacement of the natural aggregates. The performance of the FRCC incorporating these recycled materials was evaluated in terms of its crack properties, toughness and water absorption. Results from this study showed that the use of recycled crumb rubber is beneficial in terms of the crack properties and water absorption. However, FRCC made with recycled asphalt exhibited higher water absorption and lower toughness. Nevertheless, the cost and sustainability assessment of FRCCs showed that the incorporation of recycled asphalt and crumb rubber indicated resulted in a significant reduction in the cost and embodied carbon of the composites.

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abst. 2684
Virtual Room
Thursday
September 3
10h30

Shear Strength of Fiber Reinforced Concrete: Is Aggregate Type Matters?

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Steel fibers have been used in reinforced concrete to reduce both crack spacing and width. Fibers enhance the load carrying capacity, post cracking tensile strength, and shear strength. Substantial amounts of energy get absorbed in debonding and pulling-out of fibers before failure. Additionally, fibers improve the aggregate interlock and dowel action. A range of literature and code attempts investigated the effect of the type of concrete on the fiber contribution to improve shear capacity. To enumerate, regardless of the type of aggregates used in concrete, shear capacity increases when the shear span to depth ratio decreases, concrete strength increases, beam size decreases, volume of fiber increases, and longitudinal steel ratio increases up to a certain limit. Recycled aggregates decrease the overall shear strength of the concrete. Fibers were more effective when utilized in high strength concrete. Hybrid fibers further enhanced the shear strength of both ultra-high-performance and lightweight concrete. Few codes accounted for the usage of fibers where the provisions provided conservative results. The goal of this paper is to elucidate and emphasize on the validity of the proposed equations to predict the shear strength of concrete, while considering the effect of aggregates types used in concrete.

Functionally graded materials and structures

A genuine novel optimization approach for FGM axisymmetric bodies

abst. 2521
Virtual Room
Thursday
September 3
10h15

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Functionally graded materials (FGMs) are a kind of composite materials, whose physical and mechanical properties vary spatially along specific directions over the entire domain [1]. Unlike conventional homogeneous materials, the spatial variation of mechanical and physical properties in FGMs can be exploited to obtain better performances by microstructural control. The optimum response of material properties to an actual environment is the main requirement in the design of FGMs, nevertheless few works deal with the problem of optimal material distribution because, often, the optimization process considerably relies on subsequent Finite Element forecasts. In addition, in the works available in the literature, finding the solution of an optimization problem usually consists in determining the values of some tuning parameters of the grading indices for prefixed classes of property variations, such that an objective function is minimized, e.g. [2,3]. We believe that an intrinsic, genuine and more realistic optimization problem should a priori consist in the search for property variations and not merely the tuning values belonging to prefixed property distributions. The resulting optimization framework is both suitable for practical aspects associated with the manufacture process – since optimal solutions are in terms of the constituents' volume fractions – and novel from the theoretical viewpoint – being applicable regardless of the involved micromechanical model. In this paper we address the problem of finding the optimal composition profile of the constituents for axisymmetric thin bodies subject to mechanical loadings. The material is assumed to be functionally graded in the radial direction. In light of these considerations, the plane theory of elasticity holds and equilibrium, compatibility and constitutive relations are recalled. Different optimization problems are then formulated and analytically solved in the context of optimal control theory. Finally, hints on the computational details of the solution are addressed. [1] Miyamoto, Y., Kaysser, W.A. & Rabin, B.H. Functionally graded materials: design processing and applications. Kluwer Academic Publishers, London, 1999. [2] Abdalla, H.M.A., Casagrande, D. & Moro, L. (2020). Themo-mechanical analysis and optimization of functionally graded rotating disks. Journal of Strain Analysis for Engineering Design. DOI: 10.1177/0309324720904793journals.sagepub.com/home/sdj [3] Khorsand, M. & Tang, Y. (2018). Design functionally graded rotating disks under thermoelastic loads: weight optimization. International Journal of Pressure Vessels and Piping 161: 33–40.

Numerical Investigation on Effective Toughening Mechanisms of Graded Composites

abst. 2563
Repository

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Graded composites, also known as functionally graded materials (FGMs), are referred to the class of materials possessing space-varying properties in different dimensions. Such material formations commonly present in various biological/natural objects, such as human/animal bones, teeth, and organs, to conveniently comply with various objectives/functions at different locations. In today's engineering society, vital structural components are manufactured by mimicking this phenomenon in order to achieve the desired toughness and responses at different crucial usage regions. Thus, it is highly important to manufacture these parts with higher toughness and lower cost. In this study, an ordinary state-based peridynamic (OSB-PD) model is purposed to enhance the toughness and decrease the material cost of such structural components having complex material zones. To account for complexity of the FGMs in OSB-PD analysis, different averaging techniques including simple, moving, and weighted averaging models are used to determine the OSB parameters of the bonds between the points with different characteristics. A comparison of these averaging techniques is carried out by solving the complex benchmark problem for mixed mode I-II fracture loading condition. The OSB model in this paper is further developed to assess the various challenging effects including the toughness enhancement of the micro and macro internal features in FGMs. For this purpose, we have solved numerous example

problems and demonstrated the enhanced toughening effects of features such as micro-cracks, holes, and strengthened/weakened material subdivisions. To evaluate the toughening effect of different features, the total rupture length is taken as the basis of comparison. It is demonstrated that the overall toughness of FGMs can highly be enhanced by precisely embedding the proposed combinations of internal features. Overall, a comprehensive fracture modelling and toughness enhancement of FGMs with various micro and/or macro discontinuities and different material sub-regions are achieved using the novel OSB-PD approach.

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abst. 2034
Repository

Functionally graded Ti(C,N) coatings and their production on titanium using solid carburizing associated with induction heat treatment

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There are many ways to improve the mechanical characteristics of titanium items using various methods of coating deposition. They include oxidation, gas-thermal spraying, PVD and CVD techniques. These methods have disadvantages, i.e. the resulting coatings are characterized by low hardness and brittle fracture resistance combined with high porosity and morphological heterogeneity, and the processes themselves are energy-consuming and not resource-saving. The urgency of the work lies in the absence of new effective approaches to improving the mechanical properties of titanium items in various friction pairs. For this reason, it is proposed to perform resource-saving solid carburizing associated with induction heat treatment (SC-IHT) in order to strengthen the surface and increase its wear life. The aim of the work is to develop a technology for the production of wear-resistant coatings of carbide and nitride composition on the titanium surface of the working parts of equipment, e.g. converters of flaw detection devices. Titanium samples were subjected to machining and ultrasonic cleaning in ethanol. The surface of the prepared samples was treated using solid carburizing. The prepared samples were placed in a refractory container and coated on all sides with a finely dispersed carbon-containing medium (graphite). The SC-IHT comprised intensive heating up to the required temperature, exposition at the quasi-stationary temperature, and subsequent cooling. As a result of this hard coatings were formed. The SC-IHT effect in the temperature range of 1100–1400 °C on the performance of micro- and nanostructure of the coatings and mechanical properties was defined. Modes selected for the coating production on the samples were assigned to double numbers: the first number corresponded to the temperature of the surface of refractory container, the second one indicated the treatment duration measured in seconds. The chemical composition of the coated samples was studied by EDX analysis, which was performed with scanning electron microscopy. The hardness of the samples with coatings was evaluated using the Rockwell and Vickers methods. During micro- and nanoindentation, a mechanical properties tester was used. The temperature field inside a refractory container with a titanium sample was determined. For this purpose finite element modeling using the "Elcut" software (the version of the "QuickField") was used. The obtained temperature values ensured the necessary chemical reactions between titanium and solid-gas medium (carbon and nitrogen), which was confirmed by phase diagrams. All obtained samples with functionally graded Ti(C,N) coatings had in their composition the main component of the substrate – titanium, the main component of the reaction medium was carbon, and nitrogen admixture, which was preserved from the atmosphere. The composition of the coatings at a minimum SC-IHT temperature of 1050–1100 °C and a process duration of 240–480 s corresponded to the carbide-nitride (TiC0.14–0.25N0.75–0.86) system. In the temperature range 1250–1400 °C, the composition of the coatings was stabilized by Ti0.32–0.37N0.63–0.68 system; however, the mechanical properties had significant differences. The microhardness H of Ti(C,N) coatings depended on the temperature T and duration t of the SC-IHT in the graphite medium. A minimum H of 10–12 GPa was observed at T = 1050–1100 °C. With an increase in temperature to T = 1250–1300 °C, the hardness grew as well reaching a maximum of about 20 GPa. In the study, the nanohardness was 47.6±12.9 GPa, which corresponded to the production of a superhard layer combined with high plasticity index of 0.16 and brittle fracture resistance of 1.28 GPa. Thus, the resulting system has a gradient of mechanical properties and it can be used under conditions of shearing and abrasion by hard fragments

of the working medium. The research was supported by the Russian Science Foundation (project No. 18-79-10040).

A Layerwise Approach to the Analysis of Porous Functionally Graded Plates

abst. 2062
Repository

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Functionally graded materials are characterized by its spatial properties' variation which provides them a better behaviour concerning strain and stress transition, hence avoiding the abrupt changes typical of composite fibre reinforced laminates. These materials may also be reinforced via the inclusion of nanoparticles, leading to a multiscale functionally graded material. Although manufacturing systems and techniques used in the production of such materials has evolved significantly, porosities may arise as non-desirable characteristic. Other situations exist where pores are desirable as they may contribute to a specific better performance. It is for example the case of medical implant applications as they contribute to enhance the biocompatibility with the host tissue. Regardless the specific application, it is expected that mechanical properties of graded material will be affected by the existence of porosities. This work presents a study on the static behaviour of plates made of functionally graded materials including nanoparticles, wherein the existence of porosities and their distribution is addressed. To this purpose, a layerwise approach considering different shear deformation theories will be used.

A Comparative Study Between ESL and LW Analysis of Multiscale Porous FGM Plates

abst. 2064
Repository

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Functionally graded materials (FGM) are known to possess attractive performance characteristics for a diverse set of application fields. Along with those intrinsic characteristics related to their tailored material phases' spatial distribution, the criterious inclusion of nanoparticles may offer them an improved behaviour. Complementarily the consideration of pores in such materials modelling process may constitute a relevant approximation to their real, physical constitution, hence enabling better predictions of associated structures' mechanical performance. The present work presents a comparative study between equivalent single layer (ESL) and layerwise (LW) approaches to analyse different configurations of FGM plates which can possess nanoinclusions and/or porosities distributions. The performance of the models developed and implemented as well as the corresponding conclusions are supported by a set of illustrative case studies.

Local heating of a thermoelectroelastic FGM coated piezoelectric half-space

abst. 2621
Virtual Room
Thursday
September 3
09h30

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Thermoelectroelastic transversely isotropic piezoelectric half-space with a functionally graded coating is considered. All properties of the coating vary with depth according to arbitrary independent functions. The surface of the coating is heated in a circular area to the known temperature. Outside this area the surface is stress-free and thermally insulated. Using the Hankel integral transformation technique, the problem is reduced to the solution of a dual integral equation. The solution is constructed by the bilateral asymptotic method and effective for any thickness of the coating. Expressions for the heat flux, temperature and displacements distributions were obtained in approximated analytical form. Features of the deformation of the coated materials are discussed and illustrated by the numerical examples. This work was supported by the Government of the Russian Federation (grant No. 14.Z50.31.0046).

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abst. 2698
Repository

Peridynamics for Predicting Damage in Functionally Graded Materials

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Traditional multi-layered composites materials have been widely used to meet desired functional performances in many engineering applications. However, the discontinuous nature of such structures may lead to stress concentrations between the material layers of composite structures. Functionally graded materials (FGMs) have been proposed to alleviate the interfacial problems between two distinct material layers. FGMs consist of two or more constituent phases and are mixed together with the volume fractions of each phase changing continuously. The desirable mechanical and thermal properties can be obtained in the structures by controlling the constituent phases and their volume fraction variations. The damage in FGMs may take place in different forms due to the non-symmetric material distribution in the structure. The dynamic crack propagation in FGMs and the effect of material variations in these structures on the stress and deformation states need to be understood to improve their service life in safe. Peridynamic (PD) theory introduced by Silling [1] is extremely suitable for the failure prediction in materials. The PD equilibrium equations are expressed in the form of integral of spatial derivatives incorporating the interaction of material points within a finite distance. The damage in PD analysis is introduced through the removal of interactions. Therefore, the crack nucleation and propagation can be investigated at multiple sites with arbitrary paths in the structure. This study investigates the influence of material variations in FGMs on the deformation and stress fields as well as their dynamic crack propagation by using PD theory. The capability of the present approach is demonstrated by considering an FG plate having different material variations with and without a crack. 1- Silling S. A., 2000, "Reformulation of Elasticity Theory for Discontinuities and Long-range Forces," Journal of the Mechanics and Physics of Solids, Vol. 48, pp. 175-209.

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abst. 2096
Repository

Application of DKMT and MITC3 Elements in Functionally Graded Materials (FGM) Plate Structures

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This paper presents the application of two triangular plate bending elements, i.e. DKMT and MITC3 in Functionally Graded Materials (FGM). These two elements taking into account transverse shear effects and can be used for thin to thick FGM plates problem. DKMT and MITC3 elements have 3 nodes and 5 d.o.f per node (three displacements and two rotations). FGM plates problems with four different boundary conditions are analyzed. The numerical results show the superiority of DKMT due to semi quadratic interpolation for the rotation variables. MITC3 element only use linear interpolation for the rotation variables. From the results, these two elements can be used to analyze FGM plate problems especially DKMT element due to his superiority compared to MITC3 element.

Nonlinear finite element model of functionally graded micro porous plates under thermal and mechanical loads

abst. 2633
Repository

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In this study, a nonlinear finite element model of functionally graded porous micro-plates based on a general third-order shear deformation plate theory is presented. The displacement-based weak-form finite element model accounts for length scale dependency, the von Kármán nonlinearity, variation of material properties and porosity through plate thickness, and temperature-dependent material properties is developed using the principle of virtual work. The static bending analysis highlights the effects of the length scale parameters, geometric nonlinearity, a power-law variation of the material composition, and the effect of distributions of porosity. The modified couple stress theory is utilized to capture length scale dependency. The variation of the two-constituent materials is assumed through the plate thickness according to a power-law distribution, while the porosity distributions vary according to cosine functions. The temperature-dependent properties are modeled using a cubic-spline interpolation from experimental data. To obtain temperature distribution through plate thickness, a one-dimensional heat transfer problem of porous media is solved based on the Maxwell-Eucken model. The numerical results are presented for static bending problems of rectangular plates with various boundary conditions. The effects of length scale parameter, power-law index, and porosity distribution on the bending deflection and stress distributions of functionally graded porous micro-plates are discussed.

Nonlinear vibrations analysis of pre-tensioned Bernoulli-Euler functionally graded nanobeams

abst. 2681
Virtual Room
Thursday
September 3
09h45

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The use of micro/nanoscale structures, made of functionally graded (FG) materials or reinforced through FG carbon nanotube (FG-CNT), has been widely increasing in several fields of nanotechnology and nanoscience due to their enhanced mechanical, electronic and thermal properties. As it is well known, these novel composite materials are designed and fabricated in a way that their properties vary gradually through preferred spatial directions so that problems related to the material discontinuities can be significantly reduced and high permeance requirements ensured [1]. Among these engineering nanostructures, nanobeams have attracted more attention due to their engineering applications such as nanoactuators, nano-sensors and atomic force microscope (AFM). Experimental studies and molecular dynamics (MD) simulations highlighted that their mechanical behavior is highly size-dependent and thus the small-scale effects should be considered [2]. In order to overcome the difficulties related to the experiments at nanoscale, as well as the highly computational cost of atomistic approaches, an alternative way to capture size effects in nanostructures is based on scale-dependent continuum models, such as Toupin's couple stress theory [3], Mindlin's strain gradient elasticity theory [4], as well as the classical (strain-driven) nonlocal theory of elasticity proposed by Eringen [5-7] and the more recent stress-driven nonlocal integral model proposed by Romano and Barretta [8-10]. In this study we present the results of a parametric investigation performed in order to analyze the effect of an initial axial force on the natural frequencies of functionally graded (FG) Bernoulli-Euler straight nano-beams, varying the nonlocal parameter and the nonlinear oscillator amplitude. The governing equation is derived by employing Hamilton's principle on the basis of both the stress-driven nonlocal integral model (SDM)

and the strain-driven model (EDM). The Galerkin method and the Hamiltonian approach to nonlinear oscillators, as suggested by He [11], have been considered to obtain the nonlinear natural frequency for different kinematic boundary conditions of the FG nano-beam of engineering interest: Simply-Supported (S-S), Clamped-Simply Supported (C-S) and Clamped-Clamped (C-C). It is shown that the nonlinear approach based on nonlocal stress model, with the appropriate constitutive boundary conditions, is capable of capturing the dynamical responses of the nano-beams and provides an advantageous method for the design and the optimization of a wide range of nano-scaled beam-like components of Nano-Electro-Mechanical-Systems (NEMS). References: [1] Islam M. El-Galy, Bassiouny I. Saleh, Mahmoud H. Ahmed, Functionally graded materials classifications and development trends from industrial point of view. SN Applied Sciences (2019) 1:1378. https://doi.org/10.1007/s42452-019-1413-4. [2] Acierno, S., Barretta, R., Luciano, R., Marotti de Sciarra, F., Russo P. (2017), Experimental evaluations and modeling of the tensile behavior of polypropylene/single-walled carbon nanotubes [U+FB01]bers. Composite Structures, 174, 12–18. [3] Toupin R.A., Elastic materials with couple-stresses. Arch Ration Mech Anal (1962);11:385–414. [4] Mindlin R.D., Micro-structure in linear elasticity. Arch Ration Mech Anal (1964);16:51–78. [5] Eringen A.C., Linear theory of nonlocal elasticity and dispersion of plane waves. Int J Eng Sci (1972);10(5):425-35. [6] Eringen A.C., On differential equations of nonlocal elasticity and solutions of screw dislocation and surface waves. J Appl Phys (1983); 54:4703–10. [7] Eringen A.C., Theory of nonlocal elasticity and some applications. Res Mech (1987);21:313-42. [8] Romano G., Barretta R., Stress-driven versus strain-driven nonlocal integral model for elastic nano-beams. Compos Part B Eng (2017);114:184-8. [9] Romano G., Barretta R., Nonlocal elasticity in nanobeams: the stress-driven integral model. Int J Eng Sci (2017);115:14-27. [10] Romano G., Barretta R., Diaco M., Marotti de Sciarra F., Constitutive boundary conditions and paradoxes in nonlocal elastic nano-beams. Int J Mech Sci (2017);121:151-6. [11] He J.H., Hamiltonian approach to nonlinear oscillators. Phys Lett A, 2010;374:2312–4.

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abst. 2663
Repository

Transient heat conduction analysis of the functionally graded structures by smoothed particle hydrodynamics

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Transient heat conduction analysis of the functionally graded structures is of great importance for the structure design and manufacturing. Meshless Smoothed Particle Hydrodynamics (SPH) method is adopted in the present study for the 2D heat conduction analysis. The computational accuracy and efficiency of traditional SPH method is enhanced by a symmetric SPH approach, which can calculate a function and its derivatives of higher order using one symmetric matrix. The heat conduction function is discretized by the improved SPH method, as well as the boundary conditions. The SPH analysis of the heat conduction in several functionally graded structures with different geometries is performed and validated by the analytical values and the FEM results in literature. The effect of the graded index on the temperature distribution in the structure domain is also studied. The present paper provides an alternative potential method for the heat conduction analysis of functionally graded materials.

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abst. 2126
Virtual Room
Thursday
September 3
09h00

Three-dimensional vibration of functionally graded sandwich shells in thermal environments by a differential quadrature hierarchical finite element method

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Shi, Tao (), ,
Xing, Yufeng (), ,

This paper carries out three-dimensional vibration analyses of functionally graded (FGM) sandwich shell in thermal and non-thermal environments by a differential quadrature hierarchical finite element method (DQHFEM). Three-dimensional elasticity theory (FSDT) is adopted for each layer. Two configurations of FGM sandwich shells are considered, the first with FGM face sheet and homogenous core, and the second having homogenous face sheets and FGM core. Effective material properties of the FGM are estimated according to two micromechanical models, namely, Voigt's rule of mixture (ROM) and Mori–Tanaka (MT) scheme. For the shells in thermal environment, a nonlinear temperature distribution in thickness direction is considered and the elastic properties are assumed to be temperature dependent. The results obtained from the proposed formulation are validated with those available in the literature. Natural frequencies obtained from Sanders', Love's and Donnell's shell theories for different geometric and boundary conditions are compared with each other first to assess the performance of different shell theories for FGM sandwich shells under non-thermal environment. Then the effects of volume fraction index, core thickness and temperature gradient on natural frequencies of FGM sandwich shells are investigated. The presented DQHFEM is much like the fixed interface mode synthesis method but does not need modal analysis and is of high accuracy. This work is the first application of the method to three dimensional analyses of functionally graded sandwich and laminated shells in thermal environments.

Conditions for bifurcational buckling of functionally graded beams

abst. 2014
Repository

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Buckling of functionally graded (FG) beams has been investigated. Material properties of the beam change in the thickness direction. Conditions for different boundary conditions and material property variations have been investigated in the pre-buckling state for flatness of the FG beam. Effect of mid-plane and neutral plane formulations has been discussed. Some parametric results have been obtained and discussed for different material and geometrical properties.

Frequency Veering in Axially Functionally Graded Nanobeam Elastic Mass Sensors

abst. 2160
Repository

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Frequency veering in dynamic analysis of structures is an interesting problem for scientists. Converging and diverging frequency characteristics could be useful sensor technologies. In the present study, frequency veering in nanobeam elastic mass sensors will be investigated. Nanobeam will be assumed as an axially functionally graded structure and governing equation of motion will be obtained with Hamilton principle and Nonlocal Elasticity Theory. Solution of the differential equation of motion of the nanobeam elastic mass sensor will be obtained with approximate Ritz Method. Effect of the arbitrary position of elastic mass to frequency veering characteristics of nanobeam will be investigated.

Wear of a functionally graded coating due to dry frictional sliding

abst. 2613
Virtual Room
Thursday
September 3
09h15

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To protect the working surfaces of mechanisms and machines with sliding contact, multilayer and functionally graded coatings are widely used. This is facilitated by the development of new methods and technologies for their application, such as magnetron sputtering, electric arc deposition, layer-by-layer deposition, pulsed laser deposition, oxidation and nitridation, centrifugation, and so on, as well as methods for their experimental research. An urgent problem is a further reduction in wear by selecting of coating materials and adjusting the heterogeneity of its mechanical properties. Dry friction is a common application for such coatings which possess extensive heating of the material. In this regard, we consider the mechanical problem of the wear of a functionally graded coating by a rigid body is considered taking into account the frictional heating. Distributions of temperature, stress, and displacements in the coating are described by the equations of the linear theory of uncoupled thermoelasticity. Using the Laplace integral transform by the time coordinate, we construct solution to the problem in the form of convolutions of the coating indentation law and the Laplace's original in the form of a contour integral of the inverse Laplace transform. The study of integrands in the complex plane allows us to determine domains of stable solutions to the problem. Unstable solutions to the problem give rise to the thermoelastic instability of a sliding contact. The boundary of the domains of stable and unstable solutions depends, inter alia, on a parameter related to the dependence of the Young's modulus on the coating depth. The obtained solutions allow us to study the influence of a dimensionless parameter characterizing the functionally graded inhomogeneity of the coating on the occurrence of thermoelastic instability of the sliding contact, as well as on the main parameters of the sliding contact: temperature, displacement, stress, and wear of the functionally graded coating material versus time. The effect of the parameters and form of the functional dependence of the Young's modulus on the coating depth and the law of indentation of the coating by a rigid body is studied. The results can be used in practice to improve the design of protective wear-resistant multilayer and functionally graded coatings of friction surfaces in tool manufacturing, mechanical engineering, microelectromechanical systems, transport and other industries. The research was financially supported by the Government of Russian Federation grant no. 14.Z50.31.0046.

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abst. 2480
Repository

Thermal Stress Analysis of Porous Functionally Graded Sandwich Plates and Shell Panels

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In this work, a simple, accurate finite element formulation for transient thermal stress analysis of porous functionally graded sandwich plates and shell panels has been presented. A layerwise theory based on the displacement field according to first-order shear deformation theory for each layer in conjunction with an eight-noded isoparametric element is used to derive the governing differential equation, based on Hamilton's principle. The upper and lower facesheets of the FGM sandwich panel are composed of pure ceramic and pure metal, respectively. In contrast, the core is composed of FGM having the top to bottom surfaces made of pure ceramic and pure metal, respectively, and the same graded along the thickness direction. Three distribution of porosity has been considered in present analysis Viz, evenly spaced, unevenly spaced with a linear and logarithmic variation, respectively. The effective temperature-dependent material property at a point is obtained using the rule of mixture. The upper facesheet of the FGM sandwich is subjected to sudden heat flux or high temperature, whereas the bottom surface is either thermally insulated or maintained at room temperature. Fourier's law of heat conduction for the unsteady state is used to obtain the solution of the temperature profile. A wide comparison study has been performed to establish the accuracy of the present layerwise finite element formulation considering different parameters. The parametric study shows the effect of porosity model, thermal loading, panel geometry, and core to facesheet ratio on transient thermal stresses induced in porous functionally graded sandwich panel.

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abst. 2476
Repository

A quasi-3D theory for functionally graded porous microbeams based on the modified strain gradient theory

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This paper investigates the size-dependent responses of functionally graded (FG) porous microbeams using a quasi-3D theory and the modified strain gradient theory (MSGT). The material distributions through the thickness follow the Mori-Tanaka scheme. The size-dependent governing equations of motion are derived using Lagrange equations and solved by finite element method. Numerical examples are carried out to validate of the present model and investigate the effects of small size, gradient index, and boundary conditions on the responses of FG porous microbeams.

Bending performance of asymmetric graded lattice core sandwich beams

abst. 2084
Repository

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This study introduces a new idea that combining graded material and lattice core for forming the asymmetric graded lattice core sandwich beam, which is based on the 3D printing technology. The asymmetric graded lattice core sandwich beams are formed by alternating width of core strut. The bending stiffness, strength and failure mechanism were investigated. A new analytical model which is based on the equivalent theory and classical sandwich beam theory were presented to estimate the performance and failure mode of the sandwich beams. Numerical simulation is also carried out to study the bending performance of asymmetric graded lattice core sandwich beam. An algorithm based on the Boolean operation is proposed to generate the models by using Python script in ABAQUS/CAE in order to make the analysis more convenience. In order to demonstrate sensitivity of geometric parameters on the bending behavior of the asymmetric graded lattice core sandwich beams, three kinds of specimens were fabricated based on the 3D printing technology and tested to probe different failure modes. The predictions of numerical simulation and theory compared very well with measurements investigated.

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abst. 2275
Repository

Structural damage detection in composite wing using convolutional neural network

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Accurate damage diagnosis has become a computationally challenging task in structural health monitoring (SHM). Convolutional neural network (CNN) has recently been applied in SHM systems to characterize the relation between the measurements and damage patterns. However, there is a lack of application regarding the combination of strain based method and CNN. In addition, most of the researches were processed with small structures and simple loading scenarios. To explore the full potential of CNN in damage diagnosis, this study designed a CNN architecture to classify simulated healthy and damaged cases. The performance and accuracy of proposed techniques was evaluated through the finite element model of an aircraft composite wing structure. Damages were simulated by reducing stiffness in a region of the wing skin. Furthermore, this study using various load distributions which are corresponding to real flight conditions as loading scenarios. Samples were trained by using strain distributions as a consequence of various loads with different damage scenarios. Results demonstrate that the developed method was achieved with high accuracy and robustness.

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abst. 2596
Repository

Intelligent surface monitoring regarding composite structures using deep neural networks and remote sensing technology

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Health monitoring of target structures is one of the most concerning issues in engineering applications. An intelligent and accurate monitoring method should be significantly considered. The manuscript proposes an intelligent surface monitoring methodology with the combination of deep neural networks and remote sensing technology, which provides novel opportunities for structural health monitoring in static loading experiments. The composite structure under continuous static loadings is monitored with the advanced remote sensing technology, e.g. the terrestrial laser scanning in current research. Point cloud data from remote sensing is approximated to generate continuous surface models and online deformation report through the parametric method. It is innovative to apply deep neural networks to predict future deformation information accurately. The final aim is to improve both the efficiency of remote sensing measurement and the accuracy of health monitoring. The mean square error and structural similarity regarding the future surface behavior are optimized through a large amount of training with respect to surface information and deformation monitoring, which applies long-short term method in current research. Through the combination of remote sensing and deep neural networks, the future deformation can be generated efficiently and accurately. Accordingly, the intelligent surface monitoring is reasonable to be applied in the prediction of the structural surface damages.

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abst. 2419
Repository

Detecting structural defect using nano engineering cement composites

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This work studied detecting method to evaluate structural defect using nano engineering cement composites. Two different approaches of mixing cement and carbon nanotubes (CNTs) were considered. The first method included cement composites were produced by adding CNT solutions to cement composites. In the second, CNT-based thin films were spray-coated and combined with cement composites. The experimental parameters were the mixing method, CNT concentrations, number of curing days, and voltages applied. It was found that the cement composites using two different mixing methods were able to detect the defect of the specimens. Finally, thermal imaging showed that increased CNT concentrations led to a corresponding increased temperature of specimens.

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abst. 2429
Repository

Low velocity impact of glass/epoxy laminates

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Advanced fibrous composites are being used in many advanced structural applications, especially in aerospace. The problem which involving the use of reinforced plastic composite materials is the susceptibility to accidental low energy impact. In particular, such damage may be invisible causing a significantly lowering of the residual strength of composite component. Therefore this critical design aspect, implies application of conservative safety factors to the ultimate load values of composite components. In particular, in order to take into account low velocity impact damages and notch sensitivity effects the ultimate load value is generally reduced by 30%. Typical sources of low velocity impact are tool falling during manufacturing or maintenance operations, hail, debris on the track, bird collision, etc. The object of the analysis are composite plates made of GFRP laminate. The purpose of this work is to analyze the behavior of a composite plates taking into account barely visible impact damage generated by low velocity impact and the damage onset and evolution. The numerical calculations were conducted with the implementation of the progressive failure algorithm, based on the material property degradation method and implementation of the Hashin criterion as the damage initiation criterion. In all analyzed cases high consistency of numerical and experimental results was achieved. The occurrence of delamination, and their evolution was modeled in accordance with a bilinear traction-separation law. The obtained results were compared with the results of the experiment. Numerical calculations showed that delamination modeling enhances the compliance of experimental and numerical results (more than Progressive Failure algorithm application). Additionally, it was found out that the correct estimation of the areas and the nature of damages caused by the impact requires taking into account the In-Situ effect. Based on the results of experimental and numerical studies, it was stated that the highest compliance of determined material degradation was achieved by using the LaRC criterion.

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abst. 2179
Virtual Room
Thursday
September 3
17h15

Predictions of Core Damage Depth in Aluminum Honeycomb Sandwich Panels due to Low-Velocity Impacts

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Honeycomb sandwich panels are widely used in the aerospace industry due to their high strength-to-weight and stiffness-to-weight ratios. However, they are susceptible to low-velocity impact damage caused by such events as tool drops and runway debris. In sandwich panels with aluminum facesheets and aluminum honeycomb core, low-velocity impacts result in dents in the facesheet and crushed core which can reduce the residual strength of the panel. In order to determine allowable dent limits for airworthiness requirements, it is necessary to be able to predict the strength of a panel that contains numerous dents of different severity and in different proximity to each other. Preliminary studies performed by the authors have shown that the depth of the crushed core has an effect on the stress in the facesheet under post-impact loading, however numerical predictions of core damage depth have yet to be reported in the literature. The current study focuses on finite element simulations for predicting core damage depth and the effect of the impact energy and core configurations on the depth of the crushed core. Dynamic finite element simulations of a 1kg sphere impacting 70mmx70mm aluminum honeycomb sandwich coupons were performed. Cell sizes of 3.175mm and 6.35mm (0.125" and 0.25") were considered with each being impacted at four different energies to produce barely visible impact damage (BVID). The simulations used an explicit solver and included plasticity in the facesheet and cells walls, cell wall buckling, contact between the impactor and facesheet, and self-contact between the cell walls. It was shown that the adhesive used to attach the facesheet to the core was a necessary feature to include in the simulations for predictions of the dent depth and the core damage depth. The adhesive fillets that form between the cell wall and the facesheet stiffen the panel and the adhesive also prevents the encased cell walls from buckling. The adhesive fillet dimensions were obtained from sectioning commercial panels and were idealized to be triangular with a width to height ratio of 1:2.

Adhesive fillet heights of 0.92mm and 1.5mm were used for simulations of the panels will cell sizes of 3.175mm and 6.35mm respectively. The predicted residual dent depth and the core damage depth were compared to experimental results from physical testing of the 6.35mm coupons and compared to an aircraft panel that had been dented in service for the 3.175mm core. The maximum residual dent depths predicted for the 6.35mm core at the four energy levels were within -8.8% to +19% of the corresponding experimental measurements. The smaller dent depths were underpredicted and the larger dent depths were overpredicted, however the simulations showed the same linear relation between impact energy and dent depth as the experimental results. The finite element simulations showed that the core damage depth was constant and independent of the impact energy for each core configuration. As the impact progressed, the folds became more severe rather than propagating deeper into the core. Cell wall buckling initiated directly beneath the adhesive fillets as was observed in the experiments. The core damage depth was predicted to be 4.29mm for the 3.175mm cell size, which overpredicted the average experimental measurement by 0.93mm. The core damage depth was predicted to be 5.39mm for the 6.35mm cell size, which underpredicted the average experimental measurement by 0.43mm. Differences between the predictions and the experimental results are attributed to the idealized adhesive dimensions and cellular structure in the simulations. Imperfections in manufactured panels such as wide variations in adhesive dimensions in each cell, cells being skewed from a hexagonal shape, cell walls not being vertical and of uniform thickness all contribute to a more random buckling pattern than what was predicted from the simulations. Additional simulations were performed for wall thicknesses of 0.018mm, 0.0254mm and 0.0508mm for both cell sizes to determine the effect of the core configuration on the core damage depth. A 0.77mm difference in core damage depth was predicted from the smallest to largest plastic wavelength which shows that the core damage depth is not influenced by the core configuration. The difference in the core damage depth between the two cell sizes was determined to be because of the size of the adhesive fillet radius. As the fillet radius was increased from 0 to 3mm for the 6.35mm cell size, the core damage depth increased by 2.97mm. Larger fillet radii were shown to offset the cell wall buckling deeper into the core and increase the core damage depth.

Intermediate Velocity Impact Damage Over Sandwich Panels of Carbon Epoxy and Agglomerated Cork

abst. 2169
Repository

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Sandwich composite panels are made from two strong and stiff face-sheets separated by a lightweight core what gives the structure a high bending and buckling resistance while maintaining a low weight. For such a reason sandwich structures are commonly found in lightweight structures in different industries such as the aerospace, automotive, and wind energy. Carbon/epoxy face sheets are widely used in sandwich panels due to their high specific strength and stiffness. However, due to their brittle behaviour and low out of plane resistance they are particularly susceptible to foreign object impact damage. In contrast, agglomerated cork is a cellular material with excellent properties for energy absorption against impact. This work presents the analysis of damage evolution in sandwich panels subjected to intermediate velocity impacts. The analysed sandwich panels are made from woven carbon/epoxy face-sheet and agglomerated cork core. A nonlinear/explicit FEA model is implemented in Abaqus with continuum damage model in order to predict both intralaminar and interlaminar damage. A hyperelastic foam model is used to determine the response of the agglomerated cork. The FE model is calibrated applying the building block approach at the coupon and element level validating previous experimental testing with simplified FEA models. The dynamic compressive response of the core material is implemented into the model using data directly obtained from dynamic compression testing. Additionally, the parameters of the interlaminar cohesive model (Mode I and II) are also determined from previous experimental research. Finally, the mechanisms for damage evolution are discussed and the damaged area after impact is measured in order to provide correlation with future experimental data. The dissipated energy and the impact force history are also recorded.

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abst. 2576
Repository

Ply-by-ply high resolution ultrasound imaging of impact damage in thick CFRP laminates by high-frequency acoustic microscopy

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Impact behavior of the carbon fiber reinforced polymers (CFRP) is still actual issue despite long history of laminate application and investigation of impact resistance. Expansion of knowledge on fracture mechanisms in reinforced composites is related to development of methods for material investigations. Study of microstructure in CFRP under low-velocity impact is labored because of most damage is appeared in the volume of optically opaque laminates. Application of non-destructive methods for CFRP bulk visualization looks more attractive, therefore development and using of new imaging approaches is necessary task for progress in composites science. Today only methods based on ultrasound and X-ray radiation could provide sufficient resolution for observing delamination, matrix cracking and fiber fracture in CFRP after impact. At the same time X-ray and ultrasound techniques are based on different mechanisms of contrast formation that determine features and limitations of the techniques. Conventional ultrasound devices are limited by low working frequency, harmonic probe signals or size of transducer. In this work we propose the approach based on using of long-focused beam of high-frequency ultrasound (50 MHz) with pulsed generation for visualization and characterization of volume microstructure in CFRP and their damages under the low-velocity impact. Short probing pulses of high-frequency focused ultrasound provide both high lateral and axial resolution in layered structures. It has been shown possibilities of the acoustic microscopy to high-resolution imaging of delamination, matrix cracking and fiber fractures through the thickness of thick laminates. Visualization of layer-by-layer morphology of impact damaged areas provides observation of vertical cracks and sharp shape of delaminations' fronts at the interfaces. The results of acoustic microscopy imaging have been presented as sets of B-scans and C-scans and 3D tomography model of the volume damages in thick CFRP laminates. Tomography mode is realized by continuous imaging of the microstructure in horizontal cross-section from upper surface into the depth. The reported study was funded by RFBR according to the research project 18-29-17039.

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abst. 2461
Repository

Mechanics of additively manufactured layered impact protectors

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This work studies the low-velocity impact response of 3D-printed layered structures made of thermoplastic materials (PLA and PETg), which form sacrificial claddings for impact protection. The analyzed structures are composed of crushable cellular cores placed in between terminal stiffening plates. The cores tessellate either honeycomb hexagonal unit cells, or hexagonal cells with re-entrant corners, with the latter exhibiting auxetic response. The given results highlight that the examined PETg protectors exhibit higher energy dissipation ratios and lower restitution coefficients, as com- pared to PLA structures that have the same geometry. It is concluded that PETg qualifies as a useful material for the fabrication of effective impact protection gear through ordinary, low-cost 3D printers.

Numerical Simulation of impact tests of woven CFRP fragment against a Hopkinson Bar

abst. 2510
Repository

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The Counter-Rotating Open Rotor (CROR) engines on aircrafts are currently being investigated in the aerospace industry, due to their better behavior related to the fuel costs and acoustic pollution. Moreover, this type of airplane engine would reduce substantially the emission of greenhouse gases. Composites are one of the different materials studied to build the engine blades. The main reason is their high ratio between mechanical performance and low weight. Nevertheless, in case of an accident one of this blade could detach from the engine and impact in the surrounding aircraft structure inducing important damages. In this work an academic simplification of the previous event has been analyzed numerically. Particularly, the impact of a CFRP fragment against a Hopkinson bar has been modelled using the commercial code Abaqus/Explicit. The simulations have been used for understanding the behavior of a composite woven laminate when is acting as an impactor. The fragments material is made of a plain woven named AGP193-PW, composed of 8552 Epoxy Matrix and AS4 carbon fibers. The size of the impactors is (in millimeters) 42x100x4 (with 20 plies), and 42x100x6 (with 30 plies). The Hopkinson bar is designed to measure the impact forces in the dynamic event. Its geometry has been selected thanks to the numerical model developed, avoiding the yielding of the structure while a sufficient sensibility is reached for registering accurately impact forces. Finally it is decided to me bade by Aluminum Alloy AA2011, with a diameter of 50mm and length of 3m. Semiconductor Strain gauges have been located to 200 millimeters from the impact face in order to obtain the strain pulse of the impact. Impact velocities has ranged between 80 and 180 m/s. Moreover, to take in account the combination of shear and longitudinal behavior and its damage mechanism, several laminates have been launched at 0º, 15º, 30º, 45º and 90º plies orientation for each impact velocity. To analyze the physical behavior of the composite material, a VUMAT User Subroutine has been performed, using solid C3D8 elements. To catch the process of delamination, cohesive interfaces have been implemented between plies.

Optimization of the stacking sequence of UHMWPE protections under high-velocity impact

abst. 2060
Repository

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Last few years have been characterized by an increase of the security forces threating levels, thus researchers are trying to increase the safety of personal protections of police, bodyguards and soldiers. Ultra High Molecular Weight Polyethylene (UHMWPE) has shown excellent properties for personal protections in terms of strength and energy absorption. There are different commercial products of UHMWPE that can be used in the design of personal protection. However, finding the combination of this materials to provide the best solution under a determinate threat is an unsolved problem. There are different threats that can lead to different solutions depending on the velocity and type of projectile. Moreover, the role of the different materials in the first, medium and last plies is not clear. The experimental analysis of several stacking sequences of different UHMWPE plies is very expensive in terms of cost and time. Thus, this work proposes a simplified numerical model based on the Finite Element Method that can provide accurate results to analyse the performance of different stacking sequences of UHMWPE protection under high velocity impacts. The numerical model is validated through comparison with experimental tests. The results of the model are used to analyse several stacking sequences with the same areal density and to propose an optimal solution.

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abst. 2612
Virtual Room
Thursday
September 3
17h00

Effects of hole-hole interaction on mechanical properties in barely visible impact damaged carbon fibre reinforced polymer laminates

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We have investigated the mechanics of hole-hole interaction in barely visible impact damaged (BVID) carbon fibre reinforced polymer (CFRP) laminates where small holes are intentionally drilled into the damaged site to facilitate the injection of resin as part of the resin-injection repair procedure. Test specimens of CFRP laminates were prepared with the following hole setup within the BVID region, namely, no hole (0H), one 2-mm diameter (D) hole (1H) or two 2-mm holes at 12D distance apart, parallel (2Hp) or normal (2Hn) with respect to the applied uniaxial force. Similar hole setup was applied to pristine laminates. Two types of holes, namely blind and open holes, were investigated here. In-plane compression testing was performed on the specimens to determine the elastic (Young's modulus, strain energy density for resilience) and fracture properties (fracture strength, fracture strain, strain energy density to fracture). Infrared thermography was used to examine the fracture morphology. Two-factor ANOVA was employed to assess the influence of mechanical condition (BVID, pristine) and hole setup (0H, 1H, 2Hp, 2Hn) on the laminate mechanical properties. The respective mechanical properties of specimens containing 1H versus 2Hp (2Hn) as well as 2Hp versus 2Hn were compared. In the case of blind holes, while the damaged laminate yielded diminution in the fracture properties (strength, toughness, fracture strain) and elastic properties (stiffness, resilience), all the elastic and fracture properties of BVID laminates were unaffected by the presence of the 2nd hole. However, some subtle differences were observed. In the case of elastic properties, the presence of the 2nd hole (2Hp, 2Hn) resulted in an appreciably stiffened BVID laminate. However, an appreciably reduced resilience was observed when the 2nd hole was introduced. No such differences were observed in the fracture properties. In the case of open holes, all the fracture properties were unaffected by the presence of the 2nd hole. In contrast, hole-hole interactions reduced the stiffness of BVID laminate as compared to the single hole BVID laminate. However, the resilience of the BVID laminate was reduced in the presence of 1H, 2Hp and 2Hn. The absence of the influence of hole-hole interaction on the fracture strength in both blind and open holes could be explained by the effects of the stress concentration around the hole vicinity. A model of the peak stress in the neighbourhood of the holes predicted there were no differences in the peak stress of 1H versus 2Hp and 2Hn, as well as 2Hp versus 2Hn. Further evaluation of this model revealed that the critical spacing, Lc, beyond which hole-hole-interaction ceased, depended on the hole-hole orientation. The Lc of the two-hole setup in parallel (Lc » 9.7D) was about 5 times larger than the two-hole (normal) setup (Lc » 2.4D). The hole-hole separation distance implemented in this study was 12D, which was more than sufficient to reduce the effects of hole-hole interation on the fracture strength. The paper is the first to clarify the influence of hole-hole interaction in BVID laminates, and to provide important insights for dealing with the resin-injection repair procedure which leads to repair outcomes that are often highly variable. It perhaps represents the first attempt to

explore the relationships between hole-hole interaction and the elastic and fracture properties of BVID laminates.

Experimental investigation on axial crushing behavior of thin-walled structures made by FDM

abst. 2213
Repository

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Thin-walled structures are wieldy used in automotive, trains and aerospace industries due to their lightweight and high performance on energy absorption. This study presents novel thin-walled structures manufactured by fused deposition modeling (FDM), using polyamide (PA) and fiber reinforced polyamide based composite. Axial crushing behaviors of the thin-walled structures are investigated experimentally. The tests are carried out by an universal material testing machine for quasi-static compression (2mm/min) and a drop hammer testing machine for low-velocity impact (10m/s). It is found that with increasing of the loading velocity, the thin-walled structures made by polyamides and polyamide based composites show ductile-to-brittle transitions. More specifically, under low-velocity impact condition, polyamides show a brittle progressive end-crushing mode, while fiber reinforced composites show an obvious spring-back mode. Moreover, the effect of cross-sectional shapes (circular, triangular, quadrangular and hexagonal) on the axial crushing properties of thin-walled structures is also investigated. Results show that the shape of cross section has significant influence on deformation mode and energy absorption capability. Circular tube shows the highest specific energy absorption (SEA). Furthermore, imperfection effect on the crushing responses is evaluated by crashworthiness indicators. It is concluded that collapse mode of thin-walled structures can be controlled by the designed imperfection to improve the energy absorption. This study offers insights on increasing energy absorption of thin-walled structures by applying composite materials with designed imperfection. Keywords: Composite material; FDM; crushing behaviors; energy absorption; failures.

Dynamic plastic behavior of a simply supported circular ring under impulsive loads

abst. 2265
Repository

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A rigid-perfectly plastic model is developed for a simply supported circular ring subjected to concentrated impulsive loads. A preliminary survey of the complete solution for the incipient deformation mechanism of the circular ring under different ranges of the magnitude of step loading is carried out. The relation between the number and location of the stationary plastic hinge and the magnitude of the applied step loading is given. It is found that with the increase in magnitude of the load, the number of stationary plastic hinges increases and the position of newly formed plastic hinges moves closer to the loading point. The theoretical results of the step loading are validated by comparison with the finite element analyses using the commercial software package ABAQUS and it shows that the proposed rigid-plastic theoretical model is capable of providing a good prediction of the deformation mechanisms of the circular ring under step loading.

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abst. 2544
Virtual Room
Thursday
September 3
16h30

NUMERICAL INVESTIGATION ON THE RESPONSE OF CFRP COMPOSITE PLATES SUBJECTED TO LOW VELOCITY REPEATED IMPACTS

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In this paper, the mechanical response of Carbon Fibre Reinforced Polymer (CFRP) plates subjected to repeated low velocity impacts is numerically investigated. The finite element package Abaqus was used to conduct numerical simulations of repeated low velocity impacts. 3D models of composite plates subjected to repeated low velocity impacts with several energy levels were developed. The numerical models were validated using experimental data coming from impact tests (single impact) on CFRP plates using drop weight tower methodology. Puck failure criterion with linear strain softening was employed for acknowledging intralaminar failure. Additionally, cohesive zone method (CZM) was employed to account for interlaminar damage. A sequence of impact is applied to the plate employing a multi-step concept. Firstly, the plate is hit by the striker undergoing a loading-unloading sequence. This is followed by a second step in which artificial damping is introduced to the model in order to mitigate the oscillations and residual elastic vibrations. Finally, the plate is subjected to the next impact load in the same location of the first one. In this study several subsequent hits are applied to composite plate. It is worth mentioning that, in the present study, damage is intended as several modes for intralaminar failure such us fibre or matrix breakage and interlaminar failure (i.e. delamination). More in detail, experimental data will be used for validating the single-impact model through the use of commonly use parameters (i.e. maximum contact force, maximum impactor displacement and energy absorption). Subsequently, the validated model will be employed for a multiple hit scenario whose results will be utilized for assessing the quantitative changes in the cited parameters.

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abst. 2566
Virtual Room
Thursday
September 3
16h45

The impact behaviour of titanium/carbon, aluminum/carbon and conventional carbon fibres laminates - a comparative study

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Impact resistance is one of the basic properties of thin-walled coating structures that is of vast importance in the aerospace industry. Being able to absorb the energy of impact force, having resistance to puncture and being able to limit internal damage to the structure affect the continued load capacity of the component. Current aerospace designs utilize composite and hybrid materials. The work compares the low-velocity impact resistance of carbon fibres-reinforced polymer, aluminium carbon reinforced aluminium and hybrid titanium carbon laminates. In the assessment measurable, experimental and analytic evaluation criteria for the phenomenon of impact and the reaction of the material to this type of load, based on diverse physical foundations were utilized. It was demonstrated that a laminate based on titanium layers has at least two times higher impact resistance than an aluminium based laminate and at least six times greater impact resistance than its conventional carbon-epoxy equivalent.

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abst. 2409
Repository

The composite structure for human body impact protection

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The article presents results of research and analysis of the currently conducted project aiming at the development of a flexible impact protector. The need to carry out the work results from the necessity of the ever-wider and more frequent use of body armours, including those resistant to blunt impacts, by the army, police and other public security services as well as a demand for impact protective elements in the civilian market. In the first part, the assumptions regarding the protective coverage under development and the origin of the topic with reference to earlier work on the use of non-Newtonian fluids in body armours are indicated. Next, the requirements for impact protectors and a review of the state of the art in the scope of this type of protective elements are presented. Finally, the results of the impact tests of armour samples are shown. The first research works of Military Institute of Armament Technology (MIAT) on using non-Newtonian fluids for human body protection were performed in the years 2009÷2014 in the framework of the project „Smart passive body armours with the use of rheological fluids with nanostructures". The project was realized in cooperation with the Faculty of Materials Science and Engineering of the Warsaw University of Technology and the Institute of Security Technology MORATEX. Ballistic protection tests (PN-V-8700:2011/K1A - 9x19 mm FMJS Parabellum) of armour samples modified with shear thickening and magnetorheological fluids demonstrated capability of both fluids (STF and MRF) to absorb and dissipate impact energy of the bullet and hence reduce the backface signature (BFS). Better protection capability with respect to mass was achieved for the STF, therefore the further works were concentrated exclusively on it. After the completion of the Smart Armour project, the research was continued in 2015 under financed from the own research fund the statutory work of the MIAT: "Development of the flexible ballistic insert with the anti-trauma pad for a bulletproof vest". The aim of the research was now to investigate protective capabilities of soft armour samples with the fluids in case of a stronger penetrator. The bulletproof tests were carried out now following the NIJ Standard-0101.04 for the IIIA class. The works were focused on the projectile which cause in this class bigger BFS - on 0.44 Magnum SJHP (semi-jacketed hollow point) bullet. The penetrator impact energy is in this case near 1500 J, which is almost three times higher than the energy of impact of 9 mm bullet for which most bulletproof tests were performed in Smart Armour project. From all the armour variants developed, the best ability to absorb impact energy and the largest reduction of BFS in reference to mass were obtained for armour with anti-trauma pads in the form of: - open-cell polyurethane foam combined with viscoelastic fluid KM - foam made with the addition of STF fluid. The aim of the currently presented research is to investigate the possibility of using the previously selected variants of protective structures as well as some new material systems as flexible impact protectors. Such an armour in different variants could be used as: 1) protective clothing for horse riders; 2) protective clothing for motorcyclists; 3) impact protectors for public security services. Due to the potential of non-Newtonian fluids recognised in the works conducted earlier it was decided to try to develop blunt force impact protectors based on them. The work was mainly concentrated on two materials: the shear thickening fluid STF developed under the Smart Armour project (based on silica nanoparticles dispersed in polypropylene glycol) and viscoelastic material used in railway dampers to absorb impact energy (based on homogeneous methyl-phenyl-borosiloxane polymer). The development of protectors providing the desired protective effectiveness with the minimized share of rigid elements, with the highest possible comfort of use, through application of light, soft and flexible elements, was assumed. Research method for protective capability determination involved the use of a Drop Tower device. The test consisted in dropping an impactor (of a given weight and shape) with a specific energy onto a sample placed on an anvil with a certain curvature. During the test, the force transmitted under the tested sample onto the anvil was measured with a piezoelectric sensor. Its maximum value over time Fmax determined whether the protective element provides the desired level of protection.

Experimental and numerical impacts of bird sustitute projectile to CFRP plates

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abst. 2140
Virtual Room
Thursday
September 3
16h15

Nowadays carbon fibre reinforced epoxy (CFRP) laminates has consolidated their position as one of the most important in the designing and manufacturing of aeronautical composite structures. Despite of the high stiffness and strength-to-weight ratio of carbon fibre reinforced epoxy laminates, they are quite vulnerable to impact loading. Literally from an EASA 2011 report, it could be said that "A critical safety issue for the design of primary aircraft structures is vulnerability and damage tolerance due to foreign object impact from bird strike, hail, tyre rubber and metal fragments". Regarding bird strike it has been studied both from the experimental and numerical point of view. However, most of the studies are referred to impacts on complex aeronautic structure, such as a composite tail leading edge [?] or to a composite helicopter cockpit [?]. In this work, it is performed an experimental test campaign in which a gelatin projectile (artificial bird: AB) is impacted into composite flat plates. Different AB projectiles have been impacted in a wide range of velocities (100-180m/s) in order to study the influence of the momentum into the impacted plates. In order to deepen into the effect of the impact on the CFRP plates high speed 3D Digital Image Correlation (DIC) has been used to analyse the out of plane displacement. Finally the extension and shape of the damage has been measured using ultrasonic inspection (C-Scan and TOF techniques). For the numerical simulation, Smoothed Particle Hydrodynamics (SPH) technique is used to model the bird sustitute. As a conclusion, this experimental and numerical test developed allows to a better understanding of the behaviour of composite laminates when subjected to soft projectile impact.

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abst. 2549
Repository

Experimental Tests and Numerical Simulations of High-Velocity Impact on Interply Hybrid Laminates

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Fiber-reinforced composites have been widely used in the manufacturing of components for defense applications due to their lower density and high specific strength compared to metals. Aramid fibers are characterized by high strength, good impact and ballistic properties, low flammability and good resistance to abrasion. The glass fibers used for ballistic applications are mainly of the R-Glass and S-Glass, characterized by high tensile strength. Aramid fibers have greater ballistic performance that glass fibers, but they are more expensive. When lower cost is a binding requirement for the design of a ballistic shield, a hybrid configuration which uses both aramid and glass fibers could be an interesting solution, for instance, in interply hybrid laminates, which are composed of plies of different fibers. In this work, interply hybrid panels made of Kevlar 29 and S-glass plain-weave layers and epoxy resin were manufactured by vacuum infusion following different staking sequences. Ballistic impact tests were performed on pure Kevlar 29, pure S-glass and interply hybrid laminates at different impact velocities to obtain the ballistic curve and the ballistic limit velocity for each panel type. The .357 Magnum projectile was chosen for the tests since it is a common threat faced by ballistic shields, corresponding to the FB3 protection level of European standard EN 1522. Numerical models were developed for the simulation of the experimental tests. The laminate was modeled at a macro scale, i.e. considering it to be an equivalent homogeneous medium with orthotropic properties, using the material model MAT162 implemented in the software LS-DYNA. This is a rate-dependent progressive composite damage model which accounts for different failure modes for the fiber and matrix phases of the composite material. It can also take into account the strain-rate sensitivity of the material properties using a logarithmic function. Delamination was effectively modeled within elements adjacent to the ply interfaces, that is, without using the usual time-consuming contact surface elements. Preliminary results show that interply

hybrid laminates have intermediate performance between pure Kevlar29 and pure S-glass laminates but a more in deep analyses concerning specific ballistic energy and costs show a more complex state.

A perspective investigation of mechanical key issues for structural impact of composite rail vehicles

abst. 2143
Virtual Room
Wednesday
September 2
12h15

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Dynamic behaviour of transportation means is governed by structural pattern and material type. While the pattern of vehicle structures often undergoes improvements, the type of vehicle materials generally keeps unchangeable. The two significant changes of rail vehicle materials had bought out two historical upgrades. The change of materials from woods to steels symbolizes the upgrade of rail vehicles from natural materials to manufacturing techniques and the change from steels to aluminum extrusions marks the launch of lightweight materials and structural integrity. After the successful employment of composite structures in commercial airplanes and racing cars, there appears an opportunity of material upgrade for another big advent of rail vehicles. Impact refers to an accidental scenario of vehicle dynamics in which vehicle structures experience extreme mechanical behaviours, resulting in high stresses beyond the plastic limit of materials and destructive damage of structures. Correspondingly mechanical behaviours of deformation pattern and energy dissipation are two qualitative indicators for implementing a new kind of materials in vehicle structures. This paper carries out a perspective investigation to identify the key mechanical issues affecting deformation behaviour and energy absorption of composite structures when supplemented to rail vehicles. The contents of this paper fall into two parts. The first part highlights the characterization of composite structures and rail vehicles, addressed from two aspects as follows. 1) Finding out the basic principle. A rule of the thumb for composite structural collapses is that structural dismantling tends to progress along the reverse processes of assembly. The damage map and progression of composite structures in impacts are depicted based on this rule. 2) Characterisation of rail vehicles. Running on rails and coupled to a rake, rail vehicles possess specific characteristics in collisions. The loading features and collapse tendencies of rail vehicles as a whole and as the assembly of different parts are analysed to provide the service background for mechanical requirements on materials and structures. After the above general discussions, the second part works on an identification of mechanical key issues for detailed interpretation, focusing on the three types of interfaces of composite structures as follows. 1) Interface between material constituents. Referring to the interface at material level, this determines how fine the progressive deformation of composite materials could be and how stiff in undergoing collapses. 2) Interface between laminar layers. Referring to the interface at component level, this determines the strength and stability of laminated multilayer in keeping integrative status and avoiding Mode-I fractures. 3) Interface between the core and faces of a sandwich. As the preferable candidate for the underframe of rail vehicles, the sandwich needs to find a way keeping stable when performing progressive collapses for crashworthiness. Apart from the analysis of design requirements, a proposal for progressive deformation of sandwiches is presented. The above five aspects in two parts constitute the backbone and depicts a picture for mechanical performances of composite structures when used in rail vehicles. Rooting on mechanical fundamentals, this paper has wide relevance for composite structures to be used in transportation means.

Dynamic Behaviour of Metal Foam Sandwich Beam under Repeated Impacts

abst. 2307
Repository

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The phenomena of repeated impacts are very common, especially on ship and ocean structures. When these structures are subjected to repeated impact loadings, the deformation and damage will accumulate as the impact number increases, resulting in the failure and damage of the structures, even leading to serious accidents. Based on the rigid-plastic assumption, the theoretical model was established to analyze the plastic mechanical behavior of MFSBs (metal foam sandwich beams) suffering from repeated low velocity impacts, in which the bounds of dynamic solution of permanent deflection and peak force were derived. Besides, the repeated impact tests were performed by using Instron 9350 Drop Tower, and then the theoretic predictions were compared with the results of impact tests. Results show that the theoretical solutions agree well with impact tests, indicating that the theoretical model is capable to predict the plastic responses of MFSBs subjected to repeated impacts. The above analytical model can provide theoretical references and technical supports for the design of the MFSBs under repeated impact loadings. Keywords: Metal Foam Sandwich Beam; Repeated Impacts; Plastic Behavior; Theoretic Analysis

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Joining

Interface characterization of hybrid fiber-metal-laminates after laser-based surface treatment

abst. 2211
Virtual Room
Friday
September 4
13h45

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Efficient manufacturing techniques are the key to advanced light-weight and hybrid material design. Mostly, joining of fiber-metal laminates to generate a durable and strong connection between dissimilar materials is one of the major challenges. Since the interface strongly determines mechanical performance of a hybrid composite, in this study, surface of the metal sheets was modified with a laser to increase bond durability and interface strength. In order to enhance recyclability, metal sheets were joined with thermoplastic-based fiber reinforced polymers. Characterization on the micro- and macroscopic scale enabled to determine the influence of surface treatment and resulting microstructure on macromechanical performance of the hybrid material. In addition, the failure behavior is analyzed. Experimental characterization pointed out that surface treatment parameters are important for interlaminar strength, bond durability and resulting failure mechanisms.

A coupled thermal-chemical numerical model to define the thermal limits of CF-PEEK in hybrid joining applications

abst. 2605
Virtual Room
Wednesday
September 2
14h30

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Abstract: A fundamental problem with composite/metal joining is that the metallic counterpart requires temperatures above the degradation temperature of the composite's polymer matrix. However, the degradation mechanisms offset on higher temperatures when high temperature-short duration processing is applied. Consequently, the thermal limits of the composite in hybrid joining applications, can be extended with the above processing conditions. Therefore, the research is focused on examining the thermal degradation mechanisms of composites, in high-temperature – short-duration processing. For this scope, a coupled thermal-pyrolytic analysis takes place in ABAQUS software, and the proposed methodology to investigate numerically the thermal degradation of composites in extreme heating conditions is presented. Due to its thermal and mechanical properties, carbon fibre (CF) reinforced poly-ether-ether ketone (PEEK) is examined. The complex thermal and chemical phenomena are simulated, by implementing the user-defined subroutines USDFLD and HETVAL in ABAQUS/standard finite element code. HETVAL is used to model the decomposition kinetics and the reaction heat in each increment, while USDFLD is used to update the material properties of the decomposing material, taking into account the calculated degree of pyrolysis. Initially, the capabilities of the model are demonstrated for heating conditions, where complete pyrolysis takes place. Then, a parametric study is carried out to identify the high-temperature - short-duration processing that would not significantly trigger the pyrolysis mechanisms, in hybrid joining applications. The conducted numerical model can determine the extent of the resulting pyrolysis that occurs in the thermoplastic composite material, under varying processing conditions. In addition, as a coupled thermal-chemical model, it is an applicable tool for modeling the thermal behaviour of CF-PEEK in a wide range of applications, where high temperatures are expected. Finally, this methodology contributes in optimising the processing conditions in hybrid joining of composites with metals, when extreme heating conditions are applied, by defining the thermal limits of the composite material and consequently reducing the effects of pyrolysis. Keywords: Joining, Composites, Thermal Degradation, Pyrolysis, Numerical Model, Abaqus Acknowledgement: This publication was made possible by the sponsorship and support of TWI. The work was enabled through, and

undertaken at, the National Structural Integrity Research Centre (NSIRC), a postgraduate engineering facility for industry-led research into structural integrity established and managed by TWI through a network of both national and international Universities.

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abst. 2310
Virtual Room
Friday
September 4
13h30

Interfacial failure characteristics of shape memory fibers on the epoxy adhesive for development of debondable adhesives

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Nowadays, metal-composite hybrid structures have been a good candidate for the structural material systems since they have enough stiffness and strength with lightweight. Due to hybrid material systems, joining between dissimilar materials is essential. Mechanical joints are more proper with the viewpoint of recycling, but stress concentration may reduce the structural strength. In other words, adhesive joints can distribute the transferred load but are very hard to be recycled. We suggested novel debondable adhesives for easy separation of adhesive joints for increasing the recycling rate of hybrid structures. Suggested debondable adhesives consist of shape memory fibers and polymer adhesives. If fibrous shape memory materials are reinforced in the adhesives, we can increase the adhesion strength like composite materials. If specific conditions, which activate the shape recovery of the shape memory materials, are applied to the adhesive joints, we can separate the adhesive joints easily since induced stresses by the shape recovery can reduce the adhesion strength. This concept was proved by FE analyses and experiments already. One of the important features for accomplishing the desired goal of the debondable adhesives is the bonding between the shape memory fibers and adhesives, which can affect the load transfer from the shape memory fibers to the adhesives during the shape recovery process. Therefore, we investigated the interfacial failure characteristics of the shape memory fibers on the adhesive. We used Ni-Ti alloys with 25mm diameter as the shape memory fibers, and structural epoxy adhesives DP460. Interfacial strength between the shape memory fibers and adhesives was compared by the microdroplet tests.

Joints

Fastener pull-out response in composite joints under rapid loading rates: Experimental and numerical study

abst. 2282
Virtual Room
Thursday
September 3
15h15

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Despite the lower structural efficiency when compared to adhesively bonded connections, mechanically fastened composite joints are widely used in modern aircrafts and other advanced vehicular structures, since they have better resistance to long-term environmental degradation and allow disassembly and reassembly of the joint for repair purposes. However, it is well accepted within the engineering community that the fastened joint areas are critical structural elements in designing safe and efficient composite structures, as they represent the potentially weakest points of the structure. In addition, further challenges are imposed when the loading rates diverge from the conventional quasi-static (static) regime and move towards dynamic (impact) events. Dynamic loading cases are far more realist load-scenarios compared to the static ones, since crash and impact events until today are, unfortunately, unavoidable in the operating environment of advanced engineering structures (e.g. car crashes and plane hard landings). In the latter case, high strain rates, high kinetic energy and inertia effects occur, which affect the failure behaviour and the corresponding strength of composite joints. Although the in-plane static and dynamic behaviour of composite bolted joints has been thoroughly investigated, only very few works exist regarding the characterization of the pure out-of-plane behaviour of composite mechanically fastened connections subjected to rapid loads; furthermore, the existing results reveal contradicting trends of the loading rate effects for pull-out joints. These joints, which are also commonly referred as pull-through joints, represent a very critical connection type in advanced aircraft structures and other transportation vehicles, given that the weak through-thickness properties of composite materials make them particularly vulnerable to out-of-plane failure modes. With the aim to bridge the aforementioned gaps and provide a further insight into the mechanical response of composite pull-out joints under rapid loads, the work herein investigates experimentally and numerically a representative aerospace material system and fastener combination, i.e. carbon/epoxy AS4/8552 laminates with titanium countersunk lockbolts, subjected to a wide velocity range, i.e. from quasi-static to 2.1 m/s. With respect to physical testing, a novel test fixture and a standard drop tower machine were combined for the conduction of the dynamic experiments, while some static results were extracted from a typical servo-hydraulic load frame for the assessment of the loading rate effects on the joint's actual response. The test results demonstrated an increase of about 15% in terms of strength values between the statically and dynamically tested coupons, while failure patterns derived from impacted samples presented a more intense damage zone. In the numerical framework, the stacked shell approach was adopted for the development of the joint finite element (FE) simulation model. The stacked shell approach is based on the idea of representing the composite laminate with a discrete number of sublaminates; these are modelled by using shell elements and are tied together with cohesive elements or contact interface elements with cohesive zone properties. The main capability of this modelling technique is the accurate representation of the out-of-plane behaviour of laminated structures, while maintaining the higher computational efficiency and simplicity of conventional shell approaches. The simulations were performed with the aid of the explicit FE code LS-DYNA and the numerical results showed very good agreement with the related experimental data. Thus, the validated simulation model can serve as a useful numerical tool for the analysis of various laminated joint configurations subjected to dynamic out-of-plane loads.

Mode I crack propagation analysis of adhesive bonded joints made of glass fiber composite material under impact and standard fatigue loading

abst. 2599
Virtual Room
Thursday
September 3
15h45

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The Colombian aeronautical industry has stimulated research into the mechanical behaviours of materials under the different loading conditions that aircrafts are generally exposed during their operation. Calima T-90, the first military aircraft that was built in Colombia, is used for the primary flights training of Colombian Air Force pilots, and is thus often exposed to adverse operating situations, such as hard landings, which cause impact loads and can subsequently produce impact fatigue. The Calima T-90's structure is mainly comprised of composites materials, generating assemblies and subassemblies of different components of it. The main method of bonding these components is by using adhesive joints with different thicknesses. This study aimed to characterise the mode I crack propagation rate on a typical adhesive joint of the aircraft under impact and standard fatigue. For this purpose, the evaluation of the effect of adhesive thickness on the mechanical performance of the joint under quasi-static loading conditions, impact and standard fatigue in double cantilever beam (DCB) specimens was performed. Cyclic impacts were induced using a drop weight impact testing machine, to obtain the crack propagation rate (da/dN) as a function of the maximum energy release rate (Gmax) diagram, likewise, this diagram was also created for standard fatigue and both of them were compared to determine the effect of each type of loading in the structural integrity of the joint, finding that crack propagation rates under impact fatigue were two orders of magnitude higher than those under standard fatigue regime. Moreover, lower loading rates decreased the maximum energy release threshold due to the increment of damage. Finally, an analysis of the fracture surface of the specimens tested, considering the mechanical interaction between the substrate and the adhesive, showed fiber tearing and debonding from the composite material matrix as well as delamination, resulting in a good adhesion mechanism.

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abst. 2565
Virtual Room
Thursday
September 3
15h30

Damage mechanisms of scarf joint repairs for wind turbine rotor blade shell applications

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Wind turbine rotor blades, made of fiber reinforced polymers (FRP), often fail before their projected 20-year lifespan, largely due to defects that originate during manufacturing and are propagated by operational fatigue and environmental conditions. The cost-intensive replacement outcomes lead to a high loss of earnings, and are one of the inhibitors of wind turbine production [1]. A potential repair alternative is to locally patch these areas of the blades with adhesively bonded structural repairs. However, the effects of such repair methods of the outer shell region on the structural integrity of the rotor blades are still largely unknown, and are thus investigated in this project. The shell components of rotor blades are made of FRP composite material sandwiching a lightweight core, often a rigid foam or Balsa wood. The repair methods involve replacing the lost load path with a new material that is joined to the parent structure [2]. Repairs in this project focus on the scarf method, which allow for a smoother load distribution across the joint, aiming to study the damage mechanism of glass FRP scarf repairs for wind turbine blade shell applications. Namely, the source and path of the damage initiation and propagation, role of the interface between parent and patch material, and the role of the fiber orientation mismatch at this interface are examined. Biaxial $\pm 45^\circ$ and $0/90^\circ$ FRP specimens are produced with the vacuum-assisted resin infusion (VARI) process using E-glass non-crimp fabric. The patch layers are then joined using VARI with a scarf ratio of 1:50, using glass FRP fabric with half the areal weight of the parent side to allow for better drapability. The methods and practices in specimen production are based on common industry practice in rotor blade shell manufacturing and repairs. The specimens are tested under uniaxial tensile load, during which they are periodically monitored for damage onset. A comparison of the $\pm 45^\circ$ and $0/90^\circ$ specimens allows for an understanding of the role of a highly mismatching fiber orientation in the transition zone between parent and patch material on the failure mechanism of the scarf joint. Although failure in both orientations begins as delamination at the joint edge, the difference in the mechanisms at play in the two different specimen types leads ultimately to different fracture paths. Namely, in the inter fiber failure mechanism of the $\pm 45^\circ$ specimens, the higher

interlaminar strength compared to the intralaminar strength of the laminate leads to intralaminar failure of the $\pm 45^\circ$ scarf joint specimens. Alternatively, the competition in the $0/90^\circ$ specimens lies between the interlaminar strength and fiber failure strength, and here we experience failure primarily across the scarf joint length. The scarf joint in the $0/90^\circ$ specimens disrupts the continuity of the load-carrying 0° layers, directing the failure path to remain primarily along the scarf joint. Experimental results are compared to finite element analyses of scarf patch repairs on glass FRP sandwich specimens with the same respective layup orientations, where the damage initiation regions are identified and correlated to fiber orientation, serving as a bridge to future work which will experimentally examine the scarf repair patches on sandwich shell specimens. References: [1] Trappe, Volker and Dustin Nielow. "Fatigue Loading of Sandwich Shell Test Specimens with Simulated Production Imperfections and In-situ NDT." In: Proc 7th International Conference on Fatigue of Composites (ICFC 7), Vincenza, July 2018. [2] Lekou, D. J., and P. Vionis. Report on Repair Techniques for Composite Parts of Wind Turbine Blades. OPTIMAT Blades, 2002, pp. 1–15.

Damage Analysis of Adhesively Bonded Lap Joints Laminated Composites

abst. 2375
Virtual Room
Thursday
September 3
08h30

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Experimental and numerical analyses of single lap joints of composite laminates were carried out in the present study. Tension and four-point bending experiments of single lap joints were performed in the experimental analysis section of this study in addition to finite element analyses performed. Three dimensional nonlinear finite element analyses (FEA) of tensile and four point bending of single lap joints were performed for the numerical analysis section by taking Hashin failure criteria for damage initiation and Continuum Damage Mechanics (CDM) approach for damage evolution into consideration. Further, cohesive element zone method was applied to check failure in adhesive region. The load and boundary conditions applied during experimental analyses were applied for FEA. Normal and shear strain distributions obtained via finite element method were presented by taking into consideration the middle line of the adhesive layer in the case of tensile and four-point bending loads of single lap joints. Damages due to tensile and four point bending load was compared with experimental result through images obtained from optical microscopes. As a result of this comparison, it was found that there was a sufficient level of compatibility in the damage predictions.

Damage tolerance enhancement of metal-composite bonded joints with through-the-thickness penetrative reinforcements

abst. 2499
Repository

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The mechanical properties of the bonded joint are very sensitive to the possible manufacturing defects and damages in service lives, which makes the bonded joints difficult to meet the damage tolerance design requirements of current airplane structures. The technologies that can effectively increase the damage tolerance performance of metal-composite bonded joints is crucial to take full advantage of the advantages of the bonded joints such as lightweight and high strength. In this study, a new technology was developed to improve mechanical properties of the metal-composite joints and its effect on the damage tolerance performance was evaluated. The reinforcement was realized by penetrating an array of thin pins on the joint area and bonding the pins together with the joint plates. Both experimental tests and numerical simulations were conducted to study effects of the reinforcements. Through the comparative analysis, it was found that the proposed through-thickness reinforcing technology improves the static load capacity, fracture energy, fatigue life and damage tolerance of the metal-composite bonded joints significantly. Moreover, the reinforcements offered the great increase on the failure strain of the metal-composite bonded joints under both quasi-static and cyclic loading greatly, even though there were disbond defects in the joints. The damage tolerance of the metal-composite bonded joints was significantly increased by the through-thickness penetrative reinforcements.

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abst. 2070
Repository

Strength prediction of composite single lap joints using a meshless method

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Adhesive joints nowadays are used in a multitude of engineering structures, such as cars and airplanes. Adhesive bonding does not require holes, unlike bolting or riveting, which can cause delamination and other defects in composites, reducing the overall strength. The increased usage of adhesive joints creates a demand for better design and strength prediction tools in order to decrease the development cost, in time and money, of these joints. Currently the most common strength prediction tool in adhesive joints are Cohesive Zone Models (CZM), which provide accurate strength predictions, but require several experimental tests to determine several material properties. The use of meshless methods, an advanced discretization technique, is an innovation for this type of structure. So, in the current work, the strength prediction of composite adhesive single lap joints is performed using the Radial Point Interpolation Method. The main aim of this work is to present a viable and accurate alternative to CZM. It was found that the strength predictions achieved using the proposed approach were satisfactory.

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abst. 2293
Repository

Fracture analysis of adhesive bonded joints using machine learning method

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The adoption of multi-materials strategy has increased in the aerospace, vehicle and marine engineering, which facilitates the necessity for using adhesive joining technologies due to its superior characteristics, such as, high strength-to-weight ratio, excellent stress transfer behaviour and the compatibility with a wide range of material types. To ensure safety structural assembly, it is essential to identify the joint performance, where the fracture mechanism is one of the key considerations to prevent catastrophic joint failure, to improve the joint design and optimise the joint behaviour, especially when a crack exists. The adhesive bonded joints always experience a complex mixed mode failure scenarios (a mixture of peel and shear modes), which is highly sensitive to several factors, such as, the type of adhesives, the materials of adherends and the joint configurations (overlap length, adherend and adhesive thickness). As it is difficult to identify the joints' dominant failure modes, therefore, Virtual Crack Closure Technique (VCCT) embedded in Finite Element Analysis (FEA) has been used to calculate the fracture energy at the crack tip under the elastic condition. However, FEA is computational expensive when considering many material and geometry combinations. Therefore, a hybrid deep learning model using Fruit Fly Optimisation (FFO) algorithm is proposed in this study to predict the fracture mechanism of the adhesive bonded joints when a crack exists, based on a large number of database calculated from finite element analysis and Design of Experiments (DoE). The baseline finite element model is validated with experimental results of two joint categories including similar aluminium-aluminium joints and dissimilar aluminium-polyphthalamide (PPA) joints bonded with epoxy adhesive (Loctite EA 9497) with an initial crack of 5 mm. The sensitivity analysis found that the elastic modulus of upper and lower adherends (E1 and E2) has a significant effect (52.8% and 15.6% respectively) on the joint's fracture mode compared with the joint's thicknesses. When the ratio of E1/E2 is larger than 2, the joint is mode I (peel) dominant and when the ratio is between 0 to 2, the joint is mode II (shear) dominant. The hybrid model proposed in this paper is a start point for using machine learning in understanding the performance of adhesive bonded joins.

Keynote Lectures

KEYNOTE LECTURE | On the Role of Advanced Structural Theories in Mechanics of Laminated Composites Analysis

abst. 1002
Repository

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Classical elasticity of solids is governed by a very few Partial Differential Equations. The intrinsic complexity of these PDEs has motivated the introduction of simplified ToS Theories of Structures. The most known are the Euler-Bernoulli theory of beams and the Kirchhoff-Love theory for plates and shells. Pioneers were clearly aware of the limitations of these simplifies models nevertheless Engineers to build any construction for more than two centuries have extensively used these theories. Improved theories are more recent the most significant ones are attributed to Timoshenko and Mindlin/Reissner, which include transverse shear deformation in the early ToS, Laminated composites are layered structures, intrinsically non-homogenous, often made by anisotropic materials. Due to these three facts, Classical ToS as well as their refinements cited above, could result inadequate to trace adequately the response of laminated structures. Higher-order theories, like the one by Reddy, Zig-Zag, Layer-Wise, and Mixed modeling would be better used. This lecture overviews the various contributions made on these advanced theories and outlines the role played by this large amount of studies on the development of the Theory of Structures.

KEYNOTE LECTURE | Modelling of Composite Materials with Higher Order Multiscale Models

abst. 1014
Repository

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The effective use of fiber-reinforced composites relies on the ability to accurately predict their deformation behavior for general loading conditions and boundary conditions. Therefore, substantial efforts have been made to develop constitutive models that can represent the material response and reduce both the cost and time of physical testing. Multiscale models based on computational homogenization have emerged as a promising constitutive modeling approach to describe materials with complex microstructural geometries and behaviors. Nevertheless, multiscale models based on the first-order homogenization are only valid if the assumption of scales separation holds true, i.e., if the RVE is smaller than the macroscopic characteristic length, such that the macroscopic deformation may be considered uniform throughout the RVE. This limits the applicability of these models that cannot be employed when the size of the micro-constituents approaches the macroscale characteristic length, or when the spatial variation of macroscopic deformations or loadings does not comply with the scale separation principle, which occurs when strain localization emerges. Moreover, these formulations cannot capture size effects from the microstructure. Therefore, a general second-order formulation for the multiscale description of composite materials, where more advanced constitutive laws can be employed to describe the microscale behavior, is presented. The variationally consistent, fully second-order homogenization formulation is derived from the Method of Multiscale Virtual Power, where a second-order continuum theory is employed to describe both the macro and micro-scale behavior. The finite element solution of the resulting multiscale equilibrium problem is described in detail. Several microstructural representative volume elements are initially considered to study the importance of the size of the RVE together with the size of the constituents under the influence of strain gradients. The RVE is subjected to a comprehensive set of stress states, and the observed deformation mechanisms together with the nonlinear homogenized response of the composite are analyzed in detail. Different aspects of the formulation are explored, and it is shown that it can be effectively used to predict the nonlinear behavior of fiber-reinforced composites under generic conditions.

KEYNOTE LECTURE | Performance of enhancement of flax biocomposites through hybridisation approach: potential for lightweight structural applications

abst. 1006
Repository

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Concerns over global warming and the end-of-life of non-recyclable conventional fibre reinforced composites have motivated research into materials which are lightweight, biobased and environmentally friendly. The effects of basalt fibre hybridisation on the low velocity impact damage behaviour of flax fibre reinforced composites have been experimentally investigated. In addition, the influence of water absorption on the impact damage characteristics have also been analysed. Furthermore, the mode I and mode II inter-laminar fracture toughness properties of flax fibre reinforced vinyl ester composites and their hybrids have been experimentally investigated. The experimental results of hybrid and without hybrid composite laminates exhibited significantly improved performance with carbon and basalt fibre hibridisation. The modified beam theory (MBT), compliance calibration (CC) and modified compliance calibration (MCC) data reduction methods were adopted to perform double cantilever beam (DCB) tests to evaluate the Mode I critical energy release rate (GIC) and the crack length (R-curve) on various neat and biocomposites such as neat vinyl ester, flax-fibre reinforced vinyl ester, flax fibre hybridised basalt unstitched and flax hybridised basalt stitched. The results obtained exhibited that for both modes (I and II) fracture toughness initiation and propagation of water immersed flax vinylester composites decreased compared to the dry samples. Both scanning electron microscopy (SEM) and X-ray micro computed tomography (X-ray μCT) were used to analyse the failure mechanisms and delamination of the different composite samples. The results obtained show that hybridisation using carbon and basalt fibre enhanced the mechanical properties, the durability and moisture resistance of the natural fibre composites significantly. In this keynote, the potential of natural fibre reinforced composites and hybrid composites for lightweight structural applications with reference to recent research and development results will be presented and discussed.

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abst. 1011
Virtual Room
Thursday
September 3
08h00

KEYNOTE LECTURE | Natural Fibre Based Hybrid composites for automotive, ballistic and packaging applications

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Natural Fiber reinforced polymer composites have been widely used in many engineering applications due to its higher specific strength and stiffness. Several researchers explored the possibility of utilizing eco-friendly natural fibers such as Kenaf, Coconut sheath, Malva, rami, curaua, bagasse, hemp, flax, oil palm, date palm, roselle, jute, bamboo, etc as an alternative to synthetic materials in automotive, ballistic and in packaging applications. Also, the demand on the natural fiber composites (NFCs) have witnessed a significant compound annual growth rate (CAGR) of 10.93% over the forecasted years (2019 – 2024). The main advantages of using natural fibers are low density, non-abrasive, non-corrosive, inherent biodegradability, low cost, easily available and recyclable. Despite its merits, major impediments of using natural fibers are hydrophilic nature, limited thermal stability and poor adhesion with adjacent counterparts. Hybrid composites contains more than two discontinuous or continues phases. The main advantage of hybrid composites relies on the fact that the benefit of one type of fiber could surpass the limitations of the other fiber. Hybridizing natural fibers and natural/synthetic fibers will combine the advantage of individual constituents and provide superior properties for advanced application. Several researchers explored the potential of natural fibre based composites in automobile industry. Mercedes-Benz introduced jute based door panels into its A-Class vehicles as long as eight years ago. Virtually, all the major car manufacturers in Germany (Daimler Chrysler, Mercedes, Volkswagen, Audi Group, BMW, Ford and Opel) started to use natural fibre composites in various application. Malaysia's leading car manufacturing company (Proton) have focussed on eco-friendly automotive products due to the increase in awareness about eco-legislations and sustainability. Numerous studies were investigated on the ballistic performance of natural fiber based polymeric composites as a partial or complete replacement in the monolithic and multilayer body armour. Personal body armor can be classified into two categories such as soft and hard body armor .Soft body armor contain multiple layers of fabrics up to 50 layers (Weigh below 4.5 kg). Soft body armor has to withstand the impact of projectile up to 500 m/s (According to National Institute of Justice (NIJ) armor standard). Further, the hard armor has to withstand the impact of the projectile more than 500 m/s (NIJ level IIIA) when worn in conjunction with soft armor vest. Replacing Kevlar fabric layers with an eco-friendly lightweight materials together with an improved kinetic energy absorption and dissipation have become an interesting approach to enhance the ballistic performance of body armor. Plastic food packaging

has been produced and consumed in an unsustainable manner. Eco-friendly packaging has been gaining rapid commercial importance over recent years due to the urge of finding a sustainable alternative to plastic-based packaging. Bioplastic is commonly used for sustainable packaging materials obtained from bio-based resources such as cellulose acetate, starch and polylactic acid (PLA) which are eco-friendly. Oil palm fiber based packaging materials have gained attention due to the availability of enormous raw material. This presentation addresses the potential of natural fibre based composites and it's hybrids for automotive, ballistic and packaging applications. Keywords: Natural fiber; hybrid composites; polymers; automobile; ballistics; packaging materials

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KEYNOTE LECTURE | Discrete-Continuous Models for Microstructured Materials: Non Classical/Non-Local Descriptions, with applications to composites

abst. 1010
Repository

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The mechanical behavior of materials with microstructure strongly depends on their microstructural features. In particular, in the modelling of these materials, such as particle composites that are polycrystals with interfaces or with thin or thick interfaces, as well as rock or masonry-like materials, the discrete and heterogeneous nature of the matter must be taken into account, because interfaces and/or material internal phases dominate the gross behaviour. And this is definitely ascertained. What is not still completely recognized, is the possibility of preserving memory of the microstructure, and of the presence of material length scales, resorting to non-classical/non-local continuum descriptions [1, 2, 3]. The classical/local Cauchy continuum (grade1), lacking in material internal scale parameters, does not seem appropriate for describing the macroscopic behavior in problems dominated by the material internal size, such as strain/stress localization phenomena, occurring even in the elastic regime in the presence of geometrical or load singularities (cracks/holes/inclusions, concentrated loads) [4, 5, 6, 7]. Moreover, the absence of proper kinematical descriptors inhibits the possibility of taking into account of the orientation of micro-heterogeneities (inclusions/voids) and to adequately represent anisotropic behavior [4, 7]. Especially for materials made of particles of prominent size and/or strong anisotropy anisotropic media, the resort to non-classical/non-local continuum descriptions is then required. This talk wants to firstly focus on the origins of multiscale modelling, related to the original discrete(molecular)-continuous models, developed in the 19th century to give explanations 'per causas' of elasticity (Cauchy, Voigt, Poincare), in order to find conceptual guidelines for deriving discrete-to scale-dependent continua, that are essentially non-local models with internal length and dispersive properties [1, 2]. Then, a discrete-to-scale dependent continuous formulation, developed for particle composite materials basing on a generalized version of Voigt's molecular/continuum approach, is proposed [8, 9, 10]. Finally, with the aid of some numerical simulations - concerning ceramic matrix composites (CMC), microcracked media and masonry assemblies – focus will be on the advantages of the micropolar modelling with respect to other non-classical/non-local continuum formulations [4, 5, 6, 7]. Acknowledgements: This research was supported by the Italian Ministry of University and Research, P.R.I.N. 2017 No. 20172017HFPKZY (cup: B86J16002300001). References [1] I. A. Kunin (1984), On foundations of the theory of elastic media with microstructure, Int. J. Engng. Sci., 22(8-10):969-968. [2] P. Trovalusci (2014), Molecular approaches for multifield continua: origins and current developments. CISM (Int. Centre for Mechanical Sciences) Series, 556: 211-278, Springer. [3] P. Trovalusci, Ed. (2016), Materials with Internal Structure. Multiscale and Multifield Modeling and Simulation, Springer Tracts in Mechanical Engineering, Vol.18:109-131, Springer. [4] N. Fantuzzi, P. Trovalusci, S. Dharasura (2019), Mechanical behaviour of anisotropic composite materials as micropolar continua, Frontiers, 59 (6):1-11 (https://doi.org/10.3389/fmats.2019.00059). [5] M. Tuna, L. Leonetti, P. Trovalusci, M. Kirka (2019), 'Explicit' and 'implicit' non-local scale dependent continuous descriptions for a plate with a circular inclusion in tension, Meccanica (https://doi.org/10.1007/s11012-019-01091-3). [6] M. Tuna, P. Trovalusci (2020), Scale dependent continuum approaches for discontinuous assemblies: 'explicit' and 'implicit' non-local models", Mech. Res. Comm, 103, 103461, (https://doi.org/10.1016/j.mechrescom.2019.103461). [7] N. Fantuzzi, P. Trovalusci, R. Luciano (2020), Multiscale analysis of anisotropic materials with hexagonal microstructure as micro-polar continua, Journal for Multiscale Computational Engineering, x(x): 1–29, 2020. In print. [8] P. Trovalusci, V., Varano,,

G. Rega (2010), A generalized continuum formulation for composite materials and wave propagation in a microcracked bar, J. Appl. Mech., 77(6):061002/1-11. [9] P. Trovalusci, A. Pau (2014), Derivation of microstructured continua from lattice systems via principle of virtual works. The case of masonry-like materials as micropolar, second gradient and classical continua" Acta Mech., 225(1):157-177 [10] V. Settimi, P., Trovalusci, G. Rega (2019), Dynamical properties of a composite microcracked bar based on a generalized continuum formulation, Cont. Mech. Thermodyn., 31(6):1627-1644

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KEYNOTE LECTURE | Localisation in buckling and post-buckling of cylindrical shells

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Buckling of axially compressed cylinders is a classic problem in engineering mechanics. Even though an analytical solution based on a linear eigenvalue analysis has existed for over 100 years, the buckling of cylinders continues to attract attention from researchers. This interest stems from the unstable nature of the buckling event with its associated severe sensitivity to initial imperfections—geometric, loading, boundary conditions, or otherwise—that rapidly erode the analytical or numerical predictions based on the perfect problem. A classical analysis of the compressed cylinder based on a linear eigenvalue analysis also suggests a periodic nature of the buckling modes, whereas high-speed photography experiments indicate that buckling is governed by the formation of one or multiple dimples that then multiply to cover the whole cylinder surface. Asymptotic expansions around the critical point, and branch-switching techniques based on extended arc-length methods, show that the periodic buckling modes branching from the pre-buckling path do indeed localise immediately after the bifurcation into solutions featuring one or multiple dimples. Tracing these dimple solutions in a path-following solver with respect to applied compression demonstrates a sequential pattern formation whereby isolated dimples multiply circumferentially through a series of de- and restabilisations. Furthermore, the single-dimple solution forms an unstable equilibrium path, almost coincident with the pre-buckling path, that corresponds to the smallest energy barrier between the pre-buckling and post-buckling regimes. The small energy barrier associated with the single-dimple solution means that the compressed, pre-buckled cylinder is exceedingly sensitive to perturbations once the level of compression is exceeded for which the single dimple exists as an unstable equilibrium. It is possible to parametrise the compressive onset of the single-dimple solution using a single non-dimensional parameter, and the ensuing relation forms an alternative lower-bound design curve that shows good correlation with experimental results in the literature and other lower-bound curves suggested recently. The fact that localisations can form as unstable equilibrium solutions anywhere across the domain of the cylinder implies a large set of possible trajectories to instability, with each trajectory affine to a particular imperfection signature. This multiplicity of possible routes to buckling leads to a large spread in buckling loads even for seemingly indistinguishable random imperfections of equal amplitude. It is shown that the ability to control the equilibrium trajectory to buckling via dominant imperfections, or elastic tailoring using tow-steered composites, creates interesting possibilities for designing imperfection-insensitive shells.

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abst. 1009
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KEYNOTE LECTURE | Length Scale Effects in Polymer Nanocomposites: Modeling and Applications

Roy, Samit (sroy@eng.ua.edu), University of Alabama, USA

This presentation describes the findings from several current research projects conducted by Prof. Roy's research group within the topic area: A) Length Scale Effect in Toughness Enhancement in Composites: Recent compact tension fracture experiments performed by my research group indicate that very significant increases in fracture toughness (200%) can be achieved by dispersing only 0.5 weight percent of nanographene platelets within a thermoset epoxy polymer using high shear mixing. In order to model the actual compact tension experiment using atomistic simulation near the crack tip while maintaining computational tractability, concurrent coupling of partitioned domains between

Generalized Interpolation Material Point Method (GIMPM) and Molecular Dynamics (MD) was carried out through the use of Embedded Statistical Coupling Method (ESCM). This numerically robust technique has proven to be very effective in coupling a local domain (continuum) to a nonlocal domain (MD) and mitigating high frequency noise that emanates due to thermal motion in the MD region from being transmitted into the continuum domain. As part of a three-year project funded by NASA Aeronautical Sciences Project on structural light-weighting of aerospace vehicles, the concurrently coupled GIMPM/MD code was employed to study and understand the strength and fracture-toughness enhancement mechanisms at the nano-scale in nanographene reinforced thermoset polymer composites at elevated temperatures, using our novel atomistic J-Integral concept which includes polymer entropic effects. Recently, a breakthrough in our understanding of fracture mechanism at the nanoscale was achieved through the use of this approach, resulting in a unique "optimum nanoparticle size" based nano-carbon reinforced composite design guideline. Ideas for scaling up this novel nanoscale building-block approach to large scale structures using nanoparticle alignment during manufacturing will be presented. B) Scalable Nanomanufacturing of CNT Scrolled Carbon Fiber: One approach to improve properties of the fiber/matrix interface in a polymer matrix composite (PMC) is the so- called "fuzzy fiber" concept, where carbon nanotubes (CNT) are grown directly on the carbon fiber through CVD. However, the high temperatures typically required for CVD processing have been observed to degrade carbon fiber properties. In our manufacturing approach, we wrap (or scroll) continuous CNT sheet on the carbon fiber at room temperature at a prescribed wrapping angle, and then imbed the scrolled fibers in a resin matrix to build a composite. Consequently, our novel nano-fabrication technique has the potential to enhance mechanical properties of the fiber/matrix interphase that directly influences the fiber/matrix debond strength and compressive strength of the composite, without degrading fiber properties. The single wall carbon nanotube (SWNT) or multiwall carbon nanotube (MWNT) sheets were prepared by pulling a well-aligned CNT forest from a substrate using a unique procedure pioneered by our multi-university team. The CNT sheets are then spiral-wrapped around a fiber, which is then embedded in a polymer matrix. Our preliminary test results indicate that a significant improvement (80%) in interfacial shear strength and compressive properties is feasible using the proposed approach. Multi-scale modeling of compressive strength and concepts for scaling up this nano-manufacturing process for large-scale scrolled fiber composite production will be discussed.

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abst. 2134
Repository

Design and analysis of GFRP devices for a mono-pile of offshore turbine against ship impact

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Offshore wind power generation was widely adopted by coastal countries. Meanwhile, the risk of collisions between ships and offshore generators in harsh offshore environment are increasing during the service period with the increase of ship routings. In this paper, a new floating energy absorption anti-collision device with glass fiber reinforced polymer(GFRP) and foam is proposed to mitigate the consequences of collisions between offshore ships and offshore structures. Ply thickness and angle of composites were designed by bearing capacity requirement using FEM. The 3MW mono-pile offshore wind platform was taken as an example to prove the energy absorption ability of the device. The energy absorption, collision force, collision time, stress and strain of mono-pile foundation during the collision scenarios are analyzed by comparing the different working conditions with and without anti-collision device. The numerical results showed that the collision time of the condition with anti-collision device is 2.36 times longer than that without the anti-collision device, and the maximum collision force is reduced by 57.5%. In addition, the simulation results show that the energy consumption of anti-collision device is mainly realized by deformation and foam material failure. This paper is of great significant in providing a practical application anti-collision device and a theoretical basis for the design of anti-collision device of offshore wind turbines.

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abst. 2697
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Elucidating the Role of Fiber Architecture on Moisture diffusivity of Fiber Reinforced Polymer Composites

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Fiber Reinforced Polymer (FRP) composites are widely used in marine environment due to their high specific strength, increased durability and corrosive resistance property. But these materials when subjected to moisture or seawater experience moisture absorption that results in the reduction of material strength due to matrix plasticization and reduced interfacial strength due to de-bonding at the fiber-matrix interface. To ensure long-term durability and damage tolerance, it is important to understand the impact of moisture diffusion and moisture-induced damage in composites. To that end, the goal of this study is to elucidate the importance of fiber architecture including fiber packing and orientation on the moisture diffusion to assist with optimal design of FRP composites for marine applications. In this paper, micromechanical models have been developed to study the long-term response of FRP composites subjected to moisture ingression. Two-dimensional micromechanical diffusion models with varying fiber volume fraction and randomly distributed fibers for both impermeable fibers (carbon,glass) and permeable fibers (Kevlar) were developed to study the influence of fiber packing on the effective diffusivity and moisture saturation. In this work, the variation in effective diffusivity is also quantitatively shown using tortuosity factor where it is inversely proportional to the effective diffusivity of composites. Input parameters for these models are saturation weight gain percentage and diffusion coefficients of the matrix and fiber. A parametric study was conducted to generate response maps for diffusivities and associated perturbation factors with varying FRP parameters mentioned above. Observations from the micromechanical models were qualitatively verified by subjecting composite samples with different volume fractions and layup orientations in water. Through the thickness, local mechanical property degradation was measured using micro-hardness testing by utilizing a time-course experiment. The

chemical structural change was also qualitatively determined using Fourier transformed infrared (FT-IR) spectroscopy in different time stamps of exposure. A detailed degradation mechanism due to moisture ingression through different fiber packing was proposed based on mechanical and chemical structural changes in the polymer.

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abst. 2569
Repository

Variational Analysis of Laminates with Divided Regions in Longitudinal Direction

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In the current work, an attempt has been made to extend the applicability of the variational approach for analyzing laminates with divided regions along the longitudinal directions based on the original variational model of Hashin's analysis. This method which we used to call it as the in-ply regional refinement method sub-divides the laminates into regions along the longitudinal direction to solve several problems involving the mixture of material properties in laminates including cracking problems. Investigating the material properties and damage behavior of laminates with fiber discontinuous ply(s) has been the main motivation for this study to be conducted wherein current work, we solved the two sub-regions problem as the first step. Similar to Hashin's original analysis, an admissible stress field that satisfies equilibrium and all the boundary and continuity conditions is constructed and it is used in conjunction with the principle of minimum complementary energy to achieve the optimal stress state. In order to determine the solution mathematically from the physical construction of the laminate, some appropriate boundary conditions at each region's border are required. Here, by involving the principle of minimum complementary energy and some mathematical means, those required boundary conditions can be systematically determined. The stress distribution results were compared to Hashin's original analysis and FEM for cracked laminates and ply (fiber)-discontinuity problems respectively where both comparisons show a good agreement in both problems. In addition, the effective Young's modulus obtained in this study showing a better agreement to experimental results compared to Hashin's original analysis which always gives a lower bound for the stiffness reduction result. The current analysis can be extended to solve the arbitrary N-regions problem that can be implemented to many other more applications in laminates.

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abst. 2519
Repository

Computational homogenization of composites by virtual and boundary elements

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Benedetti, Ivano (ivano.benedetti@unipa.it), Department of Engineering, University of Palermo, Italy

The Boundary Element Method (BEM) [1] is today largely employed in several problems concerning the mechanics of materials and structures. Its appeal is largely related to its ability to provide highly accurate results at a generally reduced computational cost, thanks to the reduction in the dimensionality of the models induced by the use of boundary integral equations as starting point of the problem formulation. The BEM has been successfully employed for the computational homogenization of materials with complex morphologies [2]. The Virtual Element Method (VEM) [3] has recently emerged as a powerful and robust extension of the finite element method, capable of dealing with very general polygonal/polyhedral meshes, including irregular or non-convex meshes. Such features are appealing for the treatment of problems involving complex morphologies, as it ensures noticeable simplification in the data preparation stage of the analysis. In this contribution, we explore the potential of a coupled VEM/BEM approach for computational homogenization of composite materials. The BEM is used to model the inclusion, representative e.g. of a fibre in a fibre-reinforced polymer composite, while the VEM is used to model the surrounding matrix material. The obtained results are validated against benchmark analytical and finite element solutions. References: [1] Aliabadi, MH. The boundary element method, applications in solids and structures, Vol. 2, John Wiley & Sons, 2002. [2] Benedetti, I, Aliabadi MH. A three-dimensional grain boundary formulation for microstructural modeling of polycrystalline materials. Computational Materials Science, 67, 249-260, 2013. [3] Beirão da Veiga L, Brezzi F, Cangiani A, Manzini G, Marini LD, Russo A. Basic principles of virtual element methods, Mathematical Models and Methods in Applied Sciences, 23(01), 199-214, 2013.

Numerical modeling of aged basalt reinforced composites behaviour under low-velocity impact loading

abst. 2695
Repository

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Basalt, as a fiber for reinforcing polymeric composites, is progressively emerging as an alternative to glass, given their comparable mechanical properties and the growing environmental awareness for eco-friendlier solutions in structural engineering. Given the mechanical properties variations that polymers may present depending on the application they are subjected to, experimental results are generally conducted to allow a cost-effective dimensioning of composite structures. As an alternative to these resource and time-costly experimental routines, numerical simulations have become a viable tool to predict the behavior of laminates. However, there might be a technical barrier when dealing with dynamic boundary conditions and explicit codes given the inherently intricate numerical model setups. Hence, the present study describes the calibration of constitutive parameters for the creation of a stacked-shell virtual laminate that faithfully reproduces the response of a cross-ply balanced basalt thermoset laminate to low-velocity impact (LVI) in a simplistic and computationally-cheap manner, validating its outcome with experiments. Knowing that most composites must be designed to endure certain environmental variations, the numerical model reproduced the behavior of the composite after accelerated ageing by high temperature and moisture exposure. The accuracy of the numerical output hereby presented was checked by a high correlation coefficient of over 97% and 94% for the force vs. time and force vs. displacement experimental curves, respectively. Furthermore, the final values of the constitutive parameters after calibration pointed out to a predominantly tensile failure in the matrix, which was corroborated by a Scanning Electron Microscopy (SEM) analysis.

Probabilistic analysis of the effect of fibre architecture distribution on the mechanical property of plain-woven composite under tensile loading

abst. 2099
Virtual Room
Thursday
September 3
14h15

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In recent years, woven composites have attracted great attention due to their high impact resistance compared with the conventional composite laminates. However, the complicated fibre architecture of woven composites may determine the presence of manufacture defects like voids and debonding of fibre and matrix, which may lead to uncertainty in the definition of the mechanical performances. This uncertainty is a key aspect, especially in the exploitation of such materials for the design and manufacturing of critical and complex components. So, it could be of interest to consider such uncertainties by means of investigating the mechanical performances of actual fibre architectures. In the present study, the effect of the fibre architecture, i.e. distribution of tows, on the mechanical properties of the woven composites under tensile loading has been investigated. Based on microscopic inspection on the cross-section, two different types of unit cells were built in a Finite Element environment for Kevlar- and Glass-fibre plain-woven composites respectively, to mimic the random distributions of fibre tows. For the Kevlar-fibre composite, a unit cell with small span and compressed fibre architecture was

created according to the distribution of tows near the exterior of real samples. Conversely, a unit cell with larger span (than designed one) between fibre tows was used to simulate the mechanical response of glass-fibre woven composite. This choice has been based on microscopic observations. The mechanical behaviour of the so built unit cells is therefore compared with the one obtained from the nominal geometry structure for each case. In this way it is possible to have an insight in one of the phenomena that may drive the variability of composites mechanical properties. To further validate such approach, tensile tests of Kevlar- and glass-fibre plain-woven composites were also conducted. The simulated results from different unit cells has been used to determine the range of tensile strength and modulus, that is compared with the scatter band of experimental data.

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abst. 2048
Repository

Non-Local finite element to model the behavior of composite structures – study of microbuckling

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The compressive failure of long carbon fiber composites is due to complex mechanisms. The knowledge of this material is important for the design of composite structures [1], because the compressive strength and stiffness of laminates is assumed less than their tensile strength. There are many articles in the literature regarding the modeling of composites compressive behavior, particularly the microbuckling phenomenon / local instability. But only few researchers modeled the mechanism at the structural / mesoscopic scale. For example, Drapier, et al. [2], proposed a 2D homogenized model, which takes into account fiber initial alignment defects, matrix plasticity and structural parameters. The model is successful in predicting the elastic microbuckling modes, but the model is 2D and assumes microbuckling is periodic in fiber direction, just one gradient in thickness direction is taken into account. Consequently, not possible to compare test results obtained with real structures. Moreover, the prediction of both the 'distribution' and 'amplitudes' of fiber initial imperfection is still not well known [3]. Recently, we have developed a simple 3D non-local model called Beam Non-Local (BNL) model in ABAQUS software to predict the elastic mode of instability in pure compression, bending, compression-torsion and next to the hole in specimen under compressive load. This model is an extension of [4] and can be applied only to Unidirectional (UD) plies and laminates, it is not possible to simulate composite structures with a complex microstructure (2D or 3D woven composite). Although, many nonlocal theories and various FE approaches has been developed over the years to solve the problem at the microscopic/mesoscopic scale, each model is restricted to some limitations and there is no particular model that has been developed to assess the compressive strength (particularly microbuckling phenomenon and nonlinear behavior of materials) of the carbon/epoxy composite at the structural scale. Hence, a homogenized nonlocal numerical model is proposed, similar to Mindlin's II gradient theory [5]. In comparison with old model [2], micro-curvatures in all the directions have been take into account in order to assess microbuckling phenomenon in UD and woven composites. The nonlocal model has been implemented in User Element (UEL) subroutine for analysis in ABAQUS, which permits to simulate the complex structures. Non-linear geometrical effects are taken into account in this non-local user element (NL U32) as well as the nonlinear behavior of the matrix with a User Material subroutine (UMAT). The tangent behavior of the non-local stiffness of microstructure is apprehended by integrating another User material subroutine (URMAT) within the element. Validation of the NL U32 element has been performed with respect to ABAQUS classical elements for both linear and non-linear (geometry and material) cases. The classical (elastic and plastic) and non-local material properties (elastic) are identified with respect to full heterogeneous microstructure. References: [1] Méchin P.-Y., Keryvin V., Grandidier J.-C., Glehen D., An experimental protocol to measure the parameters affecting the compressive strength of CFRP with a fibre micro-buckling failure criterion, Composite Structures 211 (2019) 154-162. [2] Drapier S., Grandidier, J.-C., Potier-Ferry, M., Towards a numerical model of the compressive strength for long fiber composites, European Journal of Mechanics /A Solids 18 (1999) 69-92. [3] Drapier S., Grandidier, J.-C., Potier-Ferry, M., A structural approach of plastic microbuckling in long fiber composites: comparison with theoretical and experimental results, Composite Science and Technology 38 (2001)

3877-3904. [4] Wisnom M. R. Analysis of shear instability in compression due to fiber waviness, Journal of Reinforced Plastic and Composites 12(11) (1990) 1171-1189. [5] Mindlin, R.D., Microstructure in linear elasticity, Arch. Rat. Mech. Anal 16 (1964) 57-78.

3D Orthotropic Damage Model for GFRP Composites

abst. 2033
Repository

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This paper presents a numerical study on the implementation of a new 3D orthotropic damage model for pultruded glass fibre reinforced polymer (GFRP) composites, adopting a user-subroutine (UMAT) in ABAQUS framework. The damage initiation is based on modified 3D Hashin criteria proposed elsewhere, and the damage evolution is based on an updated version of the Matzenmiller-Lubliner-Taylor (MLT) formulation with equivalent stress and strain. In order to prevent mesh dependency, classical fracture energy regularization is performed. To validate this new damage model, three examples are tested and compared with previous experimental results. The results of numerical simulations are also compared with results of previous 2D numerical damage models obtained by the authors. The first examples comprise classical compact tension (CT) and compact compression (CC) tests. The second example is the double edge notched (DEN) tensile test. The third example is a web crippling test in a pultruded GFRP profile, in which the 3D damage behaviour (of a fully-3D problem) is simulated.

Buckling experiments of additively manufactured structures

abst. 2667
Virtual Room
Thursday
September 3
14h30

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Klunker, André (), ,

For experimental investigations of the buckling and postbuckling behaviour of structures, additive manufacturing is a convenient tool for rapid specimen production. Columns, for example, are common structural elements in large scale civil engineering constructions and their critical buckling load can be determined by the well-known Euler load. Upon introduction of so-called cable- or fibre-stays, an increase of the critical load can be achieved in large scale columns since their global buckling behaviour is changed. The group is currently working on transferring this concept on smaller length scales. Therefore buckling experiments of axially loaded, simply-supported 3D-printed unit cells of a fibre-stayed lattice material have been conducted. The small-scale specimens reached a critical load higher than the bare columns with interactive buckling characteristics in the postbuckling range. This was also verified with numerical modelling. Furthermore, outcomes of the group's digital teaching semester are presented. Students had to work completely off-campus and developed their own (post-)buckling devices. With the aid of the devices, buckling characteristics of columns were investigated and compared to analytical results.

On the Influence of Tensor Interpolation Methods in Virtual Process Chains for Fiber-Reinforced Plastics

abst. 2676
Repository

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Their preeminent weight-specific mechanical properties predestine fiber-reinforced plastics (FRPs) for application in structural components. Accurate simulation results for this material class are only achievable if the entire process sequence is captured by its digital twin by means of so-called CAE-chains interlinking virtual models with corresponding constitutive laws and boundary conditions for each sub-step involved as indicated in [1, 2]. In common solving techniques, spatial discretization of governing equations yield discrete solution spaces, in which field values are only available at certain locations. Since mesh type, mesh topography and mesh fineness are usually tailored to the specific problem, mesh-to-mesh mapping must be embedded in the interfaces between the individual simulation modules. For receiving meaningful data and reducing the loss of relevant information, as an unavoidable side-effect of the mapping operation, the underlying averaging and interpolation schemes have to be mathematically and physically consistent. An interpolated value is a function of at least two available values at specific locations and their corresponding weights. In engineering applications, interpolation of tensors is usually executed by means of components, treating each component as an independent scalar-field and thus neglecting the tensorial character and its physical meaning. However, in the field of medicinal image processing and in computer graphics, several investigations have been conducted into the development of alternative interpolation methods acting on corresponding metrics [3] or using decomposition-reassembling approaches [4]. In this work, such sophisticated techniques are presented and their influence on the qualitative and quantitative interpolation results is assessed for application to fiber orientation tensors (FOT). Field recovery is performed for different information density and the evolution of systematical errors is statistically evaluated revealing significant bias for certain tensor characteristics induced by conventional component-wise interpolation. References [1] Kärger, L.; Bernath, A.; Fritz, F.; Galkin, S.; Magagnato, D.; Oeckerath, A.; Schön, A.; Henning, F.: Development and validation of a CAE chain for unidirectional fibre reinforced composite components. Composite Structures (2015) 132:350–358. [2] Görthofer, J.; Meyer, N.; Pallicity, T. D.; Schöttl, L.; Trauth, A.; Schemmann, M.; Hohberg, M.; Pinter, P.; Elsner, P.; Henning, F.; Hrymak, A.; Seelig, T.; Weidenmann, K.; Kärger, L.; Böhlke, T.: Virtual process chain of sheet molding compound: Development, validation and perspectives. Composite / B (2019) 169:133–147. [3] Arsigny, V.; Fillard, P.; Pennec, X.; Ayache, N.: Log-Euclidean metrics for fast and simple calculus on diffusion tensors. Magnetic resonance in medicine (2006) 2:411–421. [4] Gahm, J.; Wisniewski, N.; Kindlmann, G.; Kung, G.; Klug, W.; Garfinkel, A.; Ennis, D.: Linear Invariant Tensor Interpolation Applied to Cardiac Diffusion Tensor MRI. MI Computing and Computer-Assisted Intervention (2012) 15:494–501.

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abst. 2247
Virtual Room
Thursday
September 3
13h45

A damage model to predict non-linear shear behaviour of ceramic matrix composites

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A model based on a single damage continuum variable defined as the ratio of saturated matrix cracking distance to current matrix cracking distance has been proposed to predict the shear damage behaviour of ceramic matrix composites (CMCs). It is postulated that matrix cracking results in non-linear shear behaviour of fiber tows. The shear strength of matrix is assumed to follow a two-parameter Weibull distribution and the maximum shear stress criterion is employed to predict the initiation of matrix cracking. Shear stresses are uniformly distributed across tows under shear loading. Shear modulus is expected to have an exponential decrease while matrix crack develops. Main parameters of the model have been studied respectively to investigate their effects on shear stress-strain curves of fiber tows. The nonlinear shear stress-strain response of a CMC tow, predicted by the damage model, has been used in a macro-scale analysis for both cross-ply and plain weave CMCs to evaluate the model's fidelity.

Electronic and optical properties of van der Waals composite structures: the case of graphene/MoS2-1H

abst. 2552
Repository

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Since its discovery, the properties of graphene have been object of study for several and manifold applications of this bidimensional material, ranging from photocatalysis to electronic employments [1-3]. However, the use of pure graphene in certain opto- and microelectronic applications is sometimes limited because of its zero band gap. Among the different methods to widen this band gap, in the present work the attention is focused on the so-called van der Waals composites (or heterostructures, or heterojunctions), namely the stacking of two monolayers of different materials that are held together by weak interactions. Being graphene the first chosen material, the second one is molybdenite (MoS2), a bidimensional semiconductor characterized by strong in-plane covalent bonds and weak out-of-plane interactions, which means that it is possible to exfoliate the material into monolayers with atomically thin thickness. Also, from the crystallographic point of view, both graphene and the monolayer of molybdenite (MoS2-1H) have a 2D hexagonal lattice and their stacking could be favourable. In this work, the electronic band structure and density of states, complex dielectric function and optical properties of the stacked van der Waals heterojunction graphene/MoS2-1H were calculated and compared to both the single monolayers of graphene and molybdenite, to understand how the interaction between the two materials may alter the above cited properties. Density Functional Theory (DFT) methods based on the Generalized Gradient Approximation (GGA), including the contribution from dispersive forces [4] and projector augmented-wave (PAW) pseudopotentials [5], as coded in the Vienna Ab initio Software Package (VASP) [6, 7] were employed and the results thoroughly checked against previous theoretical and experimental data. The analysis of the band structure in the van der Waals composite clearly showed a small direct band gap related to the transition →* (ca. 2. 5 meV) in correspondence of the high symmetry point K. The heterojunction showed, as expected, some important variations in the complex dielectric function and related properties in the visible-light spectral region. The results obtained in the present work could be of use for future development of this kind of 2D composite materials with tailored electronic and optical properties. References [1] Tahir M, Tasleem S, Tahir B. Recent development in band engineering of binary semiconductor materials for solar driven photocatalytic hydrogen production. International Journal of Hydrogen Energy. 2020. [2] Geim AK. Graphene: Status and Prospects. Science. 2009;324:1530-4. [3] Geim AK, Novoselov KS. The rise of graphene. Nature Materials. 2007;6:183-91. [4] Grimme S, Antony J, Ehrlich S, Krieg H. A consistent and accurate ab initio parametrization of density functional dispersion correction (DFT-D) for the 94 elements H-Pu. Journal of Chemical Physics. 2010;132. [5] Kresse G, Joubert D. From ultrasoft pseudopotentials to the projector augmented-wave method. Physical Review B. 1999;59:1758-75. [6] Kresse G, Furthmuller J. Efficiency of ab-initio total energy calculations for metals and semiconductors using a plane-wave basis set. Computational Materials Science. 1996;6:15-50. [7] Kresse G, Hafner J. Ab-initio molecular-dynamics for open-shell transition-metals. Physical Review B. 1993;48:13115-8.

Micromechanical Analysis of Composites through Difference Based Deep Learning Neural Network

abst. 2635
Repository

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Analysis of composite materials using finite element method (FEM) has been computationally expensive especially in situations like optimization and multi-scaling, where several analyses are required and each analysis needs to run iteratively until convergence. This necessitates a surrogate method that enables stress predictions circumventing the traditional path using FEM. Prior studies have focused on encoder-decoder neural network as a surrogate for stress prediction and have observed great potential. However, these neural networks were purely based on image processing and were targeted for structures with simple shape and homogeneous material. To facilitate stress analysis and optimization process in micromechanics of composite materials and further improve stress prediction accuracy, our paper focuses on constructing a new neural network framework which embeds physics and engineering knowledge, which is capable of achieving higher accuracy in different types of composite materials. To our best knowledge, this is the first attempt to bring neural network into stress contour prediction for composite materials. The Difference-Based Neural Network presented here is first developed based on plate with cutout model, later the performance is validated using three different composite material structures, including square-packed, hexagonal-packed and particle reinforced materials, and prove that our method can successfully strengthen the prediction capability in key areas and improve stress prediction accuracy especially the maximum stress under limited training data with similar training and predicting durations, compared to existing neural networks. Typically, existing encoder-decoder neural networks are trained using geometry and stress contours directly as inputs. Instead, we have focused on training the differences between a pair of training geometry and stress contours with a reference set of geometry and stress contours, which is determined by the mean of training samples. Contours recording these differences are further normalized to avoid internal covariance shifting and improve training efficiency, which are later brought into neural network for training purpose. After the encoder-decoder structure, which first extracts high level features and re-expand to original dimension, a denormalization module is applied on obtained contours, followed by a dense module to add stress difference contour and 'reference set' stress contour. For composite materials with cutout region, we propose to add an additional smoothness module before denormalization to further enhance statistical stability. Training on difference contours instead of original contours could highlight the changes between different composite material designs and improve stress prediction accuracy especially on maximum stress. In addition, we proposed to label the geometry with different values based on Young's modulus and approximated stress concentration factors, which helps neural network further understand pixel-wise stress relations. To summarize, our neural network is capable of predicting stresses for different composite materials with high accuracy. Besides, by introducing our prior physics and engineering knowledge into neural network, the neural network pays special attention on key areas and shows strong ability for predicting high stress in relevant regions of the model.

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abst. 2600
Repository

Tensile performance of aluminum composite reinforced with randomly distributed graphene nanoplatelets

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Due to their extraordinary properties, graphene and its derivatives such as graphene nanoplatelets (GPLs) have been widely used as reinforcing nanofillers to achieve significantly improved mechanical properties of polymer- or metal-based composites. In real fabrication process, the geometry, size, location, and orientation of GPL reinforcement inside the matrix are all random in nature. This effect, however, is not taken into account or correctly reflected in the majority of the existing studies, consequently leading to great discrepancy between simulation results and the data obtained from experiments. This study presents a numerical investigation at nanoscale on the mechanical behaviors of GPL reinforced aluminum (GPL-Al) composites by employing molecular dynamics (MD) simulation based on a Large-scale Atomic/Molecular Massively Parallel Simulator (LAMMPS), with a particular focus on the effects of the size, distribution and orientation angle of long GPLs on the tensile performance of GPL-Al composites. Empirical potentials are used to model the interaction between different atoms, with the embedded atom model (EAM) potential for the interactions between Al atoms, the adaptive

intermolecular reactive empirical bond order (AIREBO) potential for the interaction between carbon (C) atoms within the GPLs, and Lennard–Jones (LJ) potential to compute the force between Al-C atoms. Numerical results indicate that for long GPLs, the distribution has a remarkable effect on the ultimate tensile strength. It is observed that when adding 7 w.t% GPLs into Al matrix, the ultimate strength can be improved from 5 GPa for pristine Al to 12 GPa which can further be increased to 15 GPa if a single GPL is divided into 4 small, equal and parallel pieces with the total weight fraction being kept unchanged. It is also found that regardless of the location of GPLs in aluminum matrix, aligned and randomly orientated GPLs can enhance the ultimate tensile strength of the GPL-Al composite by 140% and 200%, respectively when compared with the pure aluminum. It is evident from our findings that GPL is efficient in strengthening the Al matrix.

Transverse Shear Effects in Dynamic Instability (Flutter) of Plated/ Shell Structures

abst. 2165
Repository

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A number of vibration problems in aeroelastic engineering arise for elastic systems both of a finite number of degrees of freedom and continuous that are subjected to forces commonly called non-conservative. It means that forces that are explicitly time independent cannot be represented as the gradients of certain energy functions. The flutter of thin plates and shells in subsonic or supersonic gas flows just belongs to this group of problems [1]. This phenomenon is an importand and significant problem encountered in the design of aircraft constructions or turbine blades in the turbomachines. Dynamic instability (flutter) is thus a major concern for the designers regarding both the safety and costs. In the flutter analysis the attention is mainly focused on the discussion of different problems that can affect the structural behaviour, i.e. the aerodynamic theories, the form of boundary conditions, the structural geometry (the analysis deals mainly with 2D structures), the material properties and the effects of aerothermoelastic coupling. Transverse shear effects play an important role in the evaluation of the stability behaviour of composite structures [2]. Aeroelastic properties of two-dimensional panels neglecting and considering the shear deformation in supersonic airflow are analytically and numerically investigated. The two types of panel are known as the Kirchhoff and Mindlin panels. A method for estimating the flutter bound of the aeroelastic structural system is proposed. The fundamental aim of the present paper is to compare the flutter characteristics for composite plates and cylindrical panels. The considerations are mainly focused on the analysis of following problems: - Free vibration analysis - Evaluation of critical (in the sense of dynamic instability) values of aerodynamic pressure - Optimal design of fibre orientations and stacking sequences of composite laminates. - Comparison of the results for different kinematical formulations. The analysis is conducted with the aid of both analytical and numerical (finite element –FE) methods. The present work is an extension of the Ref [3] dealing with the analytical prediction of aeroelastix characteristics for laminated plates. [1] Muc, A., Flis, J., Augustyn, M., Optimal Design of Plated/Shell Structures under Flutter Constraints. A Literature Review. (2019) Materials, 12, submitted for publication. [2] Muc, A. Transverse shear effects in stability problems of laminated shallow shells (1989) Composite Structures, 12 (3), pp. 171-180. [3] Muc, A., Flis, J. Closed form solutions – Analysis and optimal design of supersonic composite laminated flat plates considering mechanical and thermal effects (2019) Composite Structures, 230, art. no. 111491.

Formulation of hexahedral 3D finite elements using curvilinear coordinates

abst. 2590
Virtual Room
Thursday
September 3
15h00

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The Finite Element Method (FEM) is a well-established method and yields accurate results for the structural analysis of any geometrical shape. However, when dealing with innovative materials - such as

metamaterials or biomaterials with complex architected microstructure - or structural components with non-conventional beam/plate geometry, this method can become very costly in calculations and time. Moreover, classical 1D and 2D models cannot be employed for the analysis of beam-like and plate-like structures that don't present conventional geometrical features, such as cylindrical geometry for beams or constant thickness for plates. In these cases, the researchers have to resort to very fine 3D meshes encountering the following main drawback: the high computational cost associated with the classical 3D elements that sometimes make the analyses infeasible. In this framework, the Carrera Unified Formulation (CUF) allows the formulation of a series of finite elements with 3D capabilities that strongly reduce the number of degrees of freedom of the analysis with respect to classical 3D elements, being equal the accuracy of the results [1]. Since the structures mentioned above usually present curved geometry, it is convinient to formulate such 3D finite elements using curvilinear coordinates. Analytical and numerical analyses of shell structures have been carried out for a very long time. Continuum mechanics based shell finite elements have been commonly used for the analysis of general shell structures and these discretizations can be used generally for both thick and thin shells. However, the use of these elements is limited to the analysis of shells with constant thickness. The study of general curved structures (with curvature also in the third direction) requires a deeper mathematical as well as physical understanding. Anyway, classical shell mathematical models have provided a strong analytical basis for the analysis of curved structures [2] and this is here resumed and extended to continuum mechanics based solid finite elements. The objective of this paper is to gain insight into the formulation of 3D finite elements in curvilinear coordinates using the fundamental equations of 3D elasticity and the Principle of Virtual Works [3]. After reviewing the mathematical model, we present the formulation of hexahedral finite elements that represent a generalization of classical shell finite elements, in which also the third direction can be curvilinear. These finite elements are equivalent to the widely-used continuum mechanics based 3D finite elements, but the adoption of local curvilinear reference system will allow the application of techniques, such as the Mixed Interpolation of Tensorial Components (MITC), to contrast the locking phenomenon in all the spatial directions. For the assessment of the present elements, we consider different examples of curved geometries: cylindrical, conical, toroidal and spherical. A free-vibration analysis of the curved 3D components is performed and the results, in terms of natural frequencies, are compared with the convergence solutions computed with the commercial software MSC Patran/Nastran. References [1] Carrera E., Cinefra M., Petrolo M., Zappino E., 'Finite Element Analysis of Structures through the Carrera Unified Formulation', John Wiley & Sons, UK, 2014. [2] Chapelle D., Bathe K.-J., 'The finite element analysis of shells - Fundamentals', 2nd edition, Springer, 2011. [3] Washizu K., 'Variational methods in elasticity and plasticity', 2nd Edition, Pergamon Press, UK, 1975.

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abst. 2604
Virtual Room
Thursday
September 3
17h30

Finite element analytical formulation for nonlinear tensegrity dynamics

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This study presents a finite element analytical approach to non-linear tensegrity dynamics based on the Lagrangian method with a nodal vector as the variable. Firstly, this paper describes bar and string assumptions, nodal coordinates, connectivity matrices, geometric and physical properties of the tensegrity system in compact vector forms. Secondly, this paper formulates the shape function of an element, kinetic energy, strain and gravitational potential energy of the whole structure. Then, tensegrity dynamics with and without boundary constraints are formulated by the Lagrangian method. By neglecting the time derivative terms in the dynamics equation, the equilibrium equations in three standard forms (in terms of nodal vector, force density, and force vector) and a compatibility equation are also given. Finally, linearized tensegrity dynamics and modal analysis equations with and without boundary constraints are derived. We believe the formulation of a general dynamics should be capable of conducting these four kinds of studies for any tensegrity structures accurately: 1. Rigid body dynamics (by setting relatively high stiffness for bars). 2. Finite element method (FEM) dynamics that allow

bars and strings to have elastic or plastic deformations. 3. Accurate modal analysis, including natural frequency and corresponding modes. 4. Dynamics with various kinds of boundary conditions, for example, nodes are fixed or in the presence of static or dynamic external loads (i.e., gravitational force, some specified forces, or arbitrary seismic vibrations, etc.). Thus, three examples (a double pendulum, a cantilever truss with external force, and seismic analysis of a tensegrity tower) are carefully selected, studied, and compared with results from rigid body dynamics and FEM software ANSYS. This study provides a deep insight into both structures and materials, allows comprehensive dynamics studies of any tensegrity structures, and interfaces to integrate control, signal processing, and other disciplines.

Material Modelling of FDM printed PLA part

abst. 2679
Repository

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This paper focuses on modelling inelasticity of additively manufactured polylactide (PLA) thermoplastic using Fused Deposition Modelling (FDM) printing technology. The material response of PLA is viscoplastic and temperature-dependent, as is typically seen for thermoplastics. The inelastic deformation of printed PLA undergoes initial yielding, strain softening, and subsequent failure. The Three-Network (TN) constitutive model was employed in this work, which captures experimentally observed material response and consists of three molecular equilibrium and time-dependent viscous networks that act in parallel. The parameter identification was performed in accordance with experimental data from uniaxial testing and a validation experiment was carried out by loading plate with a hole and measuring its strain distribution using Digital Image Correlation (DIC) method, which was compared with the predictions from Finite Element Analysis (FEA).

FML panels buckling and postbuckling with delamination

abst. 2102
Repository

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Confirmed and verified in service the hybrid multilayer Fiber Metal Laminates features have responded to industry demand on modern composite materials with favourable strength-to-weight ratio. FMLs as advanced composites are mainly used in airspace industry but their application is extended into others area. Their structure of bonded thin metal sheets and fibre reinforced polymers (FRP) plies leads to improved fatigue resistant but also brings all problems of multi-layered structures as complex failure mechanism. The thin-walled nature of FML elements may be a source of buckling phenomena in their behaviour. Then the load capacity is limited not only by the strength but by buckling. A mixture of both problems i.e. failure and buckling of FML panels is a competing problem for research and analysis but seems to be necessary to design durable materials and structures. In this investigation failure mechanisms in both FML constituents (plasticity in aluminium sheet and fiber and matrix cracking in prepreg layer) and between them debonding (delamination between layers) has been implemented into numerical FEM model. This procedure allows to obtain more reliable results on the behaviour of FML thin-walled structure under in-plane compression, buckling and postbuckling response and also to analyse the influence of material destruction on the load carrying capacity. Numerical results are compared with experimental tests on short FML plate panels of open cross-sections.

Two-stage numerical approach for reliable recognition of the occurrence and evolution of dry spots during VAP infusion of large composite parts of complex shape

abst. 2593
Virtual Room
Thursday
September 3
14h00

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The technologies of composite structures manufacturing using vacuum broad their application in the production of large-sized structures of good quality a in aviation, shipbuilding, automotive, wind energy and other industries, due to its low workload, simplicity of the necessary equipment and the satisfactory environmental conditions. The vacuum infusion process includes laying dry reinforcing material, usually on an open mould, which provides the desired shape of the part; then covering the entire preform with a flexible vacuum bag and sealing. Vacuum is supplied through a vent hole (outlet) into the preform cavity, as a result of which atmospheric pressure acting on the vacuum package contracts the reinforcing structure of the preform. The liquid resin is then introduced into the vacuuming porous preform through the resin gate (inlet), the resin pressure being kept constant or subject to controlled change. Sometimes the process of filling the preform executed with a controlled change in temperature. Under ideal conditions, the resin fills the entire volume of the prepreg in a short time without the formation of serious defects such as voids and incomplete saturation. The last stage of the process is the curing of the composite, which is realized when exposed to temperature in accordance with some schedule. Due to the presence of a flexible vacuum bag covering the upper surface of the infusible preform, the movement of the resin, the viscosity of which depends on temperature and time, develops under conditions of a continuous change in the permeability of the preform, depending on the position of the resin front at each time instant. The problem of ensuring the quality of manufactured parts, the solution of which in a production environment requires a significant investment of time using the trial and error method and material costs due to the high cost of components, necessitated the development of process modeling and optimization tools. However, the problem of reliable prediction of the moments and positions of the dry spots formation, the evolution of their size has not been resolved to date. The proposed approach uses a methodology according to which the ruling equation describing the evolution of the interface between two phases - the front of the resin is the phase field equation. The auxiliary equation of the coupled problem, which describes the dynamics of the resin motion depending on the pressure and porosity of the preform, is the Richards equation, which relates the field of pressure in the resin to the field of its velocities. Moreover, the permeability of the preform is a function of its porosity, depending on the position of the resin front, and the rheology of the resin is a function of time and local temperature distribution. The finite element model provides simulation of all these processes in 3D areas of the preform and mould, the exact geometry of which is imported from the CAD model of the assembly. Adequacy of the simulation results of an unsteady process is ensured by adjusting the simulation parameters, which requires a simple experiment to be performed in the preform material and in a highly permeable medium in order to evaluate the velocities of the resin front in them. The experimental data obtained using the DSC and DEA methods should also be available to correctly describe the cure kinetics of the resin and related viscosity changes. The diffusion component inherent for the phase field equation motivate an apparent filling of initially void dry spots, which is not true. This adverse feature is eliminated through the use of a special algorithm for postprocessing the history of the resin propagation, which allows reconstructing the process of occurrence and change of dry spots volume during the entire cycle of a preform filling. Since the occurrence of each dry spot closed inside or on the edge of the preform, this algorithm tracks its evolution, preventing the penetration of the resin into such a "dry trap" due to diffusion and taking into account the change in pressure inside it along with the pressure of the surrounding resin. The results of such postprocessing, which allow reconstructing the positions of dry spots in the preform and their final dimensions, are used to exclude the process patterns (arrangement of vacuum vents and resin gates) and thermal schedules that do not give defect-free composite parts. This ability is very important when simulated forward problem is repeatedly called by the process optimization algorithm. The proposed method is illustrated by the example of a large-sized aviation CFRP part of complex 3D geometry.

Multi-material Topology Optimization for Dynamic Scaling Application using a Gradient-based Optimization Approach

abst. 2598
Virtual Room
Tuesday
September 1
16h15

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In this study, a Multi-material topology optimization for a lifting surface of a small scaled model is developed based on 3D printing potentialities. The main goal of the optimization is to produce a scaled model that has the same dynamic behavior than the full-scale model. Here, the objective function of the proposed optimization approach is the difference between the eigenfrequencies of the scaled model and the eigenfrequencies of the full-scale model. The material distribution of the scaled model is obtained using the topology optimization framework. The Solid Isotropic Material with Penalization (SIMP) is employed for the topology optimization. A density filter was implemented to remove the checkerboard-patterns. The Sequential Approximate Optimization (SAO) technique is used to ensure a reasonable fast optimization. The proposed topology optimization is applied to a wing-box with aluminum material as a case study. The small scaled model is 10 times smaller than the full-scale model. Different materials are considered to find the material distribution of the small scaled model in the optimization process. A single-material topology optimization is addressed in a first step. Then, the multi-material topology optimization is applied to increase the flexibility and freedom in the design space. The Modal Assurance Criterion (MAC) of the results illustrates that the material distribution of the small scaled model for the single material and multi material designs have a similar dynamic behavior compared to the full-scale model.

Robust identification of material model by means of forced sinusoidal excitation measurements

abst. 2570
Virtual Room
Thursday
September 3
14h45

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Dynamic Mechanical Analysis (DMA) test instruments are commonly employed to identify the mechanical behaviour of materials at different temperatures and frequencies. In a typical dynamic measurement, a sinusoidal excitation is applied to a beam specimen of known geometry and the displacement response is obtained. The DMA output can be processed to obtain the D() material stress () versus strain () relationship, i.e. ()=D()×(), by means of the Timoshenko or Euler-Bernoulli beam model assumption. Nevertheless, the approach shows some limitations since these model assumptions do not take into account of the many other factors influencing the measurement output such as the effective boundary conditions, the structural instrument frame model coupling and the inertial and dissipative contribution of the excitation moving substructure, so that a multi-DOF (MDOF) system results. Many techniques are known for identifying a MDOF system model typically requiring measurements being done in some experimental DOFs, and requiring data not directly available from within the typical DMA set-up, so that an additional test measurement system is needed, being not synchronized with the DMA measurements. Some calibration procedures are commonly proposed by the many commercial instrument firms, but the related accuracy is generally poor, as it is shown in this work in some identification examples related to a harmonic steel specimen. This work deals with specimens in the form of slender, uniform, homogeneous beams with clamped double pendulum boundary conditions, excited by means of a sinusoidal flexural force at different frequencies at the mobile free beam end, where both excitation and displacement response are measured at the same time, i.e. in the single cantilever experimental set-up. A single experimental DOF is measured with respect to both input and output, frequency range [0.01-200] Hz. In this work a calibration technique for dynamic mechanical analysis (DMA) experimental systems, using only data obtained from tests made within the commercially available instrument itself, is adopted and it is shown as a part of the identification procedure.

The calibration technique is based on an optimisation algorithm and deals with the identification of a 2 DOFs frame model coupled to the specimen beam model by using as input the single beam DOF force and displacement measurements made on some reference uniform specimens. The aim is to obtain measurement estimates being filtered from the contribution of the experimental system. The robustness of the proposed technique is tested on some numerical model cases with added noise. A sensitivity based numerical technique is also proposed to evaluate the contribution of each identification unknown during the optimisation process. The technique is applied to some dynamical measurements made on material specimens whose model is known in advance and then to some non standard material configurations. The technique is also applied on two DMA systems made by two different manufacturers. The results are shown and critically discussed.

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abst. 2608
Virtual Room
Thursday
September 3
13h30

Matrix cracking driven stress redistribution in ceramic matrix composites

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Ceramic matrix composites (CMCs) exhibit a large non-linear region beyond the initial linear elastic region leading to enhanced strength and toughness compared to monolithic ceramics [1,2]. The non-linear behaviour is attributed to microscale damage mechanisms such as multiple matrix cracking and interfacial debonding driven by a weak fiber-matrix interface [2]. The weak interface causes matrix crack deflection at the interface leading to interfacial debonding and the formation of multiple matrix cracks. The occurrence of multiple matrix cracks causes the aforementioned non-linear region until the ultimate failure brought about by fiber failure. The weak fiber-matrix interface can be further engineered by introducing an interphase between the fiber and matrix [3]. The interphase provides a low energy crack propagation path parallel to the fiber orientation and promotes matrix crack deflection further enhancing the strength and toughness of CMCs. The evolution of multiple matrix cracks in unidirectional fiber reinforced CMCs is dictated by the stress distribution in the matrix segment between two adjacent matrix cracks. The stress distribution depends on the microstructural features of the CMC such as constituent properties and volume fractions. The spacing between adjacent matrix cracks also plays an important role since load transfer occurs by shear around a matrix crack and there exists a critical crack spacing below which further matrix cracking does not occur [1]. A correlation between the microstructural features, crack spacing and stress distribution aids in tailoring the CMC microstructure to obtain optimal mechanical properties which forms the focus of the current work. The microscale stress distribution in unidirectional CMCs in the presence of matrix cracks has been studied in the present work. The microstructure of the CMC at microscale has been modelled as a three phase 3D repeating unit cell [4] consisting of fiber, intephase and matrix. Periodic boundary conditions [5] have been applied on the unit cell with suitable modifications to simulate longitudinal loading of a segment between two adjacent matrix cracks. The stress distribution in the constituents between adjacent matrix cracks has been obtained by Finite Element Analysis. Parametric studies have been conducted to study the effect of constituent volume fractions and matrix crack spacing on the microscale stress distribution in the CMC. References [1] Lissart, N. and Lamon, J., 1997. Damage and failure in ceramic matrix minicomposites: experimental study and model. Acta Materialia, 45(3), pp.1025-1044. [2] Evans, A.G. and Marshall, D.B., 1989, Overview no. 85 The mechanical behavior of ceramic matrix composites. Acta Metallurgica, 37(10), pp. 2567-2583. [3] Naslain, R., 1993. Fibre-matrix interphases and interfaces in ceramic matrix composites processed by CVI. Composite Interfaces, 1(3), pp.253-286. [4] Drago, A. and Pindera, M.J., 2007. Micro-macromechanical analysis of heterogeneous materials: Macroscopically homogeneous vs periodic microstructures. Composites Science and Technology, 67(6), pp.1243-1263. [5] Li, S., 2008. Boundary conditions for unit cells from periodic microstructures and their implications. Composites Science and Technology, 68(9), pp.1962-1974.

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abst. 2356
Repository

Halo approach to better simulate cracks initiation and propagation in homogeneous and heterogeneous materials using DEM

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The present contribution is performed in the frame of VARIATION project which aims at promoting the mass production of natural fiber reinforced composite and controlling their mechanical performance and durability by means of numerical simulation. For that purpose, we consider an original numerical approach based on the Discrete Element Method (DEM) which is an interesting alternative to classical continuous methods such as Finite Element Method (FEM). Indeed, FEM turns out to be poorly efficient to model multi-scale materials in which cracking phenomena occur, while DEM naturally takes into account discontinuities. However, in DEM simulation the stress field is locally distracted, which leads to a heterogeneous field, even in the case where this latter is theoretically homogeneous. As a result, the process to initiate cracking is systematically accelerated. In order to tackle such a difficulty, we introduce an approach enabling to better control the level of the stress field dispersion. The main idea consists in evaluating the stress at a mesoscale described by a sphere of same center than the investigated DE and a radius of controllable size. This sphere, designated as the Halo of the DE, is composed of a set of particles from which we can derive a suitable stress using Love-Weber formulation. Investigations are led in three distinct parts. In a first step, the level of stress dispersion as function of Halo size is accurately determined using a specific configuration characterized by a theoretical homogeneous stress field. Results exhibit a reduction of the Coefficient of Variation (CoV) from 68% without Halo to less than 3% with a Halo of radius 20 times the particle radius. In a second step, we consider the compression diametrical test which provides an accurate theoretical background in terms of stress field and failure process. Results highlight the ability of the Halo approach to provide a suitable stress level for a Halo radius set to 15 times the particle radius. Cracks initiation and propagation are also investigated using the Removed Discrete Element Failure (RDEF) process the paradigm of which lies on the deletion of DE when a given stress criterion is reached. A breaking test based on Griffith stress criterion is set up. Numerical outputs show suitable cracking process and pattern for the determined Halo size. Finally, in a third step, we consider the context of a UniDirectional (UD) fiber composite composed of a bio based epoxy matrix reinforced with flax fibers. A uniaxial tensile test is simulated using DEM. Once again, results exhibit suitable stress fields in comparison with numerical predictions given by FEM for a Halo radius set to 15 times the particle radius. Failure process is also studied using the RDEF process based on Rankine criterion. Cracking process and pattern turn out to be very similar to comparative outputs provided by the eXtended FEM.

Simulation of Operating Loads of Ablative Composite Shields Used in Flight Data Recorders

abst. 2577
Repository

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Flight Data Recorders (FDR) are designed to record the main flight parameters and operational parameters of the work of aircraft assemblies for evaluation: flight safety, piloting techniques, the status of on-board systems, causes of an accident or plane crash. In addition, the recorders of operation

parameters of various operational objects are increasingly used by car manufacturers, locomotives, ships, and even architecture, in order to assist all emergency services involved in removing the consequences, and then determining the causes of the existing communication (building) disasters. Endurance tests of recorder covers are very destructive, causing damage to them, and even complete desolation during the tests. Their implementation requires the design and execution of a measurement station and the production of a series of covers that will be subjected to strength tests. These are usually destructive tests. Complementary method of strength analysis is mathematical modeling. The ANSYS 15.0 software was used for numerical analysis of dynamic loads of guards. The objects of the mathematical simulation were two covers of the same shape, but different geometrical dimensions. The protective covers were made of the following components: 14 layers of aramid fabric with a weight of 230 g/m2, alternating and uniformly distributed in the composite - in a polymer matrix of Epidian 52 epoxy resin, crosslinked TFF hardener, modified with 15% addition of layered aluminosilicate Bentonit Specjal Extra with 75% content of calcium montmorillonite MMT. The wall thickness of the model (cover) was 12.65 mm. For each of the two guards, four variants of the composite material were considered in correlation with the metal casing, as well as three load cases, in accordance with the normative documents. In addition, a numerical analysis of dynamic tests was performed to determine the durability of the recorder. It consisted in dropping a weight of 227 kg, terminated with a properly shaped tip, from a height of 3 m, onto the protective housing of the recorder. Due to the axial symmetry of the dome, the calculation was limited to its section, constituting $\frac{1}{4}$ of the whole. As a result of the conducted analyzes, stress values were obtained in all load cases and for all kinds of placement of the composite in correlation with the metal reinforcement casing. The displacements of the entire model and stress x were analyzed that can cause delamination and stress yz capable of cutting inter-cutting, as well as a detailed distribution of stresses reduced in subsequent layers of the cover material. The distribution of kinetic and potential energy during piercing of the composite thermo-protective casing was determined by numerical simulation and the housing of recorder made of an epoxy ablation composite, with a metal casing located inside the casing. On the basis of the analysis carried out it can be concluded that the metal layer will not be damaged during breakthrough, while the composite layer will be partially damaged in both cases, which will reduce its thermo protective properties. In both cases the punch will be reflected from the tested structure. When loading a model reinforced with an inner metal layer, higher stresses in the composite can be observed compared to the second case. Results have been analyzed and conclusions have been made regarding the possibility of creating a real shield for the recorder, which will meet the normative requirements. Keywords: thermo-protective composite shields, ablative materials, flight data recorders, endurance tests of recorder covers, mathematical modeling, numerical simulation

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abst. 2585
Repository

A computationally efficient model to predict the uniaxial tensile loading response for dry woven fabrics

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Dry woven fabric is an essential component widely used as reinforcement in composite materials. The woven yarns, which consist of large amounts of small filaments that are not held in place by a polymeric matrix but are free to slide past each other as the yarns deform, present certain difficulties in constructing homogenized model to predict their mechanical response. In the present study, a computationally efficient model is developed to predict the uniaxial tensile response for an orthogonally weaved dry fabric. The influence of the filaments, the weaving pattern and the surface contact at the crossover of the yarns are taken into account by the proposed model. For the weaved yarns, complex yarn geometries can be easily modelled with various yarn curve assumptions. A uniaxial tensile test, for which the deformation is measured by the digital image correlation (DIC) method, was constructed to validate the accuracy of the proposed model. The significant different responses of the fabric for the loading direction along the warp and weft yarns are mimicked well by the proposed model. Moreover, the proposed model is capable of giving accurate predictions of the effective in-plane Poisson's ratio and the change of the thickness of the fabric. With high computational efficiency and by constructing the relationship between the microstructure of the woven fabric and its macroscopic uniaxial tensile

response, the proposed model makes it potentially helpful for designing woven materials with high mechanical performance.

A meshfree-based micromechanics model for elastic homogenisation of automated fibre placement (AFP) composites

abst. 2334
Virtual Room
Friday
September 4
17h45

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Automated fibre placement (AFP) composites are relatively new materials fabricated by stacking and curing a required number of interleaved, multi-directionally oriented tapes. These materials have received increased attention in the recent decades for manufacturing large load-bearing structures, owing to them being capable of combing the advantages of unidirectional (UD) and woven composites. On one hand, the use of tape-based manufacturing processes allows for these materials to be employed for the rapid production of large, complex composite structures. On the other hand, the woven-like internal architecture in AFP composites generates layer connectivity in the thickness direction [1], offering increased resistance to interlaminar delamination and transverse impact. In spite of AFP composites providing a more balanced performance compared to traditional composites, little attention has been paid to developing predictive models for these materials, which may be partly attributed to AFP composites having overcomplicated geometrical interactions among tapes. The present work was aimed at developing a micromechanics unit cell (UC) model for predicting the effective elastic properties of AFP composites. The UC model features the use of a layup reproducing procedure proposed to reveal and describe the internal architecture of AFP composites. Instead of taking a finite element (FE)-based approach, the UC model is numerically implemented using the moving kriging (MK)-based element-free Galerkin (EFG) method [2] to bypass the need for explicitly building the geometrical features and assigning the ever-changing tape orientations of AFP composites. A computer program is developed based on the proposed model. The validity of the model is tested by running the computer program to predict the effective elastic properties of a wide tape-based AFP composite and comparing the results with experimental data.

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abst. 2574
Repository

Investigation on the mechanical properties of novel bio-based hybrid composites for marine applications

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The idea of improving the toughness of fiber-reinforced composites is currently of growing interest. During the past decade, there were several suggestions pertaining to the toughness improvement via matrix additives or by blending two polymers [1]. Another way is through the fiber hybrids, where a secondary reinforcement with a relatively higher failure strain than the primary reinforcement is introduced to the composite part [2]. The latter is more attractive as additives to the matrix are rarely welcomed in the case of high-performance composites. In the literature, several works employed synthetic fiber hybrids such as glass/carbon[3] or carbon/polypropylene[4] and even natural fiber hybrids [5,6], but completely bio-based hybrid composites are rarely discussed. In very recent work, the tensile behavior of novel self-reinforced(SR) PLA composites were discussed [7]. To further explore this area of bio-based SR composites, in this work, we investigate novel flax fiber self-reinforced PLA(SR-PLA) composites, which are entirely biobased and even biodegradable materials. In this work, the influence of hybridization of flax/SR-PLA composites is characterized to identify the optimum fiber volume fraction ratio between the primary and secondary reinforcements within the hybrid fiber preforms based on the mechanical performance of the composites. The hybrid fiber preforms constituted flax fibers and self-reinforcing PLA in different fiber volume fractions. The preforms were manufactured by winding the SR-PLA filament over the flax fabrics until the required fiber volume fraction (Vf, PLA) was achieved. The composite parts were manufactured using the compression molding process. Two different characterizations were carried out on the composites to determine the influence of SR-PLA filaments in flax composites. Firstly, void content measurements were carried out to study the contribution of Vf, PLA on the air evacuation, and impregnation quality during compression molding. It was identified that irrespective of the fiber volume fraction of SR-PLA, there was a gradient of void volume fraction with the highest being present at the central part of the plate and lowest at the edges. The gradient was observed to be similar for every Vf, PLA, but the local void fraction showed an increase with an increase in Vf, PLA. Priliminary flexural tests indicated the hybridization effect with the addition of SR-PLA to flax composites. When the composite specimens were tested along the winding direction of SR-PLA filament, there was a positive hybridization effect where the failure strain for composites with 20% Vf, PLA was relatively 100% higher than the composites with 0% Vf, PLA. On the contrary, a negative hybridization effect was observed when the specimens were tested across the winding direction. The failure strain of 20% Vf, PLA composites was similar to that of 0% Vf, PLA composites, but a 27% drop in flexural strength was noted. These differences in the flexural properties point out the composite parts with these specific hybrid preforms should be designed to maximize the positive hybrid effect. Finally, these lightweight composites can equally compete with the existing natural fiber hybrids currently employed in the automobile industries. Acknowledgments: This work is carried out within the framework of the project SEABIOCOMP, which has received funding from the Interreg 2 Seas program 2014-2020 co-funded by the European Regional Development Fund under subsidy contract No 2S06-006. References [1] Lomov S V., Gorbatikh L, Kotanjac Ž, Koissin V, Houlle M, Rochez O, et al. Compressibility of carbon woven fabrics with carbon nanotubes/nanofibres grown on the fibres. Compos Sci Technol 2011;71:315–25. [2] Swolfs Y, Gorbatikh L, Verpoest I. Fibre hybridisation in polymer composites: A review. Compos Part A Appl Sci Manuf 2014;67:181–200. [3] Fotouhi M, Jalalvand M, Wisnom MR. High performance quasi-isotropic thin-ply carbon/glass hybrid composites with pseudo-ductile behaviour in all fibre orientations. Compos Sci Technol 2017;152:101–10. doi:10.1016/j.compscitech.2017.08.024. [4] Tang J, Swolfs Y, Longana ML, Yu HN, Wisnom MR, Lomov S V., et al. Hybrid composites of aligned discontinuous carbon fibers and self-reinforced polypropylene under tensile loading. Compos Part A Appl Sci Manuf 2019;123:97–107. [5] Dhakal HN, Zhang ZY, Bennett N. Influence of fibre treatment and glass fibre hybridisation on thermal degradation and surface energy characteristics of hemp/unsaturated

polyester composites. Compos Part B Eng 2012;43:2757–61. [6] Graupner N, Sarasini F, Müssig J. Ductile viscose fibres and stiff basalt fibres for composite applications – An overview and the potential of hybridisation. Compos Part B Eng 2020;194:108041. [7] Goutianos S, Van der Schueren L, Beauson J. Failure mechanisms in unidirectional self-reinforced biobased composites based on high stiffness PLA fibres. Compos Part A Appl Sci Manuf 2019;117:169–79.

abst. 2157
Repository

Size-Effect Independence of Roller-Compacted Concrete by Means of a Micromechanical Numerical Model

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During last decades, roller-compacted concrete (RCC) has increasingly attracted the interest of the researchers because of its cost-effectiveness and high placement speed [1]. Moreover, such a material has a low cement content and an aggregate grading curve more continuous with respect to a typical Portland cement concrete, and has been proved to be characterized by good mechanical properties [2]. As is well-known, one or more than one type of fibres may be employed in order to improve both durability and strength of concrete. When RCC is reinforced with more than one type of fibres, the reinforced RCC is named hybrid RCC. Previous studies have investigated the influence of fibres type, geometry and content on mechanical properties and density of hybrid RCC [2,3]. The aim of the present paper is to prove the size-effect independence of hybrid RCC fracture toughness by applying the Modified Two-Parameter Model (MTPM), recently proposed by some of the present authors [4], to measure such a parameter. In more details, three-point bending tests have been carried out on single edge-notched specimens of both plain RCC (without fibres) and hybrid RCC. The fibres are randomly distributed in the cementitious matrix, and the volume fraction is equal to 0.7%. Moreover, a micromechanical numerical model [5] is applied to evaluate the mechanical behaviour of such RCC specimens. Note that the spatial arrangement of the fibres is taken into account by means of a statistical description of their orientation, whereas the mechanical effect of the fibres on the cementitious matrix is considered by means of a homogenization approach. Finally, RCC specimens characterized by different geometric sizes are numerically analysed, and the values of fracture toughness are analytically determined by means of the MTPM. Keywords: hybrid RCC, homogenization approach, micromechanical model, size-effect. REFERENCES [1] Brotman, I., Crist, M., Gaul, J., Roller compacted concrete pavement: properties, design, and construction. ASCE Geo – Denver, 169, 1-10, 2007. [2] LaHucik, J., Dahal, S., Roesler, J., Amirkhanian, A.N., Mechanical properties of roller-compacted concrete with macro-fibres. Constr. Build. Mater., 135, 440-446, 2017. [3] Neocleous, K., Angelakopoulos, H., Pilakoutas, K., Guadagnini, M., Fibre-reinforced roller-compacted concrete transport pavements. Proc. ICE-Transport, 164, 97–109, 2011. [4] Carpinteri, A., Berto, F., Fortese, G., Ronchei, C., Scorza, D., Vantadori, S., Modified two-parameter fracture model for bone. Eng Fract Mech, 174, 44-53, 2017. [5] Brighenti, R., Carpinteri, A., Scorza, D., Micromechanical model for preferentially-oriented short-fibre-reinforced materials under cyclic loading. Eng. Fract. Mech., 167, 138-150, 2016.

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abst. 2150
Repository

A hybrid hierarchical/concurrent two-scale model for the nonlinear analysis of nacre-like staggered composite structures

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Bio-inspired composite materials, combining stiff and soft microscopic constituents arranged in different geometrical patterns, exhibit superior mechanical properties compared to conventional materials, for instance, the capacity to withstand considerable stress and deformation providing high load-carrying capacity and stiffness. To predict in a reliable manner the complex mechanical behavior of such materials across relevant length scales, while accounting for the effects of both geometric and material nonlinearities, multiscale modeling approaches have been proved to be effective, being characterized by a contained computational effort. However, due to the lack of scale separation for realistic problems, classical multiscale models may not be suitable in general, thus enhanced approaches are needed. Here, a novel hybrid hierarchical/concurrent multiscale modeling approach is proposed to investigate the mechanical behavior of bio-inspired nacre-like staggered composites in a large deformation context. Several results giving more information about the influence of the main microstructural parameters on the macroscopic properties were obtained, deducing how the geometrical arrangement of the composite phases can be manipulated to enhance the overall performances of such composites, with special attention to flexibility and penetration resistance. The obtained numerical results demonstrate the proposed multiscale technique as an effective tool to conduct further research on the optimization of microstructural configurations for a wide class of bio-inspired composite materials.

Assessment of flexural ductility in strengthened masonry with composites including the effect of matrix

abst. 2700
Virtual Room
Friday
September 4
12h00

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The benefits of intervention strategies based on innovative systems were demonstrated in many engineering applications. Experimental studies have shown the high performances of innovative composites. Masonry materials are characterized by brittle behaviour and the strengthening strategy generally aims to improving their strength. However, under seismic actions it is crucial to estimate also the ductility capacity of the strengthened elements. The available models both in literature and building codes do not accurately predict the ultimate capacity of the strengthened masonry elements. In particular, for heritage buildings optimized strengthening strategies are necessary. The available models are generally derived from the FRP where the contribution of the matrix is generally neglected. However these models do not provide reliable results for composites based on inorganic matrix (i.e. cementitious or lime-based). For these systems, the stress-strain constitutive relationship generally depends on the contribution of both constituents (fiber and mortar matrix). Therefore, the ultimate behaviour in terms of flexural capacity and ductility capacity depends on the characteristics of both constituents. In this paper, a generalized approach is proposed to assess the ultimate behaviour of masonry elements strengthened with composites. The impact of several parameters of both the masonry and the composite has been assessed on the ultimate behaviour of strengthened masonry. The numerical results were provided in a dimensionless form. This approach allows to obtain generalizable results extendible to any case.

Numerical and Experimental Analysis for Structural Performance of NFRCM-Strengthened Masonry

abst. 2230
Virtual Room
Friday
September 4
11h15

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This research deals the innovative strengthening technology based on natural systems to improve the seismic capacity of historical masonry structures. The positive impact of the sustainability of these solutions is compared with the effectiveness of the contribution to the structural performance of masonry buildings. Natural fabric-reinforced cementitious matrix (NFRCM-strengthened masonry) is proposed as an alternative to well-known traditional technologies used to improve the seismic behaviour of buildings, such as the portuguese technique "gaiola pombalina", the Italian "baraccata house" and the turkish "himis house". Starting from an experimental research carried out on a wall built by "baraccata" technology, parametrical analysis with NFRCM system is performed. From the experimental results of in-plan incremental load test a numerical model is calibrated by non-linear pushover analysis to evaluate the behaviour of wall strengthened with natural fibers with several configurations. In the first phase both strengthened technologies, NFRCM and "baraccata", are compared considering the out-of-plane behaviour to emphasize the wood-masonry interface effects of "baraccata" solution. In the second phase the in-plane non-linear pushover analysis is carried out to assess the seismic capacity of NFRCM solution by reference to "baraccata" technology. This research hollows to demonstrate the structural contribute of NFRCM technology, both for the insignificant thickness avoiding out-of-plan and torsional mechanisms and for the global intervention involving the whole surface preventing failure local mechanisms.

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abst. 2106
Repository

Periodic homogenisation of a one-dimensional non-linear elasticity problem.

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The periodic homogenisation method is often used to study the behaviour of heterogeneous media, like [U+FB01]bre enforced composites, soils or tissues. In this present work, the method is applied to derive the homogenised behaviour of a one-dimensional elastic heterogeneous medium under non-linear deformations. For the microscopic description of the problem the St. Venant-Kirchho [U+FB00] model for hyperelastic material is used. An expression corresponding to the homogenised stress at the macroscopic scale is obtained. The model is tested by studying a special case of a heterogeneous medium composed of two materials with constant Young's moduli. The obtained stress curve represents realistic values. Furthermore, it is shown that di [U+FB00]erent approaches used in the homogenisation process can lead to di [U+FB00]erent results (e.g. linearisation of non-linearities). Therefore, the importance of non-dimensional formulation before homogenisation process is underlined. Finally, an example of numerical computations at the micro- and macroscopic scales is presented. The results are coherent and enabled us to validate the modeling.

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abst. 2687
Virtual Room
Friday
September 4
11h30

Homogenization of heat transfer in fibrous composite with stochastic interface defects

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Fiber-reinforced composite is under consideration and its effective physical properties [1] are determined numerically for the Representative Volume Element (RVE) using the Finite Element Method technique. This RVE has rectangular shape, it includes a single round fiber and very thin interphase surrounding a fiber about its circumference, which includes all stochastic interface defects in-between fiber and matrix. Deterministic numerical solution of linear heat transfer resulting from a uniform heat flux affecting a single edge and periodic boundary conditions on the remaining RVE edges is obtained using quadrilateral elements in the FEM system ABAQUS. Physical properties of this interphase are further modelled as random to insert interface defects uncertainty into the homogenization model and they are distributed according to Gaussian probability distribution [2]. Uncertainty analysis is carried out by gradual modification of heat conductivity coefficient of the interphase and determination of additional series of the effective conductivities for the entire composite. These series thanks to the application of the Least Squares Method enable to recover polynomial basis further used in a triple probabilistic approach consisting of common application of the Monte-Carlo simulation, of the semi-analytical approach as well as of the iterative generalized stochastic perturbation approach. The entire implementation of probabilistic procedures is completed in the computer algebra system MAPLE, where polynomial basis are subjected to statistical simulation and estimation, symbolic integration with Gaussian PDF and Taylor expansions relevant to the perturbation method. The additional input parameter of this study is statistical scattering of the interphase parameters, which enables to find out how interface defects uncertainty affects the resulting probabilistic characteristics of this composite effective parameters. Expected values, coefficients of variation, skewness and kurtosis of the homogenized heat conductivity are computed and shown all as the functions of the composite uncertainty. A coincidence in-between various probabilistic numerical techniques enables to check their applicability and efficiency. Further study will concern uncertainty analysis in the RVEs containing larger number of the fibers or particles (in 3D models), especially with anisotropic (accidental) spatial distribution of these inclusions. Very interesting issue would be numerical homogenization of the composites in nonlinear heat transfer, where one of the composite constituents has temperature or time-dependent physical parameters. References: [1] P. Ostrowski, B. Michalak, A contribution to the modelling of heat conduction for cylindrical composite conductors with non-uniform distribution of constituents. Int. J. Heat & Mass Transfer 92: 435-448, 2016. [2] M. Kamiński, Homogenization of particulate and fibrous composites with some non-Gaussian material uncertainties. Composite Structures 210: 778-786, 2019.

Blending in Multiscale Design of Composite Laminates

abst. 2149
Virtual Room
Friday
September 4
11h00

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Blending represents one of the open topics in laminated composites structures design. Moreover, the industrial interest in handling such topic is of primary entity. Nowadays, blending is often disregarded or faced with a priori hypotheses on the stacks, i.e. adopting classical design rules, which may lead to only sub-optimal solutions. The proposed approach is focused on the optimal multi-scale two-level (MS2L) design of structures made of composite laminates [1]. The first step is dedicated to the search of the optimal stiffness distribution, which is a minimizer of the objective function, e.g. the mass. The second step is dedicated to the search of stacks, blended throughout the structure, which may recover the target optimal elastic properties determined at the first step. In this framework, blending is faced in full generality. Firstly, a new expression of blending constraints (with respect to those presented in [2]), meant to be imposed in the first step, have been derived considering the whole set of uncoupled and quasi-homogeneous stacks. The result is based on a necessary and sufficient characterization of this set [3]. Secondly, an iterative algorithm is presented, aiming at recovering blended stacks and orientations, pointing at the optimal elastic properties. For the second step, a different strategy can be

adopted considering the cases of thin or thick laminates. In the former case, the aforementioned set characterization allows the enumeration of all the existing uncoupled and quasi-homogeneous stacks for laminates of different numbers of plies, as pointed out in [4]. Therefore, a database consisting of all the possible stacks is profitably exploited by the second-step algorithm. In the latter case, where creating the database is cumbersome, thick-laminate stacks are generated using some results achieved in [4]. REFERENCES [1] M. Montemurro, A. Vincenti, P. Vannucci, "A two-level procedure for the global optimum design of composite modular structures - Application to the design of an aircraft wing. Part 1: theoretical formulation", Journal of Optimization Theory and Applications, 2012. [2] E. Panettieri, M. Montemurro, and A. Catapano, "Blending constraints for composite laminates in polar parameters space", Composites Part B: Engineering, vol. 168, pp. 448–457, 2019. [3] M. Picchi Scardaoni, M. Montemurro, "Quasi-triviality as a necessary and suf[U+FB01]cient condition for membrane/bending uncoupling and homogeneity of composite laminates", Journal of Elasticity, (submitted). [4] T. Garulli, A. Catapano, M. Montemurro, J. Jumel, and D. Fanteria, "Quasi-trivial stacking sequences for the design of thick laminates", Composite Structures, vol. 200, pp. 614–623, 2018.

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abst. 2188
Repository

Chiral/Auxetic/Orthotetragonal behaviors of homogenized micro-structured composites using Cosserat theory

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Several multiscale approaches and methods are proposed in the literature for investigating composite materials. The aim of such approaches is to deal with a complex problem due to inhomogeneities present at the meso- and micro-scales of the material reconducted to a homogeneous continuum problem. The mathematical backgrounds of such approaches are based on Cauchy, Couple-stress or Cosserat continuum theories which have different kinematic descriptors. It has been observed that Cosserat model is able to describe very well composite materials when a micro-structure is present. In particular, with respect to classical models (Cauchy) or constrained ones (Couple-stress), Cosserat has the extra degree of freedom of particle rotation which gives the relative rotation and curvature as extra strain measure in the material allowing to take into account non-symmetries in the strain and stress behavior and of size effects. The present work focuses on composite materials made of rigid particles/tiles/crystals which interact through elastic interfaces. An energy equivalence criterion is considered as basis of an homogenization procedure from discrete to continuum. According to the selected pattern for the particles (of hexagonal shape), different material behaviours are modelled such as chiral, auxetic and orthotetragonal. Applications show the validity of the present equivalent model and the advantages of Cosserat theory with respect to other models with internal constraints. ACKNOWLEDGMENTS This research was supported by the Italian Ministry of University and Research, P.R.I.N. 2017 No. 20172017HFPKZY (cup: B86J16002300001).

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abst. 2411
Repository

Variationally consistent nonlocal strategies for composite structures

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Investigation of mechanical behaviour of nano-structures and -composites has gained significant attention due to their vast application in a broad spectrum of Nanotechnologies, including Nano-Electro-Mechanical-Systems (NEMS). Rapid developments in Nano-Engineering have caused an intensive interest in mechanics of composite structures, since suitable control over the exclusive properties of advanced materials can lead to progresses applicable also to NEMS. When a principal feature of interest is the nanoscopic study of field quantities, the classical theory of local continuum is well-established to be not able to capture small-size phenomena. Development of adequate analytical and numerical strategies is therefore of major significance in design and optimization of structural parts of complex nano-systems. The present study intends to provide new insight in mechanics of innovative materials and structures at different scales. Variationally consistent strain- and stress-driven formulations of nonlocal continua are developed, providing thus effective methodologies to assess size effects in composite structures, nano-engineered materials and modern devices. Enhancements of existing techniques in modelling and design of smaller and smaller structures are research key goals. Keywords: Nano-beams; Nonlocal integral elasticity; Constitutive boundary conditions; Advanced materials; NEMS.

Dynamic Analysis of Functionally Graded Beams with Periodic Microstructure

abst. 2019
Repository

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It is known from experimental studies that softening or hardening material behaviours of structures change with the microstructure of the considered material. However, most of the size dependent continuum models (nonlocal stress gradient, strain gradient and couple stress theories) predict only softening or hardening material behavior. Except of these size dependent theories Doublet Mechanics (DM) predicts both softening and hardening responses of the material like experiments in micro/nano-structures. In the present study, free vibration analysis of functionally graded (FG) periodic beams is investigated via DM theory. Periodic microstructure FG beams are modeled as a simple crystal lattice type. Micro strains and strains are expanded in Taylor series and obtained micro relations transformed into macro stress-strain relations in DM. Thus, by use of bottom-up approach yields the more physical and accurate analysis of structures in DM model. After deriving the governing equations of a periodic microstructure FG beam, vibration problem is examined for general boundary conditions. Ritz method is used in the solution. Tailoring of softening and hardening responses of the material gives a beneficial optimization and design of microstructures.

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abst. 2661
Repository

Analysis of carbon and graphene nanoplatelets porous doubly-curved nano shells using the nonlocal elasticity theory

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FG materials could be classified as a type of composite in which their properties have gradual variation in specific direction. The first type of FG material invented by Japanese was a mixture of metal and ceramic. After the synthesis of this FG materials, many researches were performed to reveal the mechanical behavior of this type of materials. The gradation of the constituents in FG materials are estimated by different micromechanical models for instance, power law function combined with rule of mixture, Mori–Tanaka scheme, Kerner method, Wakashima-Tsukamoto model, Hashin-Shtrikman scheme and Halpin-Tsai model [1]. The extraordinary material properties of CNTs make it a suitable reinforcement part for the polymer composites [2]. Recently a new type of FG reinforced nanocomposite has been suggested in which CNTs are playing the reinforcement phase. In this study, by means of nonlocal elasticity theory with using a higher order shear deformation theory [3], the size-dependent via nonlocal elasticity [4] wave propagation in functionally graded (FG) doubly-curved shells is investigated. In this HSDT, an exponential function along with a trigonometric formula represents the displacements and the implementation of Hamilton's principle resulted in obtaining the governing equations. Shells are considered to be made of three different types of material properties: 1. FG carbon nanotubes-reinforced composite (FG-CNTRC), 2. FG graphene nanoplatelets-reinforced composite (FG-GNPRC), 3. FG porous ceramic-metal (FG-PCM). The properties for FG-CNTRC are estimated by the rule of mixture, for FG-GNPRC are evaluated by Halpin-Tsai model and for FG-PCM are modeled by a power law function combined with a cosine formula. The accuracy of proposed models are verified with open literatures' results. The effects of CNTs' percentage, GNPs' weight fraction, intensity of porosity, distribution patterns of CNTs as well as GNPs and porosities, wave numbers, nonlocal parameter and thickness of shells on the results of FG doubly-curved shells are also presented. Keywords: Carbon nanotube reinforced composite, Graphene nanoplatelets-reinforced, porous ceramic-metal, Doubly-Curved Shell, Size-Dependent model. References: [1]Zuiker JR. Functionally graded materials: Choice of micromechanics model and limitations in property variation. Compos Engn 1995;5: 807-19. [2] Shen H.-S. Nonlinear bending of functionally graded carbon nanotube-reinforced composite plates in thermal environments. Compos Struct 2009;91:9-19. [3] Reddy JN. Mechanics of laminated composite plates and shells : theory and analysis. Boca Raton: CRC Press (in English), 2004. [4] Eringen AC. On differential equations of nonlocal elasticity and solutions of screw dislocation and surface waves. J of Appl Phys 1983; 54: 4703-4710.

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abst. 2415
Repository

A numerical and experimental multi-scale analysis of a nano-vascularized epoxy resin

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In recent years nanofibers obtained by electrospinning have been increasingly used to toughen composite materials. In this context, to take full advantage of nano-reinforced composites is necessary to develop models capable of predicting and explaining the mechanical behavior at the macroscale. However, toughening mechanisms of nanofibrous reinforced composite laminates have not yet been fully understood. Some authors affirm that the increase in fracture toughness is mainly due to the nanofiber bridging effect, while others ascribe it mainly to energy-absorbing mechanisms, such as debonding, plastic yielding, pull-out, void growth and matrix shear deformation. These nanoscale effects have an impact on the mesoscale, toughening the composite through stress shielding effects. In this work an

attempt to simplify the problem was done, evaluating how the mechanisms related to the geometric cavities generated by the presence of nanofibers affect the mesoscale, separating them from the mechanisms related to the presence of nanofibers themselves. To this purpose, a random nano-vascularized system was created out a structural epoxy resin and tested in tension and bending, respectively. Then, a Representative Volume Element (RVE) model of the nano-vascularized matrix was developed and validated against experiments. First of all, experimental tensile tests were carried out on neat epoxy resin specimens and the stress-strain curves were obtained through a 3D Digital Image Correlation (DIC) analysis. The stress-strain behavior was fitted and extrapolated to higher failure strains using the Ramberg-Osgood model. In fact, it is known from the literature that epoxy resins show a higher strain to failure at the microscale than on tensile tests. The Ramberg-Osgood model was then adopted to model the epoxy resin into the nano-vascularized RVE. A series of Three-Point Bending (3PB) tests on the neat epoxy were also done to check for possible asymmetry of the stress-strain behavior in compression. The RVE has been realized by means of a Computer-Aided Design (CAD) software starting from the analysis of a random nanomat of Pullulan nanofibers observed under an Electronic Scanning Microscope (SEM). A random nanofibers' arrangement has been chosen since it is notoriously the most adopted for nano-reinforcing and when the delamination direction is not known a priori. In order to guarantee a statistical value to the results, several RVEs have been extrapolated from the SEM image. This allowed us to obtain several stress-strain characteristic curves and to interpret the results considering the geometric features of each RVE. The mean stress-strain curve thus obtained was imported into Finite Element (FE) models of macroscale cases. These latter correspond to the models of a 3PB test and a tensile test of a nano-vascularized epoxy. Simulated stress-strain curves were compared with the experimental ones. To manufacture the nano-vascularized specimens, a 4 mm thick Pullulan nanofibrous mat was electrospun seamlessly. The nanomat was then impregnated and integrated into the epoxy resin and vacuum cured in autoclave. Once cured and milled, the nano-structured specimens were immersed in distilled water to dissolve the Pullulan nanofibers, thus generating the nanochannels. By adding Rhodamine B to the Pullulan solution, it was possible to electrospun red-colored nanofibers. Thanks to this, the evaluation of the dissolution level of nanofibers was made by visually checking the color of the aqueous solution in which they were immersed. Finally, also the nano-vascularized specimens were tested at both 3PB and tensile tests. Again, the tensile tests were analyzed using a 3D DIC system. The results obtained were compared with FE simulations, thus validating the proposed model. The fracture surfaces of both 3PB and tensile tests specimens were analyzed at the SEM in order to understand also the actual failure mechanisms present in the nano-vascularized epoxy matrix.

On vibrations of a nanobeam considering dynamic an surface-related flexoelectric properties

abst. 2559
Virtual Room
Friday
September 4
14h30

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We discuss the influence of dynamic flexoelectric properties and surface flexoelectricity on vibrations of a nanobeam. Flexoelectricity is the general property of dielectrics. Although the magnitude of the [U+FB02]exoelectric e[U+FB00]ect is generally small, its contribution may become signifcant or even dominant at the nanoscale. The static flexoelectric response relates the electric polarization with the strain gradients and vice versa whereas dynamic flexoelectric response extends the form of the kinetic energy [1] including time derivatives of the polarization. In addition, the surface/interfacial flexoelectricity is also described [1, 2], which includes surface/interfacial densities of strain and kinetic energy. The aim of the lecture is to discuss all mentioned above responses considering oscillations of a nanobeam. For simplicity we consider isotropic materials and infinitesimal deformations. We apply the Timoshenko-type kinematics. In other words, we consider a beam with kinematicallly independent translations and rotations. Various boundary conditions are considered. For the derivation of the governing equations we used the least action principle generalized for dynamic flexoelectricity. Here the functional includes both surface and bulk strain and kinetic energies. After dimensional reduction we get the 1D equations of motion for the beam. The related 1D constitutive relations are discussed and

influence of dynamic and surface flexoelectricity on the 1D effective parameters is underlined. The eigenfrequencies are calculated and their dependence on the material parameters are analysed. References [1] Yudin, P. V., Tagantsev, A. K. (2013). Fundamentals of flexoelectricity in solids. Nanotechnology, 24(43), 432001. [2] Wang, B., Gu, Y., Zhang, S., Chen, L. Q. (2019). Flexoelectricity in solids: Progress, challenges, and perspectives. Progress in Materials Science. 106, 100570

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abst. 2492
Repository

Analysis of Periodic Composite Materials by Using Peridynamics

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Composite materials are widely used in many different industries due to their superior properties with respect to traditional metallic structures. Although composite materials can show homogenised properties at the macroscopic scale, their microstructural properties can be very influential on the overall material behaviour especially on the fracture strength of the composite material since defects such as microcracks and voids can exist. Analysing each and every detail of the microstructure can be computationally expensive. Therefore, homogenisation approaches are widely used especially for periodic composite materials. However, some of the existing homogenisation approaches can have limitations if defects exist since displacements become discontinuous if cracks occur in the structure which requires extra attention. As an alternative approach, peridynamics can be utilised since peridynamic equations are based on integro-differential equations and do not contain any spatial derivatives. Hence, in this study peridynamic modelling of periodic composite materials will be presented and the capability of the approach will be demonstrated with several numerical examples with and without defects.

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abst. 2277
Repository

Structure-Property Correlations Between Nano Reinforced Cellular Materials and Their Mechanical Properties

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Defining micromechanics of foams through their physical and chemical properties is still a challenge to establish the structure-property relationship effectively. Hence, cellular geometry can therefore be treated to link the micromechanical performance to composition of foams. Within the demanding nature of advanced applications, modification of polymer foams with nano and/or micron scale fillers is of interest from several researchers. When this is also considered, the physical and chemical compositions of polymeric foams require more detailed investigations for further characterizations. Although, many studies can be found to investigate the mechanical properties of nano/micro particle reinforced polymer foams, until this time, synergetic effects of nanomaterials on the cell geometry and mechanical properties of these cellular structures have not been studied, extensively. The present study discusses how to establish a correlation between the cellular geometry and the mechanical properties of Nano-reinforced rigid polyurethane (PU) foams through various fillers such as titanium dioxide (TiO2), silica (SiO2) and multi-walled carbon nanotubes (MWCNT). These nanoscale inclusions with different geometries from spherical to cylindrical greatly affect the cellular geometry by varying the cell aspect ratio and cell size of PU foams. Additionally, the effect of weight fraction of these fillers have also been studied to identify the optimized weight fractions needed to enhance the mechanical performance of PU foams. Optical

microscopy as a straightforward and easy tool was used to characterize the cellular structure of neat and reinforced PU foams and a Matlab code is established to perform the image processing. Compression tests was also executed to analyze the enhancements of mechanical properties from neat to reinforced PU foams. Moreover, a link to micromechanics of PU foams have been studied to identify the effects of nano-scale fillers on the geometry, and the volume fraction to the overall strength and stiffness. It is observed that during the foam processing, different nanoparticles affect foaming direction by way of cell stretching mechanism which tends to be formed distinctive anisotropic cell nature. Cylindrical shape of MWCNTs tends to increase viscosity of PU and gas diffusion increase while the foam processing. This affect mainly accounts for cell forming. However, viscosity has restriction to use MWCNTs amount in PU foam due to dispersion difficulties. It is also important to understand transition from micromechanics to macro mechanics. Consequently, analytical approaches have been also studied to evaluate physical and mathematical results. According to characterization results, cell spans and cell edge thickness change with respect to additive type and weight fraction. If we compare the morphological results among the maximum amount of dispersed nanoparticles in PU foam, it is understood that MWCNTs predominate the cell span length. This outcome can be result from viscosity effects. In other words, spherical nanoparticles tend to decrease cell edge length however cylindrical nanoparticles give rise to increase cell edge length. When mechanical test results are analyzed, maximum gain for compressive strength (18%) and elastic modulus (16%) belongs to TiO2 reinforced PU samples due to perfect dispersion quality of TiO2 in PU. This result is also matched with analytical results. Spectacularly, even though MWCNT weight fractions are less than other nanomaterials in PU foam, compression test results are remarkable with the 15 % increase in compressive strength.

ELECTROMAGNETIC FIELD AIDED MICROSTRUCTURAL ENHANCEMENT IN DIELECTRIC POLYMER NANOCOMPOSITES

abst. 2478
Virtual Room
Friday
September 4
14h45

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High performance fibre-reinforced polymer composites are widely used in advanced industrial applications, in which epoxy is mostly employed as the matrix material with its outstanding mechanical properties and processability. However, process-induced defects occurring during curing and microcrack ingress from impact and internal stresses may significantly deteriorate the mechanical properties of such materials, which may lead to catastrophic failure. Numerous researches have been out to overcome this issue by the incorporation of nanomaterials. However, the challenge of inaccessible damage during their service time still remains. Therefore, to overcome these limitations, high permittivity nanoparticles have been introduced to not only enhance the mechanical properties but also serve as a second phase to introduce compressive stress field at microscale to their surrounding matrix by agitation activated by external electromagnetic field stimulation. The micro-compressive stress field induced by the excitation of the dielectric nanoparticles, therefore, enhances the crack closure ability at microscale in order to prevent material failure. Barium titanate nanoparticles with size of 200nm are embedded in epoxy at different weight loading, 1%, 5%, 10%, and 15%. Silane coupling agent is utilised for particle surface functionalisation to achieve optimal performance through uniform dispersion. X-ray diffraction, Fourier transform infrared (FTIR) spectroscopy and field emission scanning electron microscopy (SEM) results shows a modified epoxy resin with uniform distribution of tetragonal phase barium titanate particles with effective functionalisation. The modified epoxy specimens are exposed to a 2.45GHz microwave field under different power intensity and field-induced strain effects are evaluated via fibre optical sensors relying upon fibre Bragg grating technique. Microwave field induced strain and temperature are measured simultaneously during exposure. Strain results shows a significant difference of contributions of strain induced from different mechanisms of specimen under higher power density. Tensile test results of specimens with microwave exposure exhibit a larger extension at failure compared to non-exposed specimens. Development of a correlation between the field strength, temperature, material dielectric properties and microwave field induced strain will be pursued based on experiment results. Theoretical constitutive material models are then employed to quantify the relationship between micro-compressive strain induction and the external field strength, and its solution is compared with the experimental data.

Numerical methods are also being developed for simulating the effects of nanoparticles on the mechanical response of the enhanced epoxy under an electromagnetic field using COMSOL. The preliminary results will be discussed and presented.

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abst. 2343
Repository

Investigation of electrical properties of hybrid nanocomposites containing different fillers on pressure sensor applications under different loadings

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Conductive elastomeric materials containing carbon-based filler (F-MWCNT, graphene, and MWCNT) were vulcanized inside cis-isoprene rubber and chloroprene polymer matrixes blends were fabricated via two different processing procedures to control sensitivity aiming at applications from pressure sensors. In this study, the chemical matters and polymer matrixes are were mixed homogeneously in the first step. In the second step, fillers and solutions were blended inside the industrial solvent and the mixture was stirred until concentrated with the mixer. The solvent of the resulting compounds was evaporated by drying in a forced ventilation oven at 50 C for 16 hours.) (Mechanical and electrical sensitivity properties were extensively studied and the structure characterization was achieved consistently. The electrical sensitivity and piezoresistive properties of cylindrical samples (MWCNT, graphene, and F-MWCNT filled mixtures, respectively.) prepared with 30 mm diameter and 12 mm height were examined. Compared to SEM images of samples prepared with three various fillers, COOH functionalized Multiwalled Carbon Nanotubes was observed to interact and distribute better with the matrix material in the nanocomposite. The internal resistance change that affects electrical conductivity exhibited the same characteristic properties as the cyclic force curve applied. The detailed examination of the sensor features depending on the loading of composites was carried out between 0.5 mm to 3.5 mm (in 0.5 mm increments) by applying the cyclic load. The best electrical conductivity values among all filler materials were obtained from the sample containing Graphene. The electrical resistance of conductive filled samples starts decreasing with the applied force. Likewise, when the force on the sample starts to be removed, the electrical resistance value of the material starts increasing. In our study, graphene filled nanocomposite showed better conductivity than F-MWCNT and MWCNT fillers under cyclic compression loading. At different compression heights from 0.5 mm to 3.5 mm, the average electrical resistance change ranged from 4.63E + 06 to 5.66E + 06 and 3.98x106 to 4.29x106 for graphene and f-mwcnt respectively. Because of the structure of MWCNT's and the inhomogeneity of the distribution in the compound was not achieved remarkable resistance valueExcessive resistance overflow has occurred in nanocomposites whose compression value surpasses 2.5 mm due to disturbances in the conductive network. The pressure sensors gained by this study will bring innovation to the automotive industry for use in air suspension systems, the examination of muscle movements in the field of health, and sensitive to high-pressure digital manometer gauges.

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abst. 2491
Repository

Smart nanocomposites with multifunctional structures and their applications in environment

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Nanomaterials are of great importance and have fast developed in the recent years. Our group mainly focus on the studies of functional nanomaterials. Several novel nanocomposites with multifunctional structures recently developed in our groups will be reported in this presentation. Their environmental applications such as contaminants removal (adsorption, photocatalysis etc.) and/or new energy generation (producing H2 and/or O2 from water splitting) will be also exhibited.

Reduction of Notch Effects in CNT-Epoxy Nanocomposites using Electric Field Application

abst. 2587
Virtual Room
Friday
September 4
14h15

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Carbon-based nanofillers such as carbon nanotubes (CNTs) and graphene have been widely researched in recent years for the development of epoxy nanocomposites with superior properties as compared to neat epoxy [1, 2]. On account of their exceptional properties, CNTs can impart additional functionalities to the epoxy matrix [3]. Furthermore, the alignment of CNTs within the matrix has been identified as an effective method to extend their exceptional properties from nanoscale to macroscopic scale [4, 5]. In the present study, the authors investigated the use of non-uniform electric fields to control CNT orientation and distribution within a epoxy matrix with the objective of reducing stress concentration effects. A typical case of a rectangular nanocomposite plate of finite width with a rectangular filleted notch subjected to far-field tensile load was considered [6]. In this direction, both numerical simulation and experimental studies were performed. Parametric studies were initially performed using ABAQUS to identify stress concentration regions in the nanocomposite plate considering various orientations of the filleted notch with respect to the loading direction. Multiphysics simulation studies were then performed using COMSOL to enable the design of different electrode configurations based on the notch orientation for controlling CNT alignment and distribution around the notch. The three-dimensional (3-D) coupled multiphysics models developed were of different length scales and account for the presence of time varying electric fields, transient epoxy viscosity due to cure progression and particle motion [7]. The results of the numerical studies enabled the design of a computer controlled Arduino Uno-based circuitry to control voltage supply to the electrodes during sample fabrication. The results indicate that the fabrication methodology is effective in reducing stress concentration effects and the details are presented in the paper. This technique can be extended to facilitate the fabrication of novel multifunctional composites with controlled distribution of CNTs to produce functionally graded materials. References: 1. N. P. Singh, V.K. Gupta, and A.P. Singh, "Graphene and carbon nanotube reinforced epoxy nanocomposites: A review", Polymer, 2019, 180, 121724. 2. V. D. Punetha, S. Rana, H. J. Yoo, A. Chaurasia, J. T. McLeskey Jr., M. S. Ramasamy, N.G. Sahoo, and J. W. Choc, "Functionalization of carbon nanomaterials for advanced polymer nanocomposites: A comparison study between CNT and graphene", Progress in Polymer Science, 2017, 67, pp. 1 - 47. 3. P.C. Ma, N.A. Siddiqui, G. Marom, and J.K. Kim, "Dispersion and functionalization of carbon nanotubes for polymer-based nanocomposites: A review", Composites: Part A, 2010, 41, pp. 1345 -1367. 4. X. Sun, T. Chen, Z. Yang, and H. Peng, "The alignment of carbon nanotubes: An effective route to extend their excellent properties to macroscopic scale", Accounts of Chemical Research, 2013, 46, 2, pp. 539 – 549. 5. J.R. Pothnis, S. Gururaja, and D. Kalyanasundaram, "Development and characterization of electric field directed preferentially aligned CNT nanocomposites", Mechanics of Advanced Mechanics of Advanced Materials and Structures, 2019, 26:1, pp. 35-41. 6. A. Negi, G. Bhardwaj, J.S. Saini, K. Khanna, and R.K. Godara, " Analysis of CNT reinforced polymer nanocomposite plate in the presence of discontinuities using XFEM", Theoretical and Applied Fracture Mechanics, 2019, 103, 102292. 7. J.R. Pothnis, D. Kalyanasundaram, and S. Gururaja, "Numerical and Experimental Studies on the Development of Variable Density Nanocomposites for Structural Applications", In ASME 2018 International Mechanical Engineering Congress and Exposition, pp. V009T12A041-V009T12A041, November, 2018.

Toughening of graphene oxide-epoxy nanocomposites through very high pressures and shear rates

abst. 2344
Repository

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We have successfully conceived and demonstrated a preprocessing method for enhancing the fracture toughness of graphene oxide - epoxy nanocomposites, without any reduction in other important mechanical parameters as stiffness or strength, as in other toughening methods. Increases of up to 225% in fracture toughness and strength, and up to 130% in stiffness have been achieved with respect to those measured in the unprocessed graphene oxide-epoxy nanocomposite. The method takes advantage of the very high pressures and shear rates occurring in lubricated superior kinematic couples, in the order of 4 GPa and $10^6 s^(-1), respectively, which promote different macroscale and nanoscale mechanisms, as polymer chain scission, matrix interfacial adhesion and nanofiller dispersion. Nanoscale experiments and observations have been carried out in s matrix adhesion. SEM observations corroborate this hypothesis, and also show a very good dispersion degree, as well as sub up, as well as in the assessment of the conservation of the improved mechanical properties in long fiber carbon fiber − epoxy prepregs.$

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abst. 2463
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Effects of different nanoparticles on surface, structural and properties of electrodeposited Ni-W nanocomposites

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In this paper, the effect of different nanoparticles such as ZrO2, TiN, BN, Si3N4 on the surface, structural and properties of Ni-W matrix nanocomposites was comparatively studied. Their microstructure, morphology, composition, roughness, crystallite size, hardness and electrochemical behaviors of the obtained nanocomposites were evaluated. Results indicated that the coatings were dense, homogeneous and crack-free. The nanoparticles are even dispersed in the Ni-W nanocomposites, which can reinforce its properties. The nanocomposite surface topography was affected by the operating parameters and is also associated with the distribution of the electric filed. The formation of protrusion clusters could be attributed to the preferentially discharge of the metal ions at the edges or tips sites. The presence of these nanoparticles could reduce the crystallite size of the texture. The average crystallite size of ZrO2, TiN, BN, and Si3N4 reinforced Ni-W nanocomposites were 13±1, 13±2, 12±1 and 18±1 nm, respectively. The average roughness values (Ra) of the ZrO2, TiN, BN, and Si3N4 strengthening Ni-W nanocomposites is about 50±2, 70±4, 89±11 and 25±1 nm, respectively. The corrosion resistance and wear of these nanocomposite can be improved by incorporation nanoparticles into the Ni-W alloy matrix. The strengthening mechanisms of the nanocomposites were analyzed. These nanocomposites exhibit potential application to meet the requirement of high anti-corrosion and anti-wear properties in harsh conditions. Keywords: Nanoparticles; Metal matrix composite; Nanocomposites; Ni-W matrix; Electrodeposition; wear resistance

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SINTERED NANOCOMPOSITES ZrO2-WC OBTAINED WITH FIELD ASSISTED HOT PRESSING

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In the paper, fabrication of nanostructural composite ZrO2 – 20 wt.%WC with Field Assisted Sintering is described. Hot pressing processes with mixtures of different proportions of tungsten monocarbide content, such as 10 wt. %, 20 wt.%., 30 wt.% were performed at different sintering temperatures. The composite was sintered out of ZrO2 and WC nanopowders in short time of 2 min at pressure 30 MPa and temperature 1350 °C activated by alternating current. Sintering time of two minutes was selected based on the preliminary studies. They demonstrated that longer exposure at the final temperature 1350 oC, when shrinkage process was completed, caused rapid growth of agglomerates of tungsten carbide. The structure of electro-consolidated zirconium ceramics was examined using a Scanning Probe Microscope Ntegra Aura and raster microscopy (microscopes Nova Nanosem and Quanta 200 3D). The ACM scanning was carried out with the semi-contact method in the air in two modes: constant amplitude (topography) and phase contrast. Areas of dimensions 1x1 micrometers, 2.5x2.5 and 5x5 micrometers were scanned. The phase analysis was performed with the Shimadzu XRD-6000 diffractometer. Nearly theoretical dense was obtained with hardness HV(147 N) = 15.5 GPa, fracture toughness K1c (147 N)= 15 MPa m$\frac{1}{2}$ and high hydro-abrasive wear resistance, higher than that of WC – 3 wt.%Co and WC – 15 wt.%Co hard alloys. Additional comparative test of performance was made for water jet nozzles fabricated out of this composite and two other materials available in the market. The conditions of sintering seemed to minimize the effect of diffusion on the particles and to promote activation of dislocation creep, which allowed the material densification without essential grain growth. The relationship between the porosity variation of the examined samples shows that with the increase in the temperature of electroconsolidation, the overall level of porosity decreases on average from 3.5% to 1%. In the obtained samples, the pore structure is represented by the closed pores of spherical or nearly spherical shape. In the samples produced at higher temperatures above 1350°C, only single isolated small pores were present in their structures. Structural transformation of monoclinic m-ZrO2 into tetragonal-t-ZrO2 phase was prevented due to the comparatively low temperature. As a result, the composite with advantageous characteristics was obtained.

Flutter and divergence of nanocomposite plates and cylindrical panels

abst. 2116
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The flutter and divergence of composite plates and cylindrical panels in gas flow is directly connected with the instability phenomena which is especially important in the design of for example aircraft constructions. In the instability investigation, the broad discussion is concentrated on various problems which can influence on the structural behaviour, such as the aerodynamic theories, the form of boundary conditions, the geometry and material characteristic, and the effects of aero thermoelastic coupling – see [1-3]. In the analysis of composites structures with nanoreinforcement subjected to the dynamic stability constraints, several topics are considered such as identification of vibration modes for nanocomposite structures and analytical evaluation of flutter and divergence. The analytical solution used in the flutter analysis of composite plates presented in [1] is adopted here for nanocomposites analysis. The material properties of nanocomposite are based on our previous analytical and numerical computations of polymeric nanocomposites reinforced with carbon nanotubes – see [4-5]. The present analysis takes into account the geometry and material properties definition of nanocomposite plates and cylindrical panels. For flat plates, the analytical relation for dynamic instabilities is reduced to the algebraic equation of the 4th order however for cylindrical panels the 8th order equation is applied [1]. The analytical solutions are looking for with the help of the symbolic package Mathematica. References: 1.

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abst. 2568
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Preparation and Properties Evaluation of Chloroprene Rubber Modified with Montmorillonite

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The present work investigates the effect of organomodified montmorillonite (Cloisite 20) and mixing conditions on the mechanical properties, structure and morphology of chloroprene rubber. The tensile and fatigue tests were carried out for rubber samples containing different amounts of montmorillonite and mixed with three different sonication amplitudes (162μm, 216 μm and 270 μm) for 15 minutes. Tensile strength and energy to break were maximally increased by approximately 15% and 70% with 3 wt.% nanoclay loading and prepared with highest sonication amplitude. The additions of solide nanoparticles and mixing amplitudes did not affect the shape retention factor of chloroprene rubber nanocomposites, hence its elasticity. As expected, the secant modulus (at 300% strain) decreased due most probably to plasticization effect. The rubber nanocomposite containing 3 wt.% nanoparticles and prepared with highest amplitude had the lowest crack growth rate and lowest tearing energy, which makes it the most resistant to fatigue crack growth. It was shown that, the highest amount of nanoparticles led to the lowest crack growth rate regardless of the type of tested nanocomposite sample. The crack growth rate systematically decreased with the increase of nanofillers content. This was attributed to the positive effect of the additional crosslinking induced during the compounding process of the rubber mixtures. The data of tearing energies as a function of displacement for rubber samples containing different amounts of montmorillonite (MMT), indicated that the lowest tearing energy was presented by the rubber nanocomposite based on 3 wt.% MMT and mixed with highest amplitude. For the other sonication amplitudes, the evolution of the tearing energy as a function of the displacement was almost independent of the MMT content. Instrumental methods such as Fourier-Transform Infrared Spectroscopy (FTIR), Differential Scanning Calorimetry (DSC), Thermogravimetric Analysis (TGA) and Scanning Electron Microscopy (SEM) were employed to analyse the structure and morphology of prepared rubber nanocomposites. FTIR spectra analysis showed increase of nanofiller band probably due to a more homogenous exfoliation of the nanoparticles between polymer chains. The variation of mixing amplitude and content of incorporated nanoparticles did not influence the DSC and TGA thermograms demonstrating among other things, a stable thermal stability of the nanocomposites. SEM micrographs indicated that, the highest sonication amplitude led to rubber mixtures with more uniform and homogeneous morphologies with nanoclay particles well dispersed and embedded in the rubber matrix as compared to lower loading. A more homogeneous composition was obtained when more energy was provided to the mixtures. This work has demonstrated the great opportunities for chloroprene rubber nanocomposites to be used in engineering applications in which high tensile strength, good fatigue resistance and adequate elasticity are required.

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abst. 2656
Virtual Room
Friday
September 4
15h15

A Hybrid Homogenization Theory for Unidirectionally-Reinforced Materials

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A new 0th-order homogenization theory, herein referred to as Hybrid Homogenization Theory (HHT), is developed for the micromechanics analysis of unidirectionally reinforced heterogeneous materials. The theory combines elements of the previously developed homogenization approaches based on the finite-volume method and exact elasticity solution of the local unit cell problem. The interior inclusion is regarded as a meshfree component and tackled with the elasticity-based approach using Fourier series representation of the local displacement field, following the previously developed locally exact homogenization theory (LEHT) [1,2]. In contrast, the exterior matrix is discretized into subvolumes and solved using the Finite-Volume Direct Averaging Micromechanics (FVDAM) [3,4]. The traction and displacement continuity conditions at the inclusion/matrix interface are then employed in a novel manner to seamlessly connect the inclusion and matrix phases of the unit cell. Comparison of stress fields and homogenized moduli generated by HHT, FVDAM and LEHT within the framework of a convergence study demonstrate the accuracy of this new approach. The execution time compared to that of FVDAM validates the efficiency of this new approach, especially in cases involving extensive unit cell discretizations. In addition, the capability to solve multi-inclusion problems with randomly distributed inclusions, which is not efficiently handled using the finite-element or finite-volume based methods, illustrates the advantage of this new approach both at the mesh discretization and execution levels. Keywords: heterogeneous materials, homogenization, elasticity and finite-volume methods. References [1] Drago, A. S. and Pindera, M-J., 2008. A locally-exact homogenization theory for periodic microstructures with isotropic phases. J. Appl. Mech., 75(5), 051010-14. [2] Wang, G. and Pindera, M-J., 2016. Locally-exact homogenization theory for transversely isotropic unidirectional composites. Mech. Res. Comm. 78, 2-14. [3] Gattu, M., Khatam, H., Drago, A.S., Pindera, M-J., 2008. Parametric finite-volume micromechanics of uniaxial, continuously-reinforced periodic materials with elastic phases. J. Eng. Mater. Technol., 130(3), 031015-15. [4] Khatam, H., Pindera, M-J., 2009. Parametric finite-volume micromechanics of periodic materials with elastoplastic phases. Int. J. Plasticity, 25(7), 1386-1411.

The preparation and characterization of the nano / micro magnetizable composites materials, by using the nanomagnetic fluids

abst. 2221
Repository

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Most nanocomposites that have been developed and that have demonstrated technological importance have been composed of two phases. The nanoparticulates composites are composed of a matrix with embedded nanoscale particles. The properties of nanocomposites can display synergistic improvements over those of the component phases individually. However by reducing the physical dimensions (s) of the phase (s) down to the nanometer length scale, unusual and often enhanced properties can be realized. An important microstructural feature of nanocomposites is their large ratio of interphase surface area to volume. [1] Polymer-embedded nanotructures are potentially useful for a number of technological applications, especially as advanced functional materials. Governing and directing the assembly of matter on the nanometre scale has the potential to provide new classes of novel materials and enable the unprecedented capability of tuning material properties by altering their

microstructure. [2] The researches have started with the idea to exploit the possibility to achieve the new materials in the context of Nanotechnology Constructions, with the aid of the inclusion of nanoparticles with the Nano Magnetic Fluids. [3] Adding nanoparticles to a polymer matrix can enhance its performance. This approach is particularly effective in yielding high performance composites, when the nanoparticles are well dispersed and the properties of the nanoscale filler are substantially different or better than those of the matrix. The use of nanoparticles in these polymer matrices, thus creating a nanocomposite, can yield an optimal multifunctional material for aerospace needs and other applications.[4] However, there are still many limitations and challenges for nanocomposites production. The processing, the compatibility, dispersion and exfoliation between nanomaterials and the polymer matrices. Only a limited number of plastic matrices (mostly thermoplastics) are compatible with nanoclays/nanotubes/nanofibers as intercalation of clays with the precursor of a polymer can change the functionality of the polymer and inhibit its properties. [5] The paper presents the possibility of creating a new category of nanocomposites, nano / micro magnetizable composites materials, by using the nanomagnetic fluids (NMF) and resins. [6,7]. The target of our research is the reparation and the characterization of new materials having magnetic and mechanical controllable properties. [8]. Bibliography: 1. Shivani Pandya, NANOCOMPOSITES AND IT'S APPLICATION-REVIEW, 2015, https://www.researchgate.net/publication/286567899; 2. Francesco Delogu, Giuliana Gorrasi, Andrea Sorrentino, Fabrication of polymer nanocomposites via ball milling: Present status and future perspectives, Progress in Materials Science, 86 (2017); 3. N. Crainic, A. Torres Marques, Nano - Composites – a state of the art review – Mareriais'2001 – 1 ISBN 0-87849-905-9; 4. Suart Milne, Nanocomposites in Aerospace, AZO NANO 2014; 5. https://www.nanowerk.com/spotlight/spotid=23934.php, Polymer nanocomposites drive opportunities in the automotive sector; 6. N. Crainic, A. Torres Marques, Doina Bica, L. Vekas, P. J. Novoa, C. P. Moreira de Sa, The Use of the nanomagnetic Fluids and the Magnetic Field to Enhance the Production of Composite by RTM – MNF, Mol. Cryst. Liq. Cryst., Vol. 418 (2004); 7. A.T. Marques, N. Crainic, Doina Bica, L. Vekas, P. J. Novoa, The Control of nanomagnetic fluids during the production of composite parts components Made by RTM, 4th EC / SF Workshop on Nanotechnology, Tools and Instruments for research Manufacturing, Workshop – 12 – 13 June 2002, Grenoble, France; 8. N. Crainic, Doina Bica, N. C. Popa, L. Vekas, A. Torres Marques, P. J. Novoa, N. Correia, C. P. Moreira de Sa, Magnetic nanocomposite materials obtained using magnetic fluids and resins, International Journal of Nanomanufacturing, Vol 6, Nr. 1- 4, 2010, ISSN 1746 – 9392);

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abst. 2642
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Parametric modelling of electric percolation and conductivity of carbon nanotubes nanocomposite

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Conductive polymers are applied in a wide variety of industry branches. One of the ways to produce conductive polymers is adding carbon nanotube (CNT) filler. 1d nature and high aspect ratio of CNTs lead to low percolation threshold and, thereby, the low weight of filler needed. This presentation aims to show approaches to modelling the electrical conductivity of nanocomposite and its results. To model conductivity of infinite medium representative volume approach is used. As polymer conductivity 18-20 orders of magnitude lower than CNT one, representative volume element (RVE) contains only of CNTs. Using SEM images of nanocomposites, one can observe that CNTs have the shape of the spatial curve. RVE geometry generated randomly with control of such parameters as length and curvature. These spatial curves are approximated with straight segments. Generated geometry is utilized to build an electrical scheme of RVE. Two phenomena impart electrical conductivity to nanocomposite: intrinsic conductivity of CNTs and tunneling conductivity between them. Intrinsic conductivity depends on diameter, chirality, and number of walls. Tunneling conductivity depends on distance and polymer presence between CNTs. Tunneling conductivity is calculated with Landauer-Büttiker formula. Using the described approach, we investigate the influence of geometry parameters on electrical conductivity. All results are obtained for multi-walled CNTs with diameter 50 nm. Segment size 0.3 μm were considered

optimal for calculation accuracy. Changing mean length of CNTs from 2.5 μm to 5 μm with diameter of 50 nm increase conductivity slightly more than 4 times on volume fraction of 2%. Changing curvature from 0 to 3.33 nm-1 decrease conductivity 1.6 times on the same volume fraction. Due to enormous difference in electrical conductivity between matrix and CNTs, nanocomposite percolation behavior can be described with Kolmogorov's zero-one law. It means that an infinite medium has a jump in conductivity when volume fraction is increasing and going through percolation threshold. However, there are finite-size effect, which depends on size of the RVE and smooths this jump. For the materials with filler fraction near the percolation threshold, finite-size effect was investigated. Percolation threshold and critical indexes for materials with different geometry parameters were calculated.

Multi-scale modeling of piezoresistive effect in composites with extreme segregation of the nanoscale carbon filler

abst. 2595
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Polymer composites with non-uniform distribution of nanoscale filler in a matrix, also called as composites with segregated structure, are often characterized by very low percolation threshold and distinct piezoresistive properties. One of the types of composite materials with segregated structure are composites based on solid-state processable ultra-high-molecular-weight polyethylene UHMWPE, in which segregation can reach extreme degrees. This takes place due to inability of the filler particles to enter volume of the solid polymer, thus forcing them to stay on the boundaries of the polymer grains. To develop a complete understanding on how such type of the segregated structure responds to external stimulus, such as deformation, a multi-scale numerical modeling approach based on finite element method was proposed. Process of modeling was divided into two stages. At the first stage, a single representative element of the segregated structure was investigated. To play that role, a thin parallelepiped (layer) was chosen, with thickness value corresponding to such in real segregated structure of UHMWPE-based composite sample. In that volume, the filler particles were distributed uniformly, while realistically representing separate filler particles, i.e. accounting for ability of nanotubes to easily assume different conformations. With the help of external procedure for calculating the electrical conductance of the obtained distribution, taking into account that contact electrical resistances domination over resistance along the filler particle length between the contacts, the volume was deformed uniaxially at various magnitudes, while at each magnitude of deformation its electrical conductance was calculated. Electrical conductance was calculated for all main directions in of the layer. The layer deformation was also performed at different angles to the plane of the layer. Thus, a series of empirical laws was obtained, angle between direction of deformation and the layer's plane, axis of the layer, magnitude of deformation and the electrical conductance value. At the next stage, a realistic volume element of composite with segregated structure was constructed numerically. To achieve that, focused ion beam scanning electron microscope was used, allowing to obtain several hundred of slices of small section of a UHMWPE-based composite sample. With the help of image processing software, a simplified surface mesh resembling the real distribution of the filler in the composite was created. The obtained mesh was successfully imported into FEA software. Each element of the mesh was characterized by conductivity change law, developed at the previous stage, relating the conductivity value in each direction of the element to orientation of the element relative to the future uniaxial deformation axis, and to a magnitude value of the uniaxial deformation. The mesh, representing the segregated structure made of the filler, was embedded into uniform parallelepipedal mesh, corresponding to the polymer matrix using embedded element technique. The obtained representative volume element (RVE) of the composite was uniaxially deformed, while to its opposite surfaces a unit potential difference was applied. In the course of deformation at series of steps the electrical current value, flowing through one of the selected surfaces was measured. The obtained results of the numerical simulation for the composite RVE was compared to the results, obtained experimentally for UHMWPE-based composite sample, to

the results obtained numerically for a single element of segregated structure, and the results obtained experimentally for a thin layer of filler, located between two polymer plates. It was concluded, that complexity of segregation noticeably affects conductance response to deformation, and that developed numerical model can produce reliable results in predicting in. The reported study was funded by RFBR according to the research project 19-03-00369.

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abst. 2164
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Non-local Approach to Free Vibrations and Buckling Problems for Cylindrical Nano-Structures

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The buckling and free vibration of cylindrical nano-structures is considered in the present paper. The cylindrical nano-structures are approximated with the use of the shell theory – Muc [1]. Then, the refined continuum transverse shear deformation theory (third and first order) is introduced to formulate the fundamental equations of the cylindrical shells. Besides, the analysis is based on the nonlocal strain and stress theories of elasticity to take into account the small-scale effects encountered in nanostructures/nanocomposites. At the nanoscale, the non-classical continuum is applied, and widely accepted models comprise: 1. Cosserat continuum – micropolar continuum (1909) 2. Mindlin couple-stress theory (1962) 3. Eringen stress gradient theory (nonlocal stress elasticity) (1983) 4. Aifantis strain gradient theory (nonlocal strain elasticity) (1999). In the present paper the non-local theories are introduced with the use of appropriate differential operators similar to those introduced for beams and plates by Reddy et al. [2]. Hamilton's principle is employed to obtained the governing equations of the shell structures. The Rayleigh-Ritz method is proposed to solve eigenvalue problems dealing with the buckling and free vibration analysis of the cylindrical panels considered. A number of examples is presented to investigate the effects of various formulations. The formulation is an extension of the work published by Chwał, Muc [3] for nano-plates. In our opinion, there is a still open question about the limits if the use of the continuum theory to the description of nanostructures. It is necessary to extend eigenproblems analysis of nanostructures/nanocomposites to the area of molecular dynamic problems – see e.g. the work Muc, Barski [4]. The proposed Rayleigh-Ritz method can be easily adopted to the analysis of different variants of boundary conditions. In view of the opposite effects on nonlocal strain and stress formulations it seems to be reasonable to investigate especially the Mindlin proposal of nonlocal theories. References [1] Muc, A. Modelling of carbon nanotubes behaviour with the use of a thin shell theory. J TheorApplMech2011, 49, 531–540. [2] Lu, P.; Zhang, P.Q.; Lee, H.P.; Wang, C.M.; Reddy, J.N. Non-local elastic plate theories. Proc R Soc A2007, 463, 3225–3240. [3] Chwał, M., Muc, A., Free Vibrations and Buckling of Nanoplates – Comparison of Nonlocal Strain and Stress Approaches, Appl Sciences, 2019, 9, 1409. [4] Muc, A.; Barski, M. Design of particulate-reinforced composite materials. Mater 2018, 11, 234.

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abst. 2658
Virtual Room
Friday
September 4
11h45

Towards structural solid-state pseudocapacitors: the electrochemical and mechanical behaviour of carbon nanotube-polyaniline composites

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The high power density, energy density, capacitance and cyclic stability of pseudocapacitors have attracted considerable attention from the research community. Studies of CNT-PANI composite electrodes have reported specific capacitances as high as 1030 F/g, much above the performance of many other capacitor materials. The reported electrode tensile strength of up to 135 MPa and Young's modulus of 5 GPa makes them promising candidate materials for structural energy storage devices. As yet, the influence of charge and discharge rate, electrode composition and state of charge upon the mechanical and electrochemical properties of these novel electrode composites remains unclear, as do the mechanisms of degradation upon cycling. Composite electrodes of direct-spun carbon nanotube (CNT) mats and polyaniline (PANI) are manufactured and tested to determine their electrochemical

and mechanical properties, and to investigate their degradation behaviour upon cycling and overcharging. Electrodes are manufactured by electrodeposition of a PANI layer on the CNT bundles within CNT mat. The PANI content is varied widely by suitable control of the electrodeposition time at a constant current density. The in-plane uniaxial stress-strain response and capacitance of the electrodes are determined as a function of the electrode composition, the PANI state of charge, after 1000 charge/discharge cycles, and after overcharging. The electrodes exhibit an elastic-plastic stress-strain response under uniaxial tension; their modulus and strength depend upon the volume fraction of CNT bundles. Electrode capacitance increases with increasing PANI volume fraction. A micromechanical model is proposed to relate the macroscopic modulus and yield strength of a CNT-PANI composite to the microstructure.

Effect of Nanopowders (TiO2 and MMT) and Aramid Honeycomb Core on Ablative, Thermal and Dynamic Mechanical Properties of Epoxy Composites

abst. 2561
Repository

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The present work investigates the ablative, thermal and dynamic mechanical properties of epoxy resin modified with nano-titanium dioxide (TiO2) and organomodified monmorillonite (oMMT). The properties of epoxy composites with aramid honeycomb core as stiffness reinforcement were compared with those without honeycomb core. Epoxy nanocomposites samples have been subjected to combustions gases at a temperature above 1900°C during 120 seconds. The effects of components on the maximum back side temperature and the average weight loss under intensive heat flow conditions have been determined together with temperature distribution on the ablation surface of the sample using a thermographic camera. Statistical methods for planning the experiments were also employed. It was shown that the best thermal protective properties, i.e. the lowest temperature of the rear surface area and the lowest ablative weight loss (the highest thermal stability) were exhibited by the composites containing 3.75% of oMMT and 1.25% of TiO2 with aramid honeycomb core. A more stabilized ablative layer and limited erosion were obtained using honeycomb core. Due to the temperature reduction ratio and the lowest weight loss, obtained parameters provide effective protection against heat flux and possess the best thermal stability of base material and the consistency of the ablative layer. It contributes to the improvement of resistance to thermomechanical stresses of composite and provides the formation of passive thermo protecting layer. Dynamic mechanical analysis (DMA) which determines the viscoelastic properties materials as a function of temperature and frequency, is widely used method in polymer characterisation. The polymer samples have been tested for their viscoelastic response including storage modulus (M'), loss modulus (M'') and damping factor (tan) in order to assess the effect of composites components as well as the variation of their concentration on these parameters. Dynamic mechanical thermal analyser measurements were carried out on an Instrument DMA SDTA861, Mettler Toledo. The tests were performed by using a compression deformation mode in the temperature range from 20°C to 140°C. The glass transition temperature (Tg) was determined from the position of the maximum value of tan . This temperature reached values from about 74°C (with tan = 0,59) to 79°C (for tan = 0,66). The dynamic loss modulus M'' can be related to the level of dissipated energy or that converted to heat through viscous flow. The pattern of the M' curves in the glass transition region reflect essentially modifications in the polymeric matrix, which changes from a glassy to an elastomeric state, due to its viscoelastic nature. In fact, the reinforcing material (nanopowders and aramid honeycomb core) does not present stiffness loss for this temperature range. The highest values of the complex modulus M* were in the range from 70 MPa to 465 MPa, for all phase compositions, but at temperature of 140°C the complex modulus M* had much lower values in the range of 20-25 MPa. Keywords: ablative and termal properties, thermal resistance, dynamic mechanical analysis, nanopowders, nano-titanium dioxide, layered silicates, aramid honeycomb core

abst. 2340
Virtual Room
Friday
September 4
14h00

Effect of heat treatment process on the dielectric properties of degradable PLA/GNPs composite films

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In this work, biodegradable PLA/GNPs composite films were prepared by solution compounding and compression molding. The effects of heat treatment process on the properties of the composite films were investigated. With increase of the GNPs, the crystallinity, mechanical properties, electrical conductivity and dielectric properties of the composite films were discussed. The microstructure of the composite films before and after heat treatment process was also observed. The electrical conductivity of the composite films is significantly improved to 42 S/m, which is attributed to an enhanced volume exclusion effect of the polymer composite during the heat treatment process. A weak movement of the conductive fillers forming concentrated conductive networks was caused as well, which directly affects the dielectric properties of the composite films.

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abst. 2462
Repository

A comparative study of the effect of ZrO2 nanoparticles on the properties of Ni-W, Ni-B and Ni-Cu matrix nanocomposites

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The effect of ZrO2 nanoparticles on the structure and properties of Ni-W, Ni-B and Ni-Cu matrix nanocomposite coating was comparatively studied. Their surface morphology, phase composition, roughness, crystallite size, surface topography and corrosion resistance were evaluated using various methods. The electrodeposition parameters, hardness, wear and corrosion behavior of the nanocomposites were optimized. Results indicated that the nanoparticles are uniformly incorporated in the nanocomposites. The nanocomposite coatings are dense with nodular-like structure. The formation of protrusion clusters was related to the uneven distribution of electric field. The presence of ZrO2 nanoparticles could refine the texture of the Ni-W, Ni-B and Ni-Cu alloy matrix to 11-13, 9-11, 15-16 nm, respectively. The corrosion resistance of these nanocomposite can be improved by incorporation ZrO2 nanoparticles into the alloy matrix. The average roughness values (Ra) of the Ni-W/ZrO2, Ni-B/ZrO2 and Ni-Cu/ZrO2 composites is about 45-53, 67-71, 16-20 nm, respectively, indicating the rougher surface of Ni-B/ZrO2 in comparison with others. The inclusion of the nanoparticles in alloy matrix improved the hardness, wear and corrosion resistance. The reinforcement effect of the anti-wear properties of the nanocomposites were proposed. These nanocomposites own excellent performance and exhibit potential application values in harsh conditions. Keywords: Zirconia nanoparticles; Metal matrix composite; Nanocomposites; Electrodeposition; Properties

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Non-destructive testing and structural heath monitoring of composite structures (chaired by L. Maio, V. Memmolo)

Strain wave prediction on carbon fibre composites subjected to extreme load events

abst. 2224
Virtual Room
Friday
September 4
16h30

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Commonly, Structural Health Monitoring (SHM) systems have as input strain signals taken from sensors placed on critical spots of the structure under analysis. The acquisition of these signals usually requires a cumbersome experimental procedure which might be non-completely straightforward and efficient. The possibility to predict the strain propagation along the composite structures is therefore of interest. Numerical simulations provide a highly adequate solution to achieve this task. They offer the possibility of studying a wide range of load cases for a large variety of geometries a-priori thus, reducing time and efforts that are required a purely experimental approach. Generally, SHM systems can be divided into active and passive. In the former, the structure is intentionally excited and the behaviour monitored so as to detect the presence, position and extension of the impact damage. Conversely, in the latter, the structure is monitored during the impact event mainly to detect the event itself and its severity. In both cases, the prediction is based on the measurement of strain waves through a sensor network. The overall scope of the present work is to understand and simulate the strain wave propagation both in the active (i.e. intentioned introduction of energy to the composite plate) and in the passive (i.e. measurement of the propagation during the impact) cases. Modelling approach will be validated comparing it with experimental data. The finite element technique will be used for modelling an 18-layer angle-ply carbon fibre/epoxy composite subjected to an impact event. The strain signal coming from the numerical model will be compared with strain signal measured experimentally. The experimental strain signals were obtained placing several Fibre Bragg Grating and piezoelectric sensor along the back surface of the laminate. During the validation process, several features of the numerical model, such as meshing strategy and mesh dimension, will be studied in order to determine the dependency of the solution to these features.

Structural Health Monitoring of Bonded Joints for Damage Detection and Fatigue Life Prediction

abst. 2176
Repository

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One of the reasons why adhesive joints are not often used in the aeronautic industry is the lack of confidence that both certification authorities and manufacturers have in the durable quality of the joint, especially as the joint is subjected to highly variable conditions of utilization such as temperature and humidity. A possible solution to this scenario would be through the emergence of a Structural Health Monitoring (SHM) system capable of online and continuously monitoring of the integrity of such structures. Usually, it is expected of a SHM system to be capable of not only detecting the presence of damage but also estimating its position, extension and finally the structure's residual strength or sometimes its residual life. The latter is an old interest of researchers and industry, and it is particularly related to fatigue damage. It has been proposed in the literature that the life estimation of bonded joints may be divided into crack nucleation and crack propagation. The number of cycles for crack nucleation may be model using a classical S-N approach, whilst the crack propagation phase is usually

modeled using a Paris-like equation relating the rate of crack growth with the Strain Energy Release Rate. As fatigue damage accumulates, the material properties are reduced, and the structure may fail under load conditions that are well below its strength limit. On the other hand, it is also expected that changes in the material properties (such as mass, rigidity and damping) will affect the structure's vibrational response, which opens the possibility for Vibration Based Methods (VBM) to be used for fatigue damage monitoring. It should be noticed that VBM are usually performed in the frequency domain, making use of modal information such as natural frequencies, modal damping, mode shapes, Frequency Response Functions, etc. Concurrently, the procedure for fatigue analysis of structures can also be performed in the frequency domain, where it is usually applied for structures under random loads, which is the case for several aeronautical components. Considering this scenario, this work proposes to further investigate how VBM (and damage metrics) can be correlated to fatigue damage and fatigue life of bonded joints, which proves useful for an SHM system capable of using the structure's vibrational response for both damage detection and prediction of its remaining service life. Thus, a methodology is proposed, which starts with the selection of the structure under analysis and a load case scenario. The calculation proceeds by finding the fatigue damage that is imposed on the structure by first finding an equivalent stress amplitude, which can be obtained from the load spectrum using the concepts of vibration-fatigue (i.e. fatigue analysis in frequency domain). In the second step, the stress distribution is combined with concepts from Linear Elastic Fracture Mechanics to predict the damage growth in the adhesive layer. Concomitantly, modal analyses are carried out in the structure after the load application and at different damage levels, while a damage index is calculated by comparing the modal response of the structure in its actual condition with the modal response from the pristine stage. Thus, the damage index is used to obtain a quantitative estimation of the damage, while it can also be correlated to the structure's fatigue life.

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abst. 2428
Repository

REAL-TIME DAMAGE DETECTION IN CARBON FIBER COMPOSITE STRUCTURES USING ELECTRICAL CHARACTERIZATION

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The use of modern carbon fiber-reinforced polymer (CFRP) composite materials is becoming increasingly widespread recently. However, the failure modes of such composite structures are extremely complex and, unlike metals, they may suffer significant degradation with barely visible surface damage. Since the damage may cause serious decrease in material strength and lead to catastrophic failure, the development of reliable structural health monitoring techniques is indispensable and has a tremendous impact on the life-cycle cost spent for inspection and repair. One of the developed methods for real-time monitoring is the electrical impedance characterization. It is low-cost, fast, effective, and have high potential to be applicable on real structures where they can be monitored online and real-time. Utilizing the changes in the electrical properties of composites to track incurred damage is promising, but the interpretation of such measurements is still challenging. Here, an electro-mechanical system is introduced to understand how well we could detect mechanical degradation in carbon-fiber-reinforced polymer (CFRP) plates undergoing a quasi-static indentation (QSI) test. The system measures the in situ, real-time changes in impedance and phase angle along the specified conductivity paths. Two different electrode configurations are proposed and tested. In all studied cases, the system effectively detected severe damage, characterized by an immediate reduction in strength, in CFRP. Using our proposed electrode configurations, we discovered that the early detection of barely visible damage strongly depends on two factors; the location of the injection measurement points with respect to the damage, and the orientation of the measurement paths with respect to the fibers orientation in the laminated CFRP surface.

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abst. 2680
Repository

Simultaneous temperature-strain measurement in a thin composite panel with embedded tilted Fibre Bragg Grating sensors

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Fibre Bragg Gratings (FBG) sensors consist of a local periodic modulation of refractive index in the fibre core, which serves as a spectral filter for guided light. The grating period and refractive index are sensitive to external and internal strains/stresses and temperature perturbations of the structure in which they are embedded. The continuous development of composite and new advanced materials and their relevant applications in the aerospace structures lead, in parallel, to the study of more sophisticated structural health monitoring techniques. Since an FBG is able to perform measurements of several parameters inside the material in an elegant and low intrusiveness way, they have raised interest for the structural health monitoring of composite structures. Fibre optics usage for structural health monitoring sensors is continuing to grow in recent years due to their inherent insensitivity to external electromagnetic fields and comparable mechanical properties and dimensions to carbon fibres. Recent research has particularly focused on the FBG as a point sensor to detect the complex state of strain. In this work, a tilted FBG (TFBG) is used to measure simultaneously and separately the strain and temperature extent in a composite plate heated up by incandescent lamps. In order to describe the sensitivity response of the TFBG well, a fully- coupled thermo-mechanical model has been developed using advanced plate theories based on Layer- Wise kinematics. The governing equations are derived from the Principle of Virtual Displacements and 2D advanced finite elements are used to solve them. The composite panels analysis results will be related to the FBG grating period by considering the steady-condition after heating and the numerical models accuracy will be compared with the experimental results.

GUIDED WAVE SCATTERING ANALYSIS AROUND A CIRCULAR DELAMINATION IN A QUASI-ISOTROPIC FIBER-COMPOSITE LAMINATE

abst. 2646
Repository

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This work investigates the scattering of the fundamental anti-symmetric Lamb wave mode by a delamination along the edge of a quasi-isotropic fiber-composite laminate. Delaminations pose a serious threat to the structural integrity of composite laminates as they often show no visible signs of damage on the surface. Due to the anisotropic nature of composites, analytical solutions are often complicated to derive for such problems. This investigation uses 3D Finite Element (FE) analysis and experimental tools to characterize the scatter by a mid-plane delamination in composites. A 5.5 cycle Hann windowed wave train was used as the input signal for both FE and experiments. A 2D Fast Fourier Transform was used to identify the mode and amplitude of the scattered field along various scattered directions. The experimental wave field image was captured using a 3D Laser Vibrometer. The results indicate that the scatter pattern is much more complex than previously obtained results for an isotropic plate. Even for the simple case of mid-plane delamination, the fiber steering effects in the outermost plies have a significant effect on the scattering pattern, relative to the isotropic case where the dominant part of the scattered field is an edge-guided wave. Computational and experimental results are presented for the scattering pattern and scattering amplitude as a function of damage size relative to wavelength. The implications of these results for the optimal placement of actuators and sensors for Structural Health Monitoring (SHM) purposes, and for devising effective approaches for the inverse problem of damage detection and sizing, are briefly discussed.

Theoretical and experimental study of resonances, Lamb waves scattering and conversion in a multi-layered plate with an interface delamination

abst. 2177
Virtual Room
Friday
September 4
16h45

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Damage detection in thin-walled composite structures might be provided employing methods based on elastic guided waves. These methods can be improved using the results of the investigations of guided waves scattering by various defects. In the current contribution, theoretical and experimental results regarding Lamb wave resonant and regular interaction with an interface delamination in an isotropic laminate structure are presented and discussed. It has been shown that Lamb wave scattering by delamination-like obstacles could be featured by resonance scattering resulting in prolonged high-amplitude damage localized motion at the eigenfrequencies. Since these frequencies strongly depend on the obstacle geometry and location within the waveguide thickness, we hope that this phenomenon could have a high potential for damage identification. To demonstrate this idea, several specimens have been manufactured via glueing of two plates made of different materials (aluminium, glass, steel) using two-sided epoxy tape excluding the strip-like delaminated zone. The Fourier transform is applied to experimental B-scan and point-wise measurements obtained scanning laser Doppler vibrometry for extraction resonance frequency from the data. Developed semi-analytical and mesh-based computational models are used to compute eigenfrequencies and eigenforms. The width and depth of delaminations are estimated by matching calculated eigenfrequencies with resonance frequencies estimated from the experiment with a good accuracy.

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abst. 2619
Repository

Effects of a thin interlayer and interface micro-defects on the propagation of the ultrasonic guided Lamb and edge waves in laminate composite plates

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Ultrasonic guided waves have been widely applied to the nondestructive evaluation and structural health monitoring for an inspection of laminate thin-walled composite structures since they are sensitive to possible faults such as cracks, pitting corrosion, voids etc. The accuracy of defects' identification and detection might be improved employing relevant computational models of wave propagation, which take into account intrinsic mechanical properties of the inspected waveguide structure. Among the latter, the presence and influence of adhesive connections between the plies of a multi-layered composite are of particular interest. In the present study, this problem is explored considering the effects of thin intermediate adhesive-like layers between laminate sub-layers and partially debonded interfaces or zones of imperfect contact between sub-layers in a laminate on the wave dynamic properties of the structure. To address the first problem, laminate specimens have been manufactured of two isotropic plates made of aluminium, glass or steel and glued together using two-sided thin epoxy tape. Employing frequency-wavenumber analysis applied to the out-of-plane velocities of piezo-induced wave motion acquired with the laser Doppler vibrometry, the wavenumbers of propagating guided waves in a wide frequency range have been evaluated. The strong influence of the adhesive sub-layer is revealed for all material pairs manifesting itself in remarkable changes in wavenumber dispersion curves of both fundamental and high-order guided waves compared to the corresponding values evaluated numerically for two-layered bi-material structures. In addition to the Lamb waves, the edge guided waves propagation is considered for the same samples. Compared to Lamb waves, edge waves represent another type of wave motion in thin-walled structures being strongly localized in the vicinity of the edges of laminates. This feature allows using them for detection and characterization of a near-surface defect. Theoretical and experimental results show the strong influence of adhesive tape on edge waves as well. The effect of imperfect contact between sub-layers on dispersion and amplitude properties of elastic guided waves propagating is analysed as the second problem of the study. Layered specimens composed of

two aluminium plates and two-sided epoxy tape have been manufactured for the experimental tests employing emery, utility knife and metal brush for surface damaging and contact quality decrease. The distributed spring model is employed to simulate partially damaged interfaces. For this purpose, analytic frequency-dependent expressions for spring stiffnesses have been derived using the ensemble average technique and the boundary integral equation method. Comparison with the experimental data demonstrates that the distributed spring model predicts closely changes in dispersion properties.

Frequency-modulated continuous-wave radar and ultrasound for ice build up detection

abst. 2708
Virtual Room
Friday
September 4
16h15

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Renewable energy sources have gained much attention due to the urge to get clean energy. Among the main options being studied, wind energy is a strong contender because of its reliability thanks to the maturity of the technology and relative cost competitiveness. In order to harvest wind energy more efficiently and to improve safety considerations, the wind turbines blades must be monitored regularly to ensure that they are in good condition. This is even truer in cold climate areas where, because of sub-zero temperatures and humid environment for larger periods of the year, icing represents a significant threat to the performance and durability of wind turbines. Therefore, a structural health monitoring (SHM) system is of primary importance. Recently, there has been a significant interest in employing high frequency radar imagery as well as ultrasound for Non-Destructive Testing (NDT) and Non-Destructive Evaluation (NDE). The main goal of this research is to check the ability of both a frequency-modulated continuous-wave (FMCW) radar, working in the frequency band 57-64 GHz, and guided waves, actuated by piezoceramic transducers, in performing ice detection on a glass [U+FB01] bre plate. The technology effectiveness to achieve the aforesaid task is proved in a climatic chamber under controlled humidity and thermal conditions.

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abst. 2225
Virtual Room
Friday
September 4
08h15

In situ detection of changes in hybrid specimens using resonant inspection techniques

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Ageing tests under cyclic temperature load are an important mean for evaluating the lifetime of hybrid parts. The different coefficients of thermal expansion of the joint materials lead to additional mechanical load and therefore to thermomechanical ageing of the structure. As shown in previous publications a test specimen consisting of a specially formed metal inlay fully surrounded by a potting material is able to depict the ageing process of a complex hybrid structure under temperature load. Being able to constantly monitor the specimen in-situ all the time would lead to a better understanding of the structure's ageing behavior than just inspecting the specimens after predefined times which is done at the moment. A suitable measuring technique should be capable of withstanding the harsh environment in the oven, especially high and low temperatures, and at the same time evaluating a high number of specimens. For example, camera systems can be prepared for intensive temperature load, but they have only limited field of view and the pictures taken cannot show what happens inside the specimen. The aim of this work is to introduce a non-destructive testing technique based on vibration measurements for constantly monitoring a big number of hybrid specimens during an ageing test under temperature load. The specimens' frequency response is constantly recorded by measuring vibrations of the structure due to a sine sweep excitation and changes in the resonance spectrum are correlated with possible defects. First, a harmonic FE-simulation for the hybrid structure is set up in ANSYS to generate a basic understanding of its vibration characteristics and to find out an optimal measurement setup for the real world experiment carried out later. The material model is based on DMA measurements taking into account the viscoelastic behavior of the epoxy part of the structure. Defects of different shape, length and position are implemented in the geometrical model and their influence in the frequency response is determined. In the next step, the results of the simulations are used to perform a real world experiment. For this purpose, the hybrid specimen is prepared with the optimal measurement setup determined by the simulation. During thermal shocking in the oven the specimen's vibration response is constantly compared to its initial one. With the knowledge gained from the simulation, possible defects are identified.

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abst. 2666
Repository

Calculation of the Lamb wave phase velocity dispersion curves using only two adjacent signals

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Ultrasonic Lamb wave testing technique is widely used for nondestructive testing applications exploiting sensitivity of velocity of the waves to the properties of objects under investigation. However,

the dispersion, multiple mode generation of the Lamb waves make interpretation of the received signals complicated. The aim of this work was the development of a complete technique for the asymmetric A0 and symmetric S0 Lamb wave's modes phase velocity dispersion evaluation, and reconstruction of the dispersion curve segments using two signals only. In the paper phase velocity evaluation algorithm presented in detail. Numerical evaluation of the algorithm was performed and the segments of the reconstructed dispersion curves were compared with dispersion curve obtained using semi analytic finite element technique. It was shown that phase velocity of the Lamb wave can be reconstructed with 0.05% uncertainty for the A0 mode and 0.1% uncertainty for the S0 mode. Experimental investigation of the proposed technique was verified on 2 mm aluminium and 4 mm thickness Glass Fibre Reinforced Plastic (GFRP) plates using contact type ultrasonic transducers. Reconstructed fragments of the dispersion curves were compared with dispersion characteristics obtained using two dimensional Fourier transform and the semi-analytical finite element (SAFE) technique. It was shown good coincidence of the results using both techniques. The Lamb waves A0 and S0 modes propagating in aluminium plate can be reconstructed with 1.05% and 0.6 % uncertainty respectively.

The chemical and microstructural analysis of the adhesive properties of epoxy resin coatings modified using waste mineral powders

abst. 2227
Repository

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The results of the tests of epoxy resin coatings modified with the addition of waste mineral powders, which make up the finishing layer of floors, especially industrial floors will be presented. The main goal of the research will be to find an additive, and its amount, that will positively affect the pull-off strength of the epoxy resin coating. In research, waste limestone powders, in several different fractions, was selected. The substrate with a thickness of 15 cm, made from C30 / 37 concrete, was made in the tests. The concrete substrates was divided into two areas with different methods of substrate surface treatment (ground surface and raw surface). To obtain the ground surface, the concrete surface was mechanically grinded and then vacuumed, no bonding agent was applied. To obtain the raw surface, the concrete surface was not undergo mechanical treatment, the concrete surface was only vacuumed and no bonding agent was applied. The morphology of the concrete surface was examined using a 3D laser scanner on surfaces with dimensions of 50 mm x 50 mm (under each measuring point where pull-off tests will be carried out). Then the epoxy resin coating with selected mineral additives was applied. The measurements of the pull-off strength of the coatings was taken after 7 days. The measurements were made at three points for each combination of coating modified with the additive using the pull-off method. Then the chemical composition of the material within the interphase between the epoxy resin modified with waste mineral additives and the substrate was investigated. From each square coated with the epoxy resin with various types of waste mineral additive, cubic specimens was cut from the interphase zone for structural testing. These specimens were examined using a scanning electron microscope (SEM). Finally, analyzing the obtained data in ImageJ and Mathematica, graphs of the fractional share of pores along the sample's height of the subsurface zone were obtained.

Evaluation of Lightning-induced Natural Fiber Composites for Wind Turbine Blade Application using Ultrasonic Wavefield Imaging Technique

abst. 2558
Virtual Room
Friday
September 4
08h00

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The use of a non-biodegradable product such as synthetic fiber has grown a significant environmental impact and greenhouse concern. In alleviating these effects, it has been a major shift to focus more on developing sustainable materials. Extensive research on bio-composite or natural fiber composites (NFC) has become the alternatives in replacing the synthetic fibers. Their main advantages are environmentally friendly, relatively low cost, low density, and high specific properties. In this research, two types of natural fibers (kenaf and flax) were used as reinforcing materials with the epoxy resins to fabricate the NFC for the wind turbine blade application. The fabrication methods used were hand lay-up method and cured using the hot press method. This paper discussed the comparison between the different types of natural fiber based on the lightning damage sizes measured on the NFC surface. The lightning strike test was performed by subjecting a high voltage impulse generated by a 20-stage Marx Impulse Generator. The lightning damages occurring on the surface of both NFCs were evaluated using the ultrasonic wavefield imaging technique. The acquired result shows a different damage size between the kenaf fiber composite and the flax fiber composite. Based on these findings, the most applicable natural fiber for the wind turbine blade fabrication has been discussed. Acknowledgment. This research was supported by Universiti Putra Malaysia, Malaysia, and was also supported by the National Research Foundation of Korea (NRF) Grant funded by the Korea government (MSIT) (No. 2019R1A2C4070280).

Porous and cellular materials

High-stiffness open cell auxetic foams: preparation, mechanical and dynamics performance.

abst. 2657
Virtual Room
Friday
September 4
17h00

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Auxetic (negative Poisson's ratio) open cell foams have always shown significant damping capacity and compliance to adapt to complex 3D shapes. Stiffness of those foams has always been one of its weakest features, with values ranging between 80 kPa - 700 kPa. We present here a new class of thermoformed auxetic open cell foam that show a negative Poisson's ratio behavior ($\nu = -0.7$) and a Young's modulus of 25 MPa. We describe in this work the manufacturing, testing (tension/compression/cyclic) and vibration transmissibility performance of these auxetic foam pads. We also propose a reduced order modelling/metamodelling approach to capture the relation between the microstructure poroelastic and manufacturing features of those foams and the mechanical/dynamic performance, and understand how to enhance the manufacturing and use of this novel class of auxetic foams.

Impact Analysis of Zero Poisson's Ratio Fish-Cells Metamaterial

abst. 2678
Virtual Room
Friday
September 4
17h15

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This paper is part of a series of articles featuring Fish-Cells zero Poisson's ratio (ZPR) metamaterial. The article aims to assert the superior crashworthiness performance of the zero Poisson's ratio Fish-Cells metamaterial compared to positive Poisson's ratio (honeycomb) and negative Poisson's ratio (re-entrant) sandwich panel structures. In this article, the impact performance of the Fish-Cells metamaterial has been studied experimentally using 3D printed PA2200 samples for two directions of impact loading with 5 m/s impactor velocity using a standard drop test setup. The results obtained from the experimental study were validated using dynamic explicit finite element modelling. Additionally, the impact performance of the Fish-Cells metamaterial has been compared to a honeycomb and re-entrant panels of identical bounding volumes for low speed (2 m/s) and high speed (5 m/s) impact velocities in three directions of impact loading using aluminium alloy as their material of construction. The parameters considered for the study include specific energy absorption, the impactor rebound characteristics and the energy transfer to the adjacent components.

Cylindrical Zero Poisson's Metamaterials

abst. 2682
Virtual Room
Friday
September 4
17h30

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The rapid development of advanced manufacturing technologies brings much attention to the fabrication of complex arbitrary structure at a microscopic scale such as Poisson's ratio metamaterials. Tuned Poisson's ratio metamaterials can exhibit positive, negative and even zero value. Zero Poisson's ratio metamaterial has no transverse displacement and unwanted double curvatures under in-plane longitudinal loading and out of plane bending. The unique characteristic leads to irreplaceable status for applications like morphing structures. The current study for Zero Poisson's ratio metamaterial mainly focused on the 2D planer; however, the cylindrical structure barely studied. In this paper, a mechanical study for cylindrical metamaterial exhibit Zero Poisson's ratio formed by Fish Cell is carried out. The method of generating the complex geometry in CAD is explained in detail. Experimental and numerical analysis are used to demonstrate the ZPR behavior of a homogenized cylindrical tessellation.

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abst. 2326
Repository

Advanced lightweight aluminium foam - cork hybrid structures

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The paper presents the findings of a pioneering study investigating the newly developed multifunctional hybrid structures based on cellular materials, which were developed and studied by combining an open-cell aluminium foam (man-made material) with cork (natural material). These hybrid structures were fabricated by impregnating the open-cell aluminium alloy with and without reinforcement of cork powders with graphene oxide. The mechanical, thermal, acoustic and fire retardancy properties of new hybrid structures were evaluated and compared to their individual cellular components (open-cell foam, cork and cork nanocomposite). Results show that the presence of the cork as the void filler of the open-cell aluminium foams significantly enhances the compressive performance of the resulting structures. Results also reveal that the novel hybrid structures developed in this work are multifunctional and thus exhibiting much better acoustic, thermal and mechanical properties than the individual cellular materials. Furthermore, the graphene oxide has also a strong positive effect in sound absorption applications.

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abst. 2329
Repository

Development and characterisation of aluminium foam – polymer hybrid structures

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The paper reports on the fabrication and characterisation of the newly developed multifunctional hybrid structures prepared by infiltrating an open-cell aluminium foam specimen with and without dense reinforced polymers (epoxy and silicone) using graphene oxide. The mechanical, thermal and acoustic performance of these hybrid structures was evaluated and compared to their individual components. Results demonstrate that the type of the polymer as a void filler of the open-cell foams and their curing temperature influence and change the mechanical performance and deformation behaviour, from a rubbery to brittle behaviour. This change is due to the low chain mobility of the polymer and effective adhesion between polymer and struts of the open-cell aluminium foam. Results also show that the non-flammability and the sound absorption coefficient of the hybrid structures were improved by the incorporation of the graphene oxide within the polymer matrix.

Graphene enhanced hollow microlattice materials and their mechanical properties

abst. 2567
Repository

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Benefiting from their ultra-light and ultra-stiff characteristics, hollow microlattice materials have great application prospects in energy absorption and vibration reduction. However, there are still very large room remained for improvement regarding to their modulus and strength. In order to furtherly improve their mechanical properties, nanocomposite electroless coating process was developed to embed the graphene material into nickel-phosphorous hollow microlattice materials. The effects of the graphene were analyzed based on the nanoindentation test results of the graphene-enhanced Ni-P coating and the in-situ compression test results of the Ni-P-G hollow microlattice materials. The nanoindentation test results manifested that the Young's modulus of the Ni-P coating was increased by 9.4% by incorporating 40 mg/L of graphene into the Ni-P electroless plating solution, and that of the nanohardness was increased by 39%. The compressive test results showed that the elastic modulus and yield strength of the full-size hollow microlattice materials were increased by 72.3% and 64.1% respectively under the similar density. The improvement of the mechanical properties of the hollow microlattice materials by the same amount of graphene is much higher than that of its Ni-P base materials.

Mechanics of Densification in Syntactic Foams under Compression

abst. 2636
Repository

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The goal of this paper is to elucidate the densification mechanics of syntactic foams under compressive loading. Syntactic foams are closed cell composite foams with hollow microparticles dispersed in a matrix resin whose closed cell structure provides excellent mechanical properties, like high strength and low density. Few widely known applications of syntactic foams are in components for boat decks, ribs, hulls and floatation modules for offshore structures. In addition, they are also used in deep sea applications like remote operated vehicles, submarines and underwater pipelines. Few potential applications of syntactic foams is as core structures in sandwich composites that could be in building facades, bridge decks, and other civil infrastructure. For designing syntactic foams with preferred overall energy absorption, it is critical that the densification mechanics is well understood. There are several parameters that can influence the mechanical properties including densification stress of syntactic foams under compression, such as, microparticle volume fraction, microparticle wall thickness, strength of the microparticles, bonding between the microparticle and the matrix, to name a few. The influence of these key parameters needs to be elucidated in detail for designing syntactic foams with better energy absorption capacity. Performing a fully experimental parametric study is very time consuming and expensive, especially when these parameters are considered independently while maintaining other parameters fixed. To that end, computational models can be used for isolating the impact of a single parameter such that its influence can be elucidated in detail. Therefore, in the current paper, micromechanical computational models are developed to elucidate the densification mechanics of GMB/HDPE syntactic foams under compressive loading while considering the key parameters mentioned above. Higher densification stresses are favorable properties under foam compression or crushing. In this paper, key parameters that significantly impact the densification stresses are identified, specifically, high densification stresses to weight ratio are evaluated which is suitable for wide variety of weight saving applications.

Bending work of laminated materials based on densified wood and reinforcing components

abst. 2706
Repository

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This work deals with the analysis of the influence of the composition of laminated material based on solid and densified beech wood and the application of a reinforcing element in the form of high-strength fibers on the values of elastic, plastic and total bending work and its ratios. These characteristics are important in determining the appropriate use of these materials in structural systems with respect to the deformation energy in the elastic and plastic stress regions and it ratios. From the point of view of the composition of the tested materials, was observed factors such as the input thickness of beech lamellas (5 and 9 mm), the degree of densification of lamellas (references, 10%, 20%, 30% and 40%) and the application of high-strength fibers (carbon and glass) were distinguished. Two approaches can be used to determine plastic work in bending, namely by quantifying more accurate total plastic work and approximated plastic work. However, the approximated plastic work works with an approximation error. One of the outputs of this work will be to determine the error of approximation for different material composition of layered materials, which will result in a modification of the calculations of the approximated work for materials with a specific composition.

Smart Composites

Mechanical and electrical behaviour of conductive 3D printed thermoplastic composites

abst. 2389
Virtual Room
Wednesday
September 2
08h45

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Additive manufacturing (AM) techniques represent a real challenge to manufacture novel composites with coupled multifunctional properties. This work focuses on the mechanical and electrical behaviors of novel 3D printed polymeric composites of polylactic acid (PLA) filled with conductive particles. The incorporation of conductive particles within the polymer matrix allows for programmable conduction paths via the printing process, whose electric properties are intimately coupled to thermo-mechanical processes. In this work, samples were prepared using a fused deposition modelling (FDM) printer, controlling the filament orientation to manufacture three different types: longitudinal (0°); transverse (90°); ±45° printing orientations. These printing conditions strongly influence the microstructure and, consequently, lead to strong anisotropy by means of both mechanical and electrical behaviors. These samples are characterized to elucidate the influence of printing parameters on the mechanical, electrical and thermal coupled behavior. To this end, four types of studies have been made: (I) from a mechanical point of view, stress-strain tensile tests were performed on standard PLA 4043D specimens and on the conductive 3D PLA composites; (II) from an electrical point of view, frequency response analysis (FRA) were conducted to characterize each type of conductive PLA between 0.3Hz and 20MHz; (III) from a thermal point of view, samples were heated and cooled inside an oven to study the effect of temperature on their DC resistance; (IV) finally, combined mechano-electrical analyses were performed to aquire stress-strain tensile curves while measuring and the evolution of electrical properties(mechanical deformation versus electrical resistivity). The results from this study show a strong dependence of printing parameters on the mechanical and electrical properties of 3D printed conductive-PLA and identify strong discontinuities when the glass transition temperature of the material is reached. Results from heating-cooling of samples show relevant hysteresis loops. The results of this work will contribute to the AM progress in functional electro-mechanical components with potential applications in the soft robotic industry.

Constitutive and FE modelling of magneto-active polymeric composites

abst. 2388
Virtual Room
Wednesday
September 2
08h30

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Soft composites that respond to external stimuli represent novel solutions for structural applications such as soft robots, sensor-actuator systems or biomedical devices. Among these materials, polymeric composites filled with magnetic particles (MAPs) have gained strong interest within the scientific community. In this regard, hard-magnetic polymeric composites have recently been proposed as novel materials that allow for shape-programmability by the addition of magnetically-hard particles within a polymeric matrix. New avenues in the development of applications based on these composites need of constitutive and computational frameworks able to describe the magneto-mechanics of hard-magnetic MAPs. This work aims at developing a constitutive and finite element (FE) framework to model the magneto-mechanical behaviour of hard-magnetic soft composites. Hence, a continuum model is proposed within a thermodynamically consistent framework formulated for finite deformations. The model accounts for viscous contributions to describe relaxation and dissipation effects in the deformation process of MAPs when subjected to external magnetic fields and/or mechanical loading. The theory is illustrated by implementing the model within an implicit static FE framework and three numerical examples are provided to explore potential applications as well as to evaluate the influence of the external magnetic field application on the viscoelastic response of the material. Finally, the framework

is implemented in an implicit dynamic FE framework to evaluate the role of inertial terms on the dynamic response of hard-magnetic MAPs.

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abst. 2422
Repository

Scalable and Integrated Strain Sensing CNT Enabled Aerospace Composite Materials and Structures

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Carbon nanotubes (CNTs) are inherently multifunctional, conductive and possess piezo-resistive characteristics. They are able to enhance various characteristics of everyday materials and even widen the spectrum of tasks these materials can be used for. Aiming at the multi-functionality of materials, nanocomposites made of thermoset epoxy resin with embedded CNTs are a promising solution for strain self-sensing applications which can provide highly integrated, high performance structures such as those in aerospace sector, i.e the structural integrity is not compromised as a result of enabling sensing capability. A composite structure with an embedded network of conductive CNTs sees its electrical conductivity vary as it is strained during varying operating loaded service (e.g. flight). A critical parameter to achieve repeatable and reliable measure is the CNT dispersion state in the polymer. Nanocomposites made of CNTs dispersed in aerospace grade epoxy resin were fabricated using straightforward stir-mixing, functionalisation and autoclave processing. The CNTs were produced using chemical vapour deposition process. To investigate the resistance-based strain sensing abilities of such material a testing apparatus was set-up and real-time measurement of strain and resistance were recorded. Gauge factors were calculated when loading in the elastic region. Load vs. Strain curves for reference cured epoxy (i.e. without CNTs) were compared to those of the nanocomposites, and the mechanical properties were investigated. Raman spectroscopy characterisation of the CNT samples, as well as SEM imaging were performed to investigate the dispersion and the quality of the CNTs molecular structure so as to correlate with the sensitivity of them in a mixture with epoxy. The feasibility of the nanocomposite as well as the effect of uncertainties associated with the embedded dispersion/distribution CNTs on the strain sensing were then elaborated as an attempt to demonstrate its usefulness for scalability to relatively larger structures.

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abst. 2637
Virtual Room
Wednesday
September 2
09h00

Piezoresistivity and Gauge Factors of Nanocomposite Strain Sensors Manufactured from Industrial Carbon Nanotube Masterbatches

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Carbon nanotubes are carbon-based nanoparticles which have been under research and industrial focus in recent years as additives for polymer matrix composites, exhibiting unique qualities such as high thermal and electrical conductivity, chemical and thermal stability and relatively high mechanical properties. When combined with polymer matrixes, a wide range of potential applications has been

identified such as gas detectors, semiconducting materials, aerospace materials and structures and various other sensor technologies. One particular field which has become relatively popular is that of nanocomposite self-diagnostic materials used for the purpose of structural health monitoring. When added to electrically non-conductive matrices, such as thermoplastic and thermoset polymers, carbon nanotubes are able to impart electrical conductivity to the final nanocomposite. Such nanocomposites conduct electricity through the percolation network which is formed during their mixing; a physical system of nanoparticles which are in contact with each other as well as near enough to allow electric current to pass between the nanoparticles through the matrix material. Such electric conductivity is dependent solely on the quality of formation of the network in non-conductive polymer matrices and thus, may change during physical deformation. This quality, known as piezoresistivity, is caused by three main factors: (1) the physical deformation of the percolation network resulting in a change in how many particles are in physical contact (2) deformation of the particles within the network resulting in particle conductivity change and (3) a change in how much current is transferred between particles through the tunneling mechanism. Masterbatches are concentrates of nanoparticles embedded or pre-mixed in a selected matrix. Since the particles are embedded in a matrix, the particles have a much lower chance of becoming airborne and dispersing in the immediate atmosphere of the handler. These concentrates can be diluted to the required final concentration using a variety of methods without high exposure for the operator or immediate environment. Masterbatches allow the implementation of such materials in existing production routes without the need for high levels of safety modification or financial input, in contrast with the handling of nano-materials in powder form. Very few published articles deal with the manufacturing of epoxy matrix piezoresistive nanocomposites from masterbatches, and even fewer have focused on the comparison of masterbatches which use different types of carbon nanotubes. In this study, three types of epoxy matrix masterbatches have been used to manufacture piezoresistive nanocomposites; two containing multi-wall carbon nanotubes (MWCNT) and one containing single-wall carbon nanotubes (SWCNT). The weight percentages of interest were 0.5, 1.0, and 2.0 % wt. Masterbatches were diluted in EPOLAM 2031 epoxy using a combination of mechanical mixing and ultrasonication. Tensile samples were cast post-processing using silicon molds according to ISO 527. Electrical resistivity testing was conducted using the Keithley DMM 6500 on representative cubic samples using silver-based glue to reduce contact resistance and showed very low resistivity for SWCNT nanocomposites (2 Ohm•cm at 2% wt.). Piezoresistivity was studied through simultaneous tensile and electrical testing. The observed gauge factor values ranged from 2 for SWCNT containing nanocomposites to 7 for MWCNT containing nanocomposites. The piezoresistive sensitivity was seen to be correlated with the resistivity of the CNT-based composites and this dependency was approximated with linear regression in semi-logarithmic coordinates GF=A*log(R0)+B. The slope A and constant B were seen to be similar to values calculated from literature.

Long Period Grating Fiber Sensor For Detection Of Impurities Infesting Smart Polymer Composites

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For aerospace, aeronautics, defence, chemistry and medical applications there is a permanent need of polymer composite or nanocomposite materials with improved characteristics. From this point of view detection of polymer composite materials infestation with impurities such as water molecules, hydroxyl radical and various metallic ions is important. Such infestation with impurities can take place during fabrication and/or exploitation of polymer composite materials. For an improved quality of

polymer composite or nanocomposite materials a method for impurities detection during fabrication and/or exploitation appears as necessary. Sensors which can be used for such measurements have to have a dual application ranges: as chemical and as mechanical sensors. Also, such sensors should have a small volume, a reduced weight and to be immune at electromagnetic fields interference. Sensors having most of these characteristics are of the optical type, more precisely are of the Long Period Grating Fibre Sensors (LPGFS) type. LPGFS can be used for chemical detection or mechanical perturbations measurement. In this way the polymer composite or nanocomposite materials become of the smart kind, the LPGFS being used as the feedback loop. The paper aims to present an analysis of LPGFS embedded in polymer matrix of smart composite or nanocomposite materials used for impurities detection. The investigated LPGFS are mounted in simple and interferometric setups in order to improve sensitivity. An important feature of LPGFS is that their cladding surface is in direct contact with the ambient medium which in this case is the polymer matrix. Any alteration of polymer matrix refractive index induced by impurity infestation cause spectral shifting and bandwidth broadening of the characteristic absorption bands of the optic fibre transmission spectrum. There are investigated the cases of polymer matrix having a refractive index lower or larger than that of the cladding. In the case of LPGFS mounted in interferometric setups there is investigated the Self Interference Long Period Grating (SILPG) case and the hyperfine structure formation and characteristics and how it is modified by impurity infestation.

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abst. 2037
Repository

Smart Composite Using Fiber Optic Sensors For Fluid Flow Characterization And Temperature Measurement

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Smart polymer composite materials have numerous applications in aircraft construction, in manufacturing pipes used in chemical industry, in agriculture and in medical devices. In all these kinds of applications the fluid, gas or liquid, flow is a main issue. As a detailed example, in aircraft construction there is an important interest in detecting if air flow over the wing surface is laminar or turbid. This is important for a clean aircraft flight with as reduced as possible chemical and sound pollution of the environment. In order to explain the above conclusion, it is necessary to mention that a laminar air flow over the aircraft wing surface is equivalent to a reduced loss of energy during flight due to generation of sounds in air. The air flow is considered as laminar if the characteristic transverse pressure wave has low frequency, in the 100 – 300 Hz range, and low amplitude of up to 1Pa. The air flow is considered turbid if the characteristic transverse pressure wave has higher frequency, of minimum 1kHz range, and higher amplitude of at least 10Pa. Detection of air flow character is important because if it is turbid the air is detached from wing surface meaning higher fuel consumption for compensating the aircraft flight sustainability loss. For an aircraft flight there is a strong need for laminar air flow optimization in the sense that over the aircraft surface, especially of its wings, the air flow should be as much laminar as possible. The situation of various fluids flow through pipes is similar in many aspects. An optimization of fluid flow for keeping it as much laminar as possible, especially at the pipes curved parts, is desirable. The main task of the paper is to present results obtained in simulation/design of four optic fiber sensors types, namely Fiber Bragg Grating (FBG), Long Period Grating Fiber Sensor, Distributed Feed-Back Fiber Laser (DFB-FL) and Distributed Bragg Reflector Fiber Laser (DBR-FL) embedded using various techniques at small depths in polymer composite or nanocomposite materials used for aircraft wing and fuselage construction on one side and for pipes manufacture as sensors for detection of fluid flow character. The first two optic fiber sensors are of passive type and the other two are of active type i.e.

being doped with Erbium or Ytterbium/Erbium active ions andgenerating laser effect at wavelengths around 1550 nm.

Computational study on the effects of perforation distribution in the graphene paper interface and the out-of-plane properties of high-performance composite

abst. 2543
Virtual Room
Wednesday
September 2
09h15

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High-performance hybrid composites, mainly graphene-based, are attractive to realize smart multifunctional structures. Resin infusion technique can be employed to fabricate such structures based on the hybrid composite composed of multilayer continuous graphene nanoplatelets (GNP) paper and polymer composite reinforced fabrics. GNPs paper demonstrates higher in-plane mechanical, electrical, and electromagnetic interface (EMI) shielding properties. However, if GNP paper is embedded in the fiber reinforced composite, it decreases the out-of-plane fracture toughness of the laminate with higher proportion due to the higher fluid barrier properties of the GNP paper preventing through-thickness resin infusion. In this work, a comprehensive numerical study is carried out to explore different possibilities which can be adopted to enhance the out-of-plane fracture toughness of the high-performance composite structures. We propose the lamination of the perforated GNP paper which consists of large number of tiny holes in different arrays configuration depending on the desired fracture toughness. Cohesive layers are defined in the GNP paper corresponding to the wetted and dry interfaces. Parametric studies will be performed to analyze the effect of ratio of fracture toughness of hole-region interface to the rest of material regions. Comparing the traction separation response obtained through the simulations for each configuration, the optimum configuration is highlighted.

Numerical analysis of micro-damage initiation and healing in composite materials

abst. 2132
Virtual Room
Wednesday
September 2
09h30

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This work presents a continuum damage healing mechanics (CDHM) based linear elastic constitutive model for modelling micro-damage initiation and healing phenomena in composite materials with self-healing capability. (Barbero et al., 2005) proposed the CDHM constitutive model for self-healing composite materials, where the healing agent is embedded in the matrix material in form of microcapsules (extrinsic self-healing) and the healing process is triggered by the rupture of a microcapsule. This model uses material with intrinsic self-healing capabilities triggered by heat. Mechanisms such as viscoelasticity and (visco-)plasticity are not considered in this research. Scalar damage and healing evolution laws are taken from (Darabi et al., 2012) while their parameters are adjusted to represent the behaviour of the material used as a matrix. Damage evolution law used in the research is strain rate-dependent and accounts for damage nucleation both during the loading and unloading. CDHM nominal, healing and effective configurations are used. Stress, strain and tangent stiffness tensors in different CDHM configurations are related by means of the strain equivalence hypothesis, what significantly streamlines the numerical implementation of the constitutive model. Thereby, it is important to

mention that damage initiation and healing is considered for the matrix material only, whilst no damage is modelled in reinforcing fibres. In this initial phase of the research, an advanced ethylene/methacrylic acid (E/MAA) copolymer, DuPont™ Surlyn® 8940 thermoplastic resin, is used as a self-healing matrix material along with unidirectional carbon fibres as reinforcement. The healing ability of ethylene/methacrylic acid (E/MAA) copolymer has already been demonstrated for healing of delamination cracks. In this approach, the E/MAA copolymer is located between the carbon fibre/epoxy composite layers, (Pingkarawat et al., 2012). Firstly, the model is developed and validated in Matlab and then implemented into Abaqus user subroutines UMAT and VUMAT. Simple static test cases as well as loading/unloading tests are applied in the validation of the proposed model. The research is carried out in the framework of the ACCESS project (AdvanCed CompositE Selfhealing Simulation), funded by the Croatian Science Foundation (HRZZ). References: Barbero, E.J., Greco, F., Lonetti, P., 2005. Continuum Damage-healing Mechanics with Application to Self-healing Composites. Int. J. Damage Mech. 14, 51–81. https://doi.org/10.1177/1056789505045928. Darabi, M.K., Abu Al-Rub, R.K., Little, D.N., 2012. A continuum damage mechanics framework for modeling micro-damage healing. Int. J. Solids Struct. 49, 492–513. https://doi.org/10.1016/j.ijsolstr.2011.10.017. Pingkarawat, K., Wang, C.H., Varley, R.J., Mouritz, A.P., 2012. Self-healing of delamination cracks in mendable epoxy matrix laminates using poly[ethylene-co-(methacrylic acid)] thermoplastic. Compos. Part Appl. Sci. Manuf. 43, 1301–1307. https://doi.org/10.1016/j.compositesa.2012.03.010

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abst. 2481
Repository

FEM STRESS ANALYSIS OF A WIND TURBINE BLADE MADE OF A SMART COMPOSITE MATERIAL USING DIFFRACTION GRATING OPTIC FIBER SENSORS

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Smart polymer composite materials have increasingly numerous applications in construction of wind turbines which are a popular source of renewable energy. The turbine blades are critical components of wind turbines. The air flow over the blade surface is an important issue in wind turbine efficient operation in converting wind energy to electric power. When generating electric power through rotation, turbine blades must withstand gravitational, centrifugal loads and wind loads. In order to convert as optimal as possible wind energy to electric power, the air flow over the blade surface must be laminar as much as possible. Turbid air flow means noise and loss of energy. In order to have laminar air flow over a larger as possible zone of its surface, wind turbine blade must have a proper attack angle into the air flow. For accomplishing this optimization status, a possibility consists in transforming the composite material into a smart one by embedding inside its matrix near its surface an array of grating fiber optic sensors which are operated as pressure detectors. The signals generated by these sensors are used as inputs to a reaction loop connected to a computer optimizing the blade attack angle rotating the blade on its axis. The whole system including the optic fiber analysis is performed using Finite Elements Method (FEM). The analysis is performed on a composite wind turbine blade made as a sandwich structure of a mixture of carbon-epoxy, glass-vinyl-ester and PVC foam which is the core sandwiched between carbon-epoxy and glass vinyl ester layers. The analysis is performed for six different types of NACA and DU airfoils used for wind turbine blade geometry. The analysis is performed in two stages: 1 - a stress analysis of the blade is performed in which it is subjected to a combination of gravitational and centrifugal loads for calculation of tip displacement, maximum stress values, and through-thickness stress distribution at several particular points on the blade; 2 - based on results obtained in the first stage there are calculated the specific responses of grating optic fiber sensor array at the investigated

points on the blade. The optical sensor is made of a single mode (SM) into which at predefined points, on lengths previously evaluated, there are induced short period gratings (Fiber Bragg Grating - FBG) or long period gratings (Long Period Grating - LPG).

FEM OPTIMIZATION OF A SMART COMPOSITE MATERIAL MICROPHONE USING A GRATING FIBER OPTIC SENSORS.

abst. 2482
Repository

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The main scope of the paper consists of presenting the results obtained using Finite Elements Method (FEM) simulations performed for optimization of a smart polymer composite material as microphone sensing element. The composite material was transformed into a smart one by embedding a grating optic fiber sensor into its polymer matrix. The short period diffraction grating (Fiber Bragg Grating - FBG) and the long period grating (LPG) versions of the optic fiber sensor were analyzed. Both grating versions were induced into a single mode (SM) optic fiber by various methods which are briefly commented. The microphone sensing element consist in three layers with different relative orientation 3-5 mm length and 2-3 mm width or a 3-5 mm diameter plate with the grating optic fiber embedded into a central position of the plate. The polymer matrix of the investigated composite material was composed of PVC or PDMS polymer. The first stage of the simulations process represents a frequency response analysis of the composite plate under bending and twisting loads under forced vibration. The frequency response of the plate was performed in terms of impedance and transverse velocity calculated at different points on the plate. During the second stage of the simulations process the response of the grating optic fiber sensor was calculated for transverse mechanical loads. There were analyzed the operational limits imposed by de-lamination or the separation of layers as a common failure mode in laminated composite materials. During simulations, the de-lamination process was considered as induced by various factors, including loading, defects in the material, and environmental conditions which can trigger the initiation and propagation of layer separation. The delamination was assumed to occur in a circular region with 0.5 up to 1 mm diameter between the first and second and between the second and third layers of the laminate and modeled using the layer-wise theory.

Energy harvesting performance of cement composites with embedded piezoelectric elements

abst. 2166
Repository

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The energy harvesting performance of cement composites with embedded piezoelectric elements was evaluated. To understand the basic performance of piezoelectric elements, an experiment was carried out to evaluate the electric power generated by converting kinetic energy into electric energy. The optimal energy harvesting system was identified using simulations, based on the results of the basic performance evaluation. The variables included in the simulation were the embedding depth of the piezoelectric element applied to cement composites, installation gap, connection method, and upper load strength. The results of this experiment confirmed that the actual energy harvesting performance of cement composites with piezoelectric elements agreed well with the expected performance.

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abst. 2167
Repository

Development of heat blocking cementitious composites to reduce the urban heat island effect

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In this study, a heat blocking cementitious composite was developed. The composite, which was made by replacing cement with blast furnace slag and fly ash, was evaluated in terms of thermal conductivity and surface temperature. To simulate the summer environment, a 120-W halogen lamp, which emitted heat and ultraviolet rays, was installed in the chamber. The heat island reduction effect was evaluated by calculating the Solar Reflectance Index (SRI) from the surface temperature. The heat blocking effect of the cementitious composite was compared to that obtained by applying thermal insulation paint or spraying water onto specimens. The test results show that the proposed cementitious composite achieved lower maximum temperatures and higher SRI values than conventional material specimens.

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abst. 2319
Repository

Relationship between the rheology and fluidity of structural synthetic fibre-reinforced self-compacting cementitious composites

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Yield stress and plastic viscosity are characteristic features of the rheological features of cementitious composites. In this study, slump flow, J-ring, and V-funnel tests were used to characterise the fluidity of structural synthetic fibre-reinforced self-compacting cementitious composites. Slump flow and the J-ring test result were high correlated with the yield stress, while the V-funnel test result was highly correlated with the plastic viscosity. In the case of plastic viscosity, a higher viscosity results in a slower flow rate. Acknowledgements This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (NRF-2018R1A2B2002207).

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abst. 2622
Virtual Room
Wednesday
September 2
08h15

An analytical three-dimensional piezoelectricity solution for arbitrarily supported cylindrical shell using the extended Kantorovich method

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Analytical solution for cylindrical bending of a thick shell structure using full constitutive and 3D equations of motion has been researched since long. This solution is required for accurate determination of through-the-thickness displacement variations and stress concentration zones across the layers of thick laminated shell structure incorporating piezoelectricity layers. Further, coupled piezoelasticity constitutive model for the electro-mechanical analysis of such laminates adds to the complexity of the governing equation and its numerical solution. Here, an analytical solution is developed using the powerful extended Kantorovich method (EKM). The EKM comprises of an iterative scheme to determine the separable univariate functions. The univariate functions say f & g are used to approximate a bivariate function as f*g. In addition, the governing equations are derived using the Reissner-type mixed variational principle considering displacements, stresses and the electric field variables as the primary variables. As a result, the boundary conditions are exactly satisfied at each and every point in the domain. In the solution, a system of 8 first-order ordinary differential equations (ODE)s each for the circumferential and the radial coordinate direction are generated iteratively. However, the system of ODEs along the radial component consists of variable coefficients which has been solved using a modified power series technique. The other system of ODEs along the circumferential coordinate consists of constant coefficients which is solved using the Frobenious method. Advantageously, only

two terms in the EKM expansion and few iteration steps could predict the electromechanical responses which is accurate and computationally powerful.

Piezoelectric Energy Harvesting Based on Tri-stable Hybrid Composite Laminate

abst. 2653
Repository

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To lower the excitation need of the harvester, a piezoelectric energy harvester with a clamped-clamped boundary condition is proposed in this work. This harvester consists of a tri-stable hybrid symmetric laminate and PZT transducers. With layers of carbon fiber, aluminum slices, and PZTs, the harvester is designed to have two stable configurations with identical and opposite-signs curvatures. When two sides of this piezoelectric laminate are clamped, it will have three stable configurations. The frequency-sweeps in two directions are carried out for this clamped-clamped piezoelectric energy harvester under the harmonic excitation with different accelerations. Compared with previous designs, this harvester exhibits cross-well oscillation mode under this relatively lower excitation level at a wider frequency range. The results show that the response is different when the initial configuration is changed, and the required excitation level for cross-well oscillation is also varied. The maximum power is 3.2mW when the harvester is under cross-well oscillation mode.

Numerical analysis of shape memory polymer based composite structures

abst. 2402
Repository

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Fiber reinforced shape memory polymer composites have better strength and stiffness compared to pure shape memory polymers without significantly compromising its shape memory properties. Hence, they can be considered as candidate materials for morphing applications in aerospace structures. In this study, a numerical framework is developed to analyze the shape memory behavior of shape memory polymer composite (SMPC) structures. This is based on the modified temperature dependent laminate theory, which is used to predict the thermally induced shape memory response and effective elastic properties of the composite. The model was used to simulate the thermo-mechanical response of various SMPC laminate and sandwich structure under different thermal and mechanical loading conditions. The findings reveal that fiber volume fraction and ply orientation influence the shape storage and shape recovery. The shape recovery is high compared to many pure SMPs due to the presence of fibers. Finally, application of this model to simulate and investigate the deformation characteristics of a SMPC based corrugated structure is presented in detail.

Optimization of shape memory polymer composite based corrugated structure

abst. 2403
Repository

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In this work a corrugated design using shape memory polymer composite has been analyzed for application in aircraft wing trailing edge. Shape memory polymers and their composites are a group of smart materials that have the ability to undergo large deformation and stay in that state in the absence of any load under favorable conditions. This makes them excellent candidates for aerospace applications. Corrugation design, owing to their geometry, have low mass, anisotropy and tailorable features compared to conventional systems used in aircrafts. For structural analysis, the behavior of

a corrugated shape memory polymer structure has been homogenized using an equivalent flat plate model. Corrugation parameters like thickness, number of corrugations, composite lay up affect the behaviour of the homogeneous plate such that it is more compliant along desired direction as compared to other directions. This behaviour is suitable for use in aircraft wing tail flap. To realize an optimum shape, ideal values of different parameters need to be obtained based on typical aerodynamic load and mission requirements. For this, optimization of the shape memory polymer based corrugated design was carried out using the genetic algorithm method. The methodology and results have been presented and discussed in detail.

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abst. 2539
Repository

Tuning the performance of the magnetoelectric energy harvester based on cylindrical composites

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Cylindrical composites have very promising applications in ME energy harvesting due to strong magnetoelectric (ME) coupling via improved interfacial and boundary conditions. However, the random distributions of frequency components of applied magnetic fields always make it difficult to induce resonant ME coupling in the harvester. In this paper, a theoretical model for ME energy harvesters using cylindrical composites is proposed. The concrete form of the solution for mechanical variables is derived via combining the constitutive equations, governing equations, and boundary conditions. Then the corresponding electrical variables including output voltage is obtained using Gauss law for piezoelectric layer. In addition, the field-dependent material constants are analytically expressed using nonlinear multi-field coupled constitutive equations of magnetostrictive materials. Based on the model, three available methods for regulation of ME performance of cylindrical composites are proposed. The results show that boundary conditions affect not only the output voltage but also the resonance frequency. The maximum output voltage appears under the clamped-clamped boundary condition while the minimum resonance frequency occurs with the free-free boundary condition. The ME effect will be dramatically enhanced and the resonance frequency can be adjusted when the stress boundary conditions are introduced. Furthermore, the geometric dimension, especially the radius of interface denoted by diameter b, can be an adjustable parameter for obtaining an appropriate response frequency, since the resonance frequency is changed linearly with altering b. Eventually, the combined magnetic and stress loadings lead to nonlinear characteristics of ME coupling. On the one hand, ME voltage is increased significantly by applying a proper bias magnetic field. On the other hand, the optimal magnetic field is related to the applying pre-stress. It should be noted that the applied fields could alter the resonance frequency by changing material constants (such as elasticity modulus) of the components. This enables the active control of ME performance of the cylindrical composites via external stimuli. Given the significance of these observations, the theory proposed may provide some significant guidance for designing high-performance ME energy harvesters.

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abst. 2270
Virtual Room
Wednesday
September 2
08h00

Impact responses of carbon fiber reinforced polymer-based shear thickening fluid hybrid composite plate

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A shear thickening fluid (STF) with the unique rheological characteristics is one of the non-Newtonian fluids. It shows the shear thickening phenomenon which can be clearly observed at the specific shear rate. This phenomenon can alter the structural behaviors including the impact characteristics when the STF is applied to structures. Our study proposes an STF hybrid composite (STFHC) structure to change its impact characteristics. The STF is fabricated using the nano-silica particles and

polyethylene glycol (PEG), and its rheological characteristics (i.e., viscosity vs shear rate) are subsequently investigated using a rheometer. Then, the CFRP based STFHC plates are fabricated by injecting the STF into the tubes embedded in the CFRP laminate. The low-velocity impact tests for the STFHC plates are performed, and their impact responses for impact energy are investigated. Acknowledgment. This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (NO. 2019R1A2C4070280).

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