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Book of Abstracts

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Welcome Address

The abstracts collected in this book represent the proceedings of the conference ICCS24 (24th International Conference on Composite Structures) , 14-16 June 2021. This book aims to help you to follow this Event in a timely and organized manner. Papers are selected by the organizing committee to be presented in virtual/phisical format. Such arrangement is due to the effects of the coronavirus COVID-19 pandemic. The event, held at FEUP-Faculty of Engineering, University of Porto (Portugal), follows the success of the first twenty-three 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.

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Abstracts

Additive Manufacturing

Influence of Process Parameters in Fused Deposition Modeling for Fabrication of Continuous fiber reinforced PLA composites

abst. 2073
Repository

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We investigate the influence of raster orientation during 3D printing of PLA matrix, reinforced with continuous fluorocarbon fibers, on tensile and flexural strength of the composite, in comparison to pure PLA with same raster orientation. Two different raster orientations, [0, 90] and [45, 135] directions in relation to the longitudinal axis of the sample, were studied. We used Fused Deposition Modeling (FDM) technology for fabrication of PLA matrix. Hand-layup was used to position the fluorocarbon fibers in predesigned channels within the printed sample. Tensile testing and three-point bending tests were used to determine tensile and flexural composite properties. Numerical simulations of composite samples during tensile and three-point bending tests were also realised, aiming to evaluate numerical models for fast characterisation of continuous fiber-reinforced composites. Numerical analysis was done by using two approaches: Mori - Tanaka method and Finite Element (FE) method. Experimental results showed that samples with raster orientation of [45, 135] had the best strength (both tensile and flexural strength). Composite samples showed significantly better performance, especially in elastic region. Unreinforced PLA [0, 90] sample, exhibited significantly lower strength than other samples, especially flexural strength. Composite structures did not completely brake and fibers did not break or pull out, whereas unreinforced, pure PLA samples fully broke. For both reinforced and unreinforced samples, fracture propagated along the raster orientation lines. Both numerical FEM methods (homogenized Mori – Tanaka model and two-material model) showed similar results and good agreement with experimentally obtained curves. Accordingly, such numerical modeling and analysis can be efficiently used for characterisation of continuous fiber reinforced composites, in low strain range. Experimental results showed that this method of composite fabrication can be used, as low-cost solution, but it needs further investigations, from aspects of fiber adhesion. Printing parameters with the hand-layup processing of composite, would benefit from further studies related to automatic software calibration that could adjust position of subsequent layers, after stopping and resuming the printing process.

Evaluating the recycling potential of additively manufactured carbon fiber reinforced PA 6

abst. 2082
Room 1
Wednesday
June 16
14h00

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3D printing is an efficient manufacturing technique for individual products or small lot sizes and can be a key to advanced light-weight material processing. With short carbon fiber reinforced PA 6 high quality 3D printed parts are achievable with superior quasi-static and dynamic mechanical properties. Theoretically, the 3D printing process itself is known for minimal waste and/or scrap. In an industrial or lab-scale environment however, waste is generated while starting up the printing process, due to poorly printed or warped parts, after using the printed part as functional prototype or as support structures which are removed from the final part. To address this issue, this study aims to identify the recycling potential of carbon fiber reinforced PA 6. In a first step, mechanical properties of specimens made from virgin PA 6/CF are determined. Then, specimens are recycled by grinding, drying and re-extruding into filament on a lab scale processing unit. With this recycled filament, further specimens are printed and mechanically characterized. Material properties of 3D-printed specimens, manufactured from virgin PA 6 / CF, serve as reference to evaluate the applicability of the recycling process. The aforementioned recycling and characterization steps are repeated several times to compare the properties over the number of the recycling cycles. Additionally, to transfer the findings to an industrial application, the so called "purge lines" and the support structures of printed parts are separated, grounded, re- extruded, re-printed and also characterized to evaluate the full potential of the recycling process.

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abst. 2107
Room 1
Wednesday
June 16
16h00

Statistical-based optimization of mechanical performance in FFF-printed unreinforced and short-carbon-fiber-reinforced PEEK

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The demand for lightweight and strong structures has been increasing over the last few years, as a preferred solution to decrease structural weight of transportation systems. Additive manufacturing (AM) techniques, such as Fused Filament Fabrication (FFF) of high-performance thermoplastics, achieves that goal by allowing the production of strong complex parts with optimized geometries. Although the feasibility of the FFF process to print unreinforced and short-carbon-fiber-reinforced poly-ether-ether-ketone (PEEK) has been demonstrated, a systematic parametric study addressing the fundamental influence of printing parameters on different mechanical loading conditions for these materials has not been still provided. Therefore, an extensive investigation of FFF printing parameters effect on the mechanical performance of unreinforced and 20% short-carbon-fiber reinforced PEEK (PEEK-CF20) was carried out by Box-Behnken design of experiments. The individual and combined effects of each main printing parameter - i.e., printing speed, printing temperature and layer height - on their tensile and bending strength, and impact resistance were evaluated by analysis of variance (ANOVA). As a result of this study, a set of optimized printing parameters was obtained for each material to produce strong parts with above-average mechanical properties in comparison to the literature. The obtained regression models proved to be reliable for both materials and display a major contribution of printing speed and layer height on the part mechanical performance under different load conditions. Furthermore, two-way interaction response surfaces were used to support the discussion of combined printing parameters effect on the mechanical properties, and strategies to reach the maximum part performance were drawn. Finally, microstructural analysis (optical and scanning electronic microscopy) revealed that a

proper selection of printing parameters can drastically reduce the amount and size of defects in the printed part, thereby, proving the importance of the proposed optimization procedure to reliably obtain the strongest printed parts.

Mechanical performance optimization and investigation of the effects of process parameters on the fused-filament fabrication of polyamide-6 reinforced by short carbon fibers

abst. 2115
Room 1
Wednesday
June 16
15h40

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The fused-filament fabrication (FFF) of short-fiber reinforced thermoplastics represents a relatively low-cost alternative to produce composite parts and structures, since it requires only a few adaptations with respect to the setup normally used for the FFF of unreinforced thermoplastics. If on one hand the incorporation of short (chopped) fibers into the thermoplastic matrix is difficult and normally leads to the presence of pores in the filament (which are carried over to the 3D-printed part as a consequence), on the other hand the mechanical resistance provided by the fibers offsets the weaknesses stemming from this residual porosity, providing important net gains in comparison to the unreinforced matrix. Moreover, there is a very large amount of possible matrix-reinforcement combinations, which therefore can be tailored according to a given application. This in particular represents several opportunities for the optimization of either material combinations or process parameters, which must be inevitably performed in order to reach the maximum performance of a given 3D-printed part on a specific scenario. In this context, the present work intends to provide a systematic optimization study for the FFF of polyamide-6 reinforced by 15 wt. % of short-carbon fibers. A 2k-full factorial Design of Experiments was deployed, whereby four process parameters were varied, namely layer height, printing speed, extrusion temperature and bed temperature, with the Ultimate Tensile Strength (UTS) as a response. The optimized set of parameters produced specimens reaching 117.1 $\pm$ 5.7 MPa, 13% superior to the available filament manufacturer data. Layer height exerted the highest influence over the UTS, while bed and extrusion temperature presented minor, but nevertheless also statistically-significant influences according to ANOVA. Mechanical testing results were correlated to the subsequent fracture surfaces, as well as to temperature profiles taking place during the process for each specific parameter set, whereby a few process-property-microstructure relationships could be established. Finally, the fracture morphology presented commonalities across all the evaluated parameter sets, especially pertaining to the matrix-reinforcement interactions. Those mostly resulted in fiber debonding, with fiber breakage (either without or following debonding) also occurring, although in a lesser extent and depending on the ply orientation.

Low velocity impact response of aluminum 2024-T3 / polyamide 6 / carbon-fiber-reinforced polyamide 6 hybrid joints produce by AddJoining

abst. 2133
Room 1
Wednesday
June 16
16h20

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AddJoining is a novel production technique combining the physics of materials joining and additive manufacturing (for both metals and polymer or composite). This technology is an unconventional approach to additively manufacture metal-polymer (composite) hybrid structures. The process feasibility

for different material combinations has been demonstrated for rolled and laser powder bed fusion-printed metals hybridized with unreinforced, short-, and continuous fibre-reinforced thermoplastic composites using fused filament fabrication (FFF) as the polymer 3D-printing tool. The authors have recently showed that high mechanical performance (lap shear and fatigue strength) Addjoints on aluminium 2024-T351/polyamide 6/continuous fiber reinforced polyamide 6 are feasible. This work evaluates the impact performance of these joints on the composite and aluminum surfaces of hybrid single-lap joints. The impact response was evaluated according to four important parameters: critical force and maximum force, energy parameters, and damage degree. The critical force showed an ascending trend with impact energy and the maximum force. From the energy parameters, it was difficult to distinguish the absorbed energies from impact events on both composite and aluminum surfaces. Delamination, impacted surface area, dent depth, and microstructural changes were studied to evaluate the impact response of hybrid single-lap joints. The existence of volumetric flaws (intrinsic to the adopted FFF process) within the composite part has caused delamination through the bulk of the 3D-printed composite part. Impact surface damage was barely visible at low impact energy of 2 J, but at high impact energy of 10 J the impact location was easier to identify. However, the permanent damage of the composite surface was extended in the fiber direction, which suggests that the fiber orientation controls its global deformation. The presence of local deformation on the impacted aluminum 2024-T3 surface is an indication of higher damage resistance than the impacted composite. Microstructural analysis suggested that the mismatch in material stiffness in the hybrid joints plays a major role in global deformation of the hybrid joint under impact loading. Post-impact mechanical testing was used to evaluate the residual lap shear strength, thereby allowing the assessment of the damage after the impact events. These tests indicate that mechanical response is sensitive to the material stiffness of the impacted surface. From the failure point of view, the interfacial-intralaminar failure mode resembled the one seen in quasi-static loading, but different morphologies were observed which are associated with high-strain rates caused by impact loading.

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abst. 2152
Repository

Screw-Extrusion based 3D Printing of Mechanically Strong and Electrical Conductive PLA/GNPs Composites

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Conductive polymer composites (CPCs) have been intensively used in many applications due to their attractive properties. The uprising demand for CPCs is also driving novel and versatile manufacturing scheme with shorter manufacturing cycle time and lower production cost, which is difficult to realize with conventional molding process. To bridge such gap, this study presents screw-extrusion based 3D printing of mechanically-reinforced and conductive polylactic acid (PLA) composites by incorporating graphene nanoplatlets (GNPs). To achieve uniform dispersion of GNPs in PLA matrix, the PLA/GNPs composite is prepared by compounding the composition in dimethylformamide (DMF) solution before vacuum dried to prepare uniform-sized pellets for 3D printing. The screw-extruded PLA/GNPs composite exhibit considerable improvement in mechanical properties as well as the electrical conductivities compared with the pure PLA. Microscopic characterization reveals the GNPs are uniformly dispersed within the PLA matrix until the concentration of GNPs exceeds 15%wt. By tailoring the composition of GNPs, the 3D printed PLA/GNPs composite thin film can achieve excellent electromagnetic absorption performance, with a reflection loss value less than -25 dB.

Experimental Analysis of Thermal Impact for 3D Printed Polymer Composites with Continuous Carbon Fibre Reinforcement Mechanical Characteristics

abst. 2165
Room 1
Wednesday
June 16
15h20

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Additive manufacturing most frequently used technology in complex configuration products production. Increasement of 3D printed composites usage for different applications requires higher and deeper analysis of materials characteristics. Composites with continuous carbon fibre reinforcement demand wider analysis not just in manufacturing processes, but also in possibilities to structures healing and improvement of the mechanical properties. In this article experimental evaluation of thermal impact for 3D printed composites with continuous carbon fibre reinforcement mechanical characteristics was presented. Presented results shows that this method could be used for composites mechanical properties improvement, just requires wider examination. One of the main challenges for printing reinforced continued carbon fibre structures using FDM (Fused Deposition Modelling) is the absence of proper technology and equipment. However, simplicity and accessibility of FDM technology as well as high level of modification allow printing the continued carbon fibre composites after some minor modifications made to the print head. In our case, industrial 'Me Creator 2' 3D printer was subject to modification, with its print head customized for printing of continued carbon fibre reinforced products. Toray's T300-1000 carbon fibre was used for the experiment. T300-1000 carbon fibre consists of 1000 filament fibre tows, 7μm of diameter each. Since the thermoplastics, polylactide (PLA) in this particular case, form the second part of the composite structure, it is important to analyse whether any process of heating (by using the carbon fibre as a conductor) may assist in filling the internal micro-pores generated during the technological process used in production. On the other hand, an important factor here is whether the process of heating may be used in general for improving the 3D printed composite characteristics. Since printing is made continuously and with continues carbon fibre reinforcement in the composite structure, it was decided to use the carbon fibre as electrical contacts at the beginning and the end of the printed sample. Later experiments were repeated with electrical contacts directly connected to the samples. For the temperature measurements in the samples, programmable direct current power supply Rigol DP831A and Flir T420 Thermal Imaging Camera were used. To verify the assumption, i.e. to verify whether and how the process of heating affects the mechanical characteristics of the printed samples, tensile tests were performed for heated and non-heated 3D printed samples. Universal testing machine Tinius Olsen H25KT was used for the tests. The tensile strength test results presented the positive impact of temperature to the composite samples. Batch of samples were taken for each part of the experiment. First of all, non-heated samples were tested and tensile strength average of 220 MPa was gotten. Second part of samples was heated until 70°C temperature and maintained for 1 minute. The tensile strength limit increased until 235 MPa. The third part of samples were heated approx. up to 125° C and kept for 1 minute, the tensile strength limit increased up to 248 MPa. The assessment of heating impact on mechanical properties suggests that such impact does exist, since in both cases the tensile strength has increased. After the initial measurements it could be stated that carbon fibre is a good conductor for electricity and may be used for reducing the number of the sample micro-pores as well as improvement of the strength properties of the composite. This field requires broader analysis; however, the initial results suggest that this method may be applied for improvement of 3D printed composites mechanical characteristics.

Characterization of fibre reinforced 3D printed polymer composites with varying fibre volume fractions

abst. 2273
Room 1
Wednesday
June 16
15h00

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Fused deposition modelling (FDM), one of the most popular additive manufacturing (AM) technique was used to investigate the elastic properties of 3D printed polyamide-based polymer composites structures. The aim of this work is to study the mechanical properties of continuous carbon fibre reinforced polyamide based polymer composite samples using tensile and flexural testing by varying the fibre volume contents with applying pressure, temperature and holding the samples for 1 hour in the platen press. The results show that the strength and stiffness increase with the increase in fibre volume content (fraction). Hot pressed samples exhibit the highest tensile strength and elastic modulus as a result of increasing the fibre volume fraction from 29 % to 34% without having a negative impact on compression strength. Synergetic effect of both short and continuous carbon fibre was also studied; it was observed that the tensile properties were higher for composite samples reinforced with both short and continuous fibre than those with only continuous fibre reinforcements. Characterization of the 3D printed polymer composites were carried out using scanning electron microscope (SEM). Following SEM analysis on the tested specimens it was observed that there is a strong correlation between the mechanical properties and the microstructure. Fibre volume fraction was determined by acid digestion method using ASTM D3171 to determine the amount of fibre content after hot pressing. From X-ray computed tomography it was confirmed that hot pressing reduces the void content which in return increases the strength and modulus.

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abst. 2279
Room 1
Wednesday
June 16
14h20

Comparisons between strain gauges and digital image correlation in experimental testing of 3D printed PLA elements

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The widespread Fused Filament Fabrication (FFF) is an additive manufacturing technique based on polymers. Recently, lots of researchers studied how 3D printed parts behave under load to design functional components. Whether for characterization or validation, mechanical tests are the primary tools; proper measuring displacements or strains is essential. The contact transducers, such as Strain Gauges (SG) for deformations or Linear Variable Differential (Inductive) Transformers (LVD(I)T) for displacements, are established instruments. However, when the tests involve materials with a low modulus of elasticity, the interaction between the sensor and the specimen might alter their output. Non-contact transducers, such as the Digital Image Correlation (DIC), do not suffer from these effects. In this work, the authors experimentally and numerically compared SG and DIC in testing 3D printed PLA components. Two sets of tensile specimens formed the test bench of this work. During the tests, SGs monitored the first set; SGs and DIC monitored the second one. The authors quantified the effect using the apparent moduli of elasticity and detected a local reinforcing effect. Specimens with bonded strain gauges appeared stiffer in terms of strains derived from the SGs themselves. However, the same specimens appeared to be consistent with the non-instrumented ones in terms of DIC strains, which allowed a global reinforcing effect to be excluded. A 2D Finite Element (FE) model was used to simulate these effects: 2D shell elements discretized both the specimens and the strain gauge, bonded together in the hypothesis of perfect adhesion. The strain gauge internal microstructure, a metal grid into polymeric layers, was simplified as an isotropic constitutive model with equivalent elastic modulus and Poisson ratio. The authors proposed a digital procedure to evaluate the volume fraction of the metal grid based on a high-resolution image of the transducer; through it, they estimated both the above equivalent mechanical properties. The simulation agreed with the experimental results: it confirmed the local reinforcing effect and its magnitude. This effect was present, although the SGs were specifically designed for low-modulus material. The estimated and equivalent elastic modulus of the strain gauge had the same order of magnitude as the tested PLA; this feature advised that the stiffening effect

could worsen in even less-stiff materials. Strain gauges can still be necessary tools, mainly when the surfaces to be analyzed are not in sight and DIC tools are ineffective. In these circumstances, the authors' experimental and numerical methods allow the output correction when calibration curves are not available.

Advanced Numerical Techniques

abst. 2021
Room 1
Wednesday
June 16
14h40

Design optimization of FGM structures

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The FGM structures provide flexible solution for complex engineering problems including different mechanical and temperature loadings. In the current study is proposed general wavelet based approach for modelling grading functions. As result the governing differential equations covering different grading functions can be derived. Thus, the optimization techniques can be applied considering general grading function.

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abst. 2042
Room 2
Tuesday
June 15
09h30

Approach to numerical modelling of time-dependent behaviour of thermoset polymers

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Rehabilitation and strengthening of civil engineering structures have experienced a boom in recent years. Materials typically used for this field of civil engineering are often related to thermoset polymers. Therefore, a different curing state, used as a measure of cross-linking of polymer chains, can be found in such applications which significantly influences not only the mechanical material properties but also the time-dependent behaviour. The main aim of this work is to describe and implement a model that is able to simulate with sufficient accuracy the behaviour of thermoset polymers under mechanical loading taking into account the curing degree significantly influencing the time-dependent behaviour of polymers. The first approach is based on the Drucker-Prager model with compressive cap in combination with the Kelvin chain model. The second approach is based on the combination of microplane model which is enhanced by the viscoelastic model directly defined on the level of individual microplanes. Base on the preliminary results, it can be concluded that the simple model based on the combination of plasticity model and Kelvin chain model is able to capture the basic behaviour of studied materials.

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abst. 2116
Room 2
Tuesday
June 15
08h50

Numerical investigation on the cold spray of fiber reinforced polymer composites

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Among thermal spray processes, Cold Spray (CS) is an innovative and promising technology commonly used to produce metallic coatings on metal substrates. During the last two decades, also the metallization of fiber reinforced polymer composites by CS has gained popularity, with the aim of improving different functionalities. For instance, in the aeronautic field, insulation from moisture, resistance against lightning strikes and impact strength are key requirements for lightweight composite structures. Recently, many experimental studies have been developed to bypass the existing technological issues and to ensure adequate metal-composite adhesion and the possibility of deposition growth on the composite substrate. Some acceptable experimental results are reported for composites with thermoplastic matrix; on the other hand, erosion occurs when coating thermoset substrates. Indeed, due to the brittleness of the polymer matrix, the high velocity of the particle during cold spraying can induce local fractures and void formation, instead of coating deposition. Novel experimental approaches were suggested considering a top pure polymer layer on composite's surface with to facilitate particle

embedment. Meanwhile, the efforts to use modeling and simulation tools have been less successful. The current study presents a numerical finite element model for the CS process of metal particles sprayed on polymer matrix composites. The simulations aim to clarify the underlying deposition mechanisms and the effects of process parameters, through various particle temperatures and velocities. The model consists of a single spherical copper particle, with a prescribed temperature and velocity, impacting a polyether ether ketone (PEEK) polymer reinforced with carbon fibers. The simulation results are compared with literature experiments to establish the effectiveness of the proposed model. The deposition mechanism is investigated and discussed in terms of particle mechanical embedment and of the resulting stresses in the substrate. The work will shed some light both on the selection of optimal CS parameters, i.e. from the technological viewpoint, as well as on the optimal pure polymer thickness at the surface ensuring structural strength and adhesion. This research has been supported by the project COSMEC (Cold Spray of Metal to Composite), funded by the Italian Ministry of University and Research (MUR), Progetti di Ricerca di Rilevante Interesse Nazionale (PRIN 2017), grant 2017N4422T.

Analysis of Thin-Walled Composite Structures using Physics-Informed Neural Networks and Extreme Learning

abst. 2164
Room 2
Tuesday
June 15
08h30

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Artificial Neural Networks (ANNs) are an effective mean for developing metamodels for the design and analysis of composite structures. For instance, an early application to the post-buckling response of stiffened panels can be found in [1]. In general, the training process requires costly numerical analyses to be performed or experimental results to be available. Thus, a common situation is that of training ANNs in a small data regime, which may lead to poor generalization performance of the network and solutions which are not physical. Physics-Informed Neural Networks (PINNs) are a new and promising class of ANNs [2,3], which can be trained to inherently satisfy the underlying physics governing the problem at hand. This feature allows relatively simple networks to be used, while making the training possible with small amounts of data available. In this work, a novel approach is developed based on the combination of PINNs with Extreme Learning Machine (ELM) for analysing the linear response of composite structures. The method allows assemblies of thin plates and shells, with straight and curvilinear fiber configurations, to be analyzed effectively, with no need for meshing and with reduced computational effort. Focus is given to bending, free vibrations and buckling problems, although the method is general and its extension to other solution procedures is straightforward. The internal parameters of the network, weights and biases, are learned by minimizing the cost function. For this purpose, ELM is adopted, the main feature being its computational advantage due to the need for training the outer layer of weights only. The training process is carried out by solving a least-square problem without any iterative process to be run. The results illustrate close agreement with finite element simulations, while offering the advantage of an easier definition of the structural model as no meshing is required. Furthermore, reduced training times and improved generalization performances are achieved with respect to similar strategies based on the Gradient Based Learning. For these reasons, the proposed framework is seen as a new and promising strategy for solving a wide range of problems in the field of composite structures, including structural analysis and optimization problems. Acknowledgements The authors would like to thank Ministero dell'Istruzione, dell'Università della Ricerca for funding this research under PRIN 2017 program. References [1] C. Bisagni, L. Lanzi. Post-buckling optimisation of composite stiffened panels using neural networks. Composite Structures, 58(2), pp. 237-247, 2002. [2] 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. [3] A.Y. Cheng, R. Vescovini, L. Dozio. Physics-Informed Neural Networks for the analysis of composite structures, ICCS23 - 23rd International Conference on Composite Structures.

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abst. 2234
Room 2
Tuesday
June 15
09h10

High-order modelling of wave propagation in multilayered plates and shells via the implicit-mesh discontinuous Galerkin method

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Composite structures have become widely employed in several fields of science and engineering because they offer a wider set of design parameters with respect to their metallic counterparts. However, due to the inherent heterogeneous nature, composite structures are characterized by an anisotropic behavior and their study is typically supported by the use of computational tools. In this work, we present a novel high-order formulation for solving the wave propagation problem in multilayered shells, which include the multilayered plates as a special case. The formulation is based on the Equivalent-Single-Layer approximation whereby the multilayered shell is replaced by a layer with equivalent mechanical properties. The governing equations are solved via a high-order discontinuous Galerkin scheme and the solution inter-element continuity is ensured via the Interior Penalty approach. The presence of cutouts is resolved by means of the implicitly-defined mesh technique, a discretization strategy that is able to resolve the presence of curved boundaries within structured meshes with high-order accuracy. To assess the robustness and capability of the formulation, numerical tests are performed on plates and generally curved shells with and without cutouts. The obtained results are compared with those available in the literature and confirm the accuracy of the proposed approach.

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abst. 2250
Room 2
Tuesday
June 15
09h50

A framework for aeroelastic analysis employing higher-order structural and aerodynamic theories

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Aeroelasticity is an essential tool for the analysis and design of structures whose operating conditions involve the interaction with aerodynamic loads, and it finds application in aerospace, mechanical and civil applications. Involving the analysis of generally complex interactions between fluids and structures, aeroelastic analyses tend to be computationally expensive, thus often resorting to suitable simplification either in the structural or aerodynamic modelling, so to reduce the computational burden. On the other hand, the employment of composite materials in several engineering sectors has given the designer an unprecedented freedom in terms of design choices. In structures subjected to aeroelastic loads, the use of composite materials extends their operational capability, increasing the divergence and flutter speed and thus enhancing the static and dynamic aeroelastic response in a paradigm known as aeroelastic tailoring. However, the employment of low-order structural theories may sometimes result in excessive simplification of the overall aeroelastic problem. Recently, higher-order structural theories based on generalized structural formulations, such as the Carrera Unified Formulation (CUF), have been developed and employed for aeroelastic analysis and have been coupled with simplified representations of the aerodynamic loads. In this work, a framework for aeroelastic analysis based on the employment of CUF for composite plates and of high order aerodynamic models is presented. The resolution of the aerodynamic fields is provided by open source aerodynamic computational tools and it is coupled with the CUF-based structural model of the composite structure for enhanced aeroelastic analysis. Some preliminary results are presented to illustrate the scope and potential of the technique.

Analysis of composite beams, plates and shells

Coupling effects in FGM micro/nano-plates within couple stress elasticity

abst. 1035
Repository

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It is well known the coupling between the in-plane deformation and bending modes in classical and higher deformation theories for bending of FGM plates within classical elasticity. According to experimental evidence, the description of small-scale structures (such as microplates, microshells and microbeams) within the classical theory of elasticity is insufficient. On the other hand, the modelling based on the 1st principles and/or molecular dynamic calculations are not only extremely expensive, but also inefficient from the point of view of searching the response of the global structural element instead of analyzing their micro-constituents like atoms and/or elementary particles. During the sixties of the last century, a lot of non-classical continuum theories were developed and some of them have been applied to bending of small-scale structures to demonstrate the possibility to describe the small-scale effects (such as the size-effect) within a phenomenological continuum theory. In the present paper, a unified formulation is developed for bending of plates with including the assumptions of the classical thin plate bending theory (Kirchhoff-Love theory, KLT) and the shear deformation theories (FSDT and TSDT) within the modified couple stress theory of elasticity which belongs to the higher-grade theories of elasticity. Besides the standard strains also the symmetric curvature tensor is considered as the deformation measure. The influence of the micro-length scale parameter as well as gradation of Young's modulus on the response of considered plates is given in parametric studies. For numerical treatment of boundary value problems, the element-free discretization method with new Moving Finite Element Approximation has been developed. Acknowledgements: The financial supports by the Slovak Research and Development Agency through grant SK-CN-RD-18-0005 as well as APVV-18-004 are gratefully acknowledged.

Influence of experimental test grip on buckling and post-buckling behaviour in composite channel section subjected to pure bending

abst. 1037
Room 1
Monday
June 14
12h20

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The presented research aims to investigate the influence of boundary conditions applied in the experimental bending test on the buckling and post-buckling behaviour of thin-walled C – section beams made of Glass Fibre Reinforced Polymer (GFRP). Two test grips were considered. The new one allows the application of the load and support in the desired location on the beam; hence the proper four-point bending may occur. Obtained results have been compared with previously conducted experiments, where only part theoretically subjected to pure bending was analysed. Eight-layer beams with three different layer arrangements were considered. The influence of laminate layup on post-buckling behaviour and failure load was investigated. The tests have been performed using the INSTRON® universal testing machine, and the beam behaviour was tracked using the Digital Image Correlation (DIC) ARAMIS® system.

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abst. 1045

Analysis of the static and vibratory behavior of circular plates in smart composite material

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This work proposes a study of circular plates in intelligent composite materials by an analytical calculation, a finite element numerical approach and the Ritz method. It details the particularities of the finite elements allowing the modeling of the composites by emphasizing the last advances of the field to model the behavior of the complex sandwich structures of circular form. The calculation of complex sandwich structures by finite elements is a relatively recent discipline that closely combines mathematics, mechanics and numerical analysis, hence its apparent complexity.

Analysis of Wood and Natural Fibre Composites

Wood as a structural material for transportation industry: Past example and recent advances.

abst. 2049
Room 3
Tuesday
June 15
11h20

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Wood was the primary material in aviation until World War II [1]. We can mention the famous Mosquito nicknamed "the Wooden Wonder". Its structure is made up of sandwich panels with skins formed from birch plies and a balsa core. It was manufactured in 7781 samples, with a "one shot" half-fuselage production and could reach 612 km/h. Until the 1990s, the Mudry CAP10 acrobatic aircraft was made entirely of wood. There is also a recent version of this aircraft with a carbon wing spar known as the CAP10BK. Today, the Aura Aviation company [2] is once again offering a French wood-carbon aerobatic aircraft. In the automotive sector, only the English Morgan offers cars with an ash superstructure but an aluminum chassis. At Le Mans 1967, the Costin-Nathan has a plywood wooden frame, the doors are in fiberglass and it weighs only 410 kg [3]. This brief and non-exhaustive historical reminder questions the intrinsic capacities of wood, especially if it is combined with current materials. This is why the members of the ICA started working on the subject in 2014. The studies focused on the manufacturing methodologies and the static response of plywood-based sandwiches with skins made of glass fibers, carbon fibers, flax fibers or aluminum [4]. These sandwiches were then subjected to impacts [5] and their compressive strength after impact was analyzed [6]. A first attempt of modeling was also carried out [7] and above all showed that the problem requires a lot of investigation. The very good compression characteristics observed convinced us to launch a second thesis still in progress on the crash. This area is particularly important because automobiles are sized according to the HIC (Head Injury Criteria), a criterion which establishes the maximum deceleration that a human being can withstand during a collision without having irreversible consequences. A first publication was recently accepted [8] which shows that poplar (one of the lightest temperate woods, very present in France and affordable) has an SEA (Specific Energy Absorption) of between 20 and 30 KJ / kg while the carbon is between 30 and 80 kJ / kg, while poplar veneers cost 40 times less. Tests with other species (oak, walnut, etc.) and with a carbon / poplar mix will also be presented. [1] B Castanié, C Bouvet, M Ginot Review of composite sandwich structure in aeronautic applications Composites Part C: Open Access, 100004. [2]https://www.aura-aero.com/ [3] https://drive-my.com/en/test-drive/item/3893-1966-costin-nathan.html [4] J. Susainathan et al Manufacturing and quasi-static bending behavior of wood-based sandwich structures Composite Structures, 182 (2017), pp. 487-504 [5] J. Susainathan et al Experimental investigation of impact behavior of wood-based sandwich structures. Composites Part A: Applied Science and Manufacturing, 109 (2018), pp. 10-19 [6] J. Susainathan et al Experimental investigation of compression and compression after impact of wood-based sandwich structures Composite Structures, 220 (2019), pp. 236-249 [7] J. Susainathan et alNumerical modeling of impact on wood-based sandwich structures Mechanics of Advanced Materials and Structures, 27 (18) (2020), pp. 1583-1598 [8] R.Guélou et al Crashworthiness of poplar wood veneer tubes. International Journal of Impact Engineering Volume 147, January 2021, 103738

Investigation of the mechanical behavior of the treated and untreated bamboo fiber reinforced epoxy composites- Assam's Bamboo

abst. 2193
Room 3
Tuesday
June 15
11h00

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The modern world has witnessed remarkable achievements in green technology in material science through the development of natural fiber reinforced composites. Natural fiber reinforced polymer composites (NFPC's) can replace the traditional synthetic composites with the benefits of light-weight, non-toxic, easy availability, low cost and biodegradable properties. Various researchers towards the concept of introducing new eco-friendly composites are increasing day by day due to the increasing awareness regarding the use of fossil fuels and its consequences side effects. Bamboo fiber material has attracted much attention in the past few years as reinforcement polymer composites due to their inherent environmental, mechanical and recyclable properties. The objective of this article is to investigate the mechanical behaviour of the treated and untreated bamboo fiber reinforced epoxy composites. In this work the bamboo fibers are chemically modified with sodium bicarbonate (NaHCO3) solution of 10 wt% concentration at room temperature and the treated and untreated fibers are prepared with epoxy resin for unidirectional composites by a hand layup technique. The BFRC's with fiber volume fraction of 10 %, 20%, 30% and 40% embedded in epoxy resin are subjected to tensile, compression, flexural and impact test and the fracture pattern is examined. Further, the effect of fiber content on the mechanical behaviour of composite is studied. Meanwhile the scanning electron microscope is employed to examine the morphological damage of the fracture surface.

Applications of Composites

Repair methods of cracked shear walls with composite materials

abst. 2027
Room 3
Monday
June 14
14h20

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The purpose of this research was to determine through destructive laboratory testing the effectiveness of composite systems, used as a seismic retrofit of seriously cracked shear walls. Composite materials are rarely used to repair pre-cracked shear walls, and this experimental work is aimed at studying possible applications in this area. Destructive testing was conducted by installing various sensors and instruments at critical locations of full-scale shear brickwork an stone masonry walls. Testing was performed on several different types of masonry composite-repaired specimens. Further evaluation methods included thermographic imaging, implemented to detect any voids between the composite retrofit system and masonry. An evaluation of the structural behaviour of unreinforced uncracked, unreinforced cracked, and cracked composite-repaired walls is presented. The results indicate that several conditions have an effect on the efficiency of the composite repair. Shear-load capacity, shear strength and stiffness, wall ductility are considered in the analysis.

Finite Element Analysis of volumetric callus growth during healing of long bone fracture fixed with composite IM nails

abst. 2078
Repository

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Chang, Seung-Hwan (phigs4@cau.ac.kr), Chung Ang University, South Korea

Healing of a diaphyseal fracture in a tibia depends on the biomechanical environment. It is a function of the gender, age, and health of a person and strongly depends upon the implant type and its material. Implants that mimic bone stiffness encourages secondary healing, which is favorable in diaphyseal fractured tibial bones. This type of healing occurs when micromovements at the fracture site are allowed. Secondary recovery provides a pathway to callus formation by the differentiation of mesenchymal stem cells (MSCs) to chondrocytes, which form cartilaginous tissues. MSCs originate majorly from the periosteum layer, differentiates into other cell phenotypes, and develop the extracellular matrix. Tissue growth causes callus formation and volumetric growth. Therefore, this study compares the stainless-steel implant with a flexible composite implant of glass/polypropylene Twintex [0]2nT for callus growth using Finite Element Analysis (FEA) and also an empirical callus growth model. A biphasic mechano-regulation algorithm was used to predict cell differentiation and a diffusion equation for local and temporal cell concentration. We then use an empirical equation to model callus growth using the initial average biomechanical stimulus inside the central callus and local cell concentration. This study found flexible composite implants of Twintex [0]2nT to prove improved healing, endochondral ossification, greater callus volume, and more mature bone tissue formation than stainless steel implants. Keywords Fracture healing, Finite element analysis, FEA, biphasic mechanical stimulus, tibial fracture of bones, volumetric growth of calluses, biocompatible composites, orthopedics

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Carbon paper electrodes with pseudo-channel effect to enhance flow characteristics of electrolyte in vanadium redox flow batteries

abst. 2088
Room 3
Monday
June 14
12h00

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Kim, Seong Su (seongsukim@kaist.ac.kr), Korea Advanced Institute of Science and Technology, Korea, republic of

Nowadays, renewable energy resources and technologies have attracted much attention for their ability to provide environmental benefits by reducing emissions from fossil fuels. However, renewable energy sources depend highly on the location and natural environment, causing the production to be

unstable. For the stable supply of renewable energy, an energy storage system (ESS) is one of the solutions to compensate for inconsistent production and meet the steady power demand. Vanadium redox flow batteries (VRFBs), one of the representative ESSs, have the advantage of design flexibility in power and capacity and high durability over 30 years. Besides, VRFBs are attracting attention as next-generation ESSs because they have the benefit of safety from explosion and fire. However, low energy efficiency (EE) of the VRFBs must be improved to expand their applications. Recently, carbon papers (CPs) have attracted much attention as alternative electrode materials for VRFBs because of their relatively high fiber volume fraction and high electrical conductivity compared with the conventional electrode material, carbon felt (CF). However, low permeability of the CPs in the in-plane direction tends to cause the side flow of electrolytes around the electrode, which in turn leads to an uneven flow of electrolytes. Consequently, the reactive surface area in contact with the electrolyte decreases, resulting in a decrease in the efficiency of the battery. In this study, a method was developed to enhance the performance of the CP electrodes with a pseudo-channel effect by means of perforated patterns in the thickness direction of the CP at uniform intervals. The electrolyte flow characteristics and electrochemical properties with respect to the patterns were analyzed by means of numerical simulations and cyclic voltammetry tests, respectively. The performances of the electrodes were analyzed through VRFB single-cell tests. As a result of numerical analysis to analyze the electrolyte flow characteristics, it was confirmed that the overall flow rate inside the electrode increased substantially, and the flow distribution became uniform owing to the pseudo-channel effect of the perforated CP, which led to an increase in energy efficiency. At a current density of 100 mA cm−2, the energy efficiency of the perforated CP electrode (85.37%) increased by 10.19% and 4.53%, compared with the corresponding values of pristine CP and commercial CF electrodes, respectively.

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abst. 2125
Room 3
Monday
June 14
11h40

Magnetic Properties of Polymer-Coated Soft Magnetic Composites for Electric Motor Core Applications with Low Core Losses

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Soft magnetic composites made from polyether ether ketone (PEEK) coated iron powders are developed based on their magnetic, electric, and mechanical properties. Different volumetric concentrations of PEEK and iron are prepared and optimized to achieve the highest possible density by hot pressing. A high purity (99.99%) iron powder is used for mesh 45, 45-150 and 150-250 micron for 14.1%, 66.4% and 19.5% traces respectively. To achieve the highest possible packing density, various mesh particle sizes are used. While the coating of the iron particles is performed by dry mixing of nano-PEEK particles in a centrifugal mixture. The increasing thickness of the polymer coating on metal powders is directly related to the reduction in hysteresis and eddy current losses while improving resistivity, coercivity, and retentivity of the magnetic composite but causing a reduction in the density and magnetic permeability. Magnetic properties of the samples are measured by using a vibrating sample magnetometer (VSM) over various densities and temperature conditions. The mechanical properties of the samples are calculated at room temperature, while surface properties are studied by using a scanning electron microscope (SEM). Based on the obtained results, the core material can be optimized for the desired performance, applications for lightweight and low power losses.

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abst. 2173
Repository

Detailed Review of Flexural Design Parameters of FRP-RC Beams Detailed According to ACI 440.1R-15

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This research investigates the critical parameters that control the flexural design FRP reinforced concrete beams following the recommendations of the ACI 440.1R-15. These parameters include reinforcement ratio, bar diameter, bar spacing, span to depth ratio, concrete compressive strength, and

type of FRP reinforcement. The results of this research suggest that while the design of beams with low FRP reinforcement ratios is controlled by serviceability limit state, beams with larger reinforcement ratios are controlled by ultimate flexural strength. In addition, tension-controlled section should be avoided when span to depth ratio is relatively large. Moreover, this research recommends detailing the cross-section with a larger number of bars with small bar diameter in comparison to a smaller number of bars with large diameter.

SELECTED CONSTRUCTION PROPERTIES OF HYBRID EPOXY COMPOSITES REINFORCED WITH CARBON FIBER AND ALUNDUM

abst. 2177
Repository

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The observed technological progress related to composites is the result of multifactorial development, including a dynamic change in the area of modifying the technology of their production and composition. These procedures prepare the material taking into account environmental standards, time and other factors that are characteristic during maintenance. Modifying their composition initiated hybrid composites that are an alternative to known construction materials and improve some of their properties with simultaneous economic benefits. The authors appreciated the strength characteristics of hybrid composites reinforced with carbon fibre and powdered alundum. The specimens were made of certified carbon fabric GG 280 T (twill 2/2, fibre 3K 200 tex, 220 g/m2). For the eight layers of the fabric configuration [0/45/90/135/0/45/90/135] from 2 mm to 3.3 mm-thick plates were obtained (depending on the mass of the filler). The matrix used for the study was based on the epoxy matrix with the trade name L285 with aviation certificates cured by using a hardener H285. The resin and the hardener were mixed in 100:40. The reinforcement phase was alundum with various grain sizes, designated as F220, F240, F280, F320 and F360. The mass percentages of these grains shared 5%, 10%, 15%, 20% and 25%. Observation of the effect of using of alundum was possible by comparing the test results with the samples without the addition of this physical friction modifier. The authors analyzed the results of tensile strength, three-point bending strength, and interlayer shear strength. Changes in the modulus of elasticity and deformation were also analyzed. At the same time, tests of abrasive wear resistance during dry linear friction of a reciprocating nature were carried out. In general, the obtained results indicate a decrease in mechanical strength and a simultaneous increase in abrasion resistance with a greater amount of alundum in the composite.

Preparation of polymer composite materials with a content of modified aluminosilicates and investigation of their resulting properties and rubber application

abst. 2183
Room 3
Monday
June 14
14h40

Pajtášová, Mariana (mariana.pajtasova@tnuni.sk), Department of Material Technologies and Environment, Faculty of Industrial Technologies in Púchov, Alexander Dubček University of Trenčín, Slovak Republic
Pecušová, Beáta (beata.pecusova@tnuni.sk), Alexander Dubček University of Trenčín FunGlass, Slovak Republic
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Ďurišová, Silvia (silvia.durisova@tnuni.sk), Department of Material Technologies and Environment, Faculty of Industrial Technologies in Púchov, Alexander Dubček University of Trenčín, Slovak Republic
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Kaolin is white sedimentary rock from dioctahedral group of minerals consisting of mineral kaolinite. The objectives of the submitted study were to prepare modified copper (II), cobalt (II) and nickel(II) forms of kaolin products and examine their structural, spectral and thermal properties by X-ray fluorescence energy dispersive spectroscopy, thermogravimetry, infrared spectroscopy and others. This study was primarly focused on the preparation of rubber tread blends with a certain amount (phr) of mentioned modified mineral products as fillers and evaluation of their resulting curing characteristics and processing properties and secondary on preparation of tread vulcanizates with a certain amount of modified mineral fillers and investigation of resulting physico-mechanical properties, hardness, resilience, elongation at break and tensile strength before and after thermo-oxidation aging and its applications in the rubber industry. Modified kaolin used as the filler in a rubber tread blend affects physico-mechanical properties positively and can be used as a partial replacement of standard fillers.

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abst. 2206
Room 3
Monday
June 14
12h20

Development of carbon composite bipolar plate structure for LT-PEMFC

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A polymer electrolyte membrane fuel cell (PEMFC), which have recently entered the market, are challenged by high price and operational reliability issues. Since the efficiency of the fuel cell is dominantly influenced by the stack resistance, the resistance of the bipolar plate needs to be reduced. In this study, a carbon composite bipolar plate structure is developed, and the mechanical and the electrical properties are verified. The developed bipolar plate structure is fabricated in one piece which the anode and the cathode side of bipolar plate were co-cured together. The carbon fibers of the co-cured anode and the cathode bipolar plate are directly contacted which eliminated the contact resistance between the anode and the cathode side of bipolar plate. Therefore, the developed carbon composite bipolar plate structure exhibits superior electrical properties. During the co-curing process, a thermoplastic channel frame is inserted between the anode and cathode bipolar plate form coolant channels. The electrical resistance and mechanical properties of the developed bipolar plates are experimentally verified and compared with those of the conventional bipolar plates.

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abst. 2207
Room 3
Monday
June 14
12h40

Development of polyanyline carbon composite bipolar plate for VRFB

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Lim, Jun Woo (jul170@jbnu.ac.kr), Jeonbuk National University, Republic of Korea

Vanadium Redox Flow Battery (VRFB) is a system that converts chemical energy into electrical energy and stores. It is considered to be alternative energy storage system due to its non-explosiveness and large energy capacity. However, there are disadvantages of low energy efficiency due to the stack resistance. This study is conducted to reduce electrical resistance of the bipolar plate of VRFB using polyaniline nanoparticles. Polyaniline is a highly conductive polymer with high acidic resistance. Therefore, polyaniline is a suitable material to increase the conductivity and chemical resistance of bipolar plate for VRFB. Polyaniline dispersed solution is sprayed on the carbon fiber prepreg to fabricate a polyaniline/carbon composite bipolar plate. Soft layer method and compression molding is used to reduce the contact resistance of the bipolar plate. The area specific resistance (ASR), mechanical properties and gas permeability are measured. Moreover, the chemical resistance is measured to verify the durability of the developed bipolar plate.

Effect of sulfonic group on the properties of the carbon felt electrode for the vanadium redox flow battery

abst. 2210
Room 3
Monday
June 14
14h00

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Since two redox couples containing vanadium ions creates the potential difference by electrochemical reactions at the active sites of the electrodes, the energy efficiency of the vanadium redox flow batteries (VRFB) can be enhanced by the modification of the electrode. In this study, a carbon felt electrode is developed and physical and chemical properties of the electrode were analyzed. The results show that the treated electrode had the better electrochemical activities as compared to the bare carbon felt electrode. Moreover, the reversibility of the VO2+/VO2+ and V3+/V2+ redox couple improved significantly. The VRFB single cell with the developed electrode had demonstrated better energy efficiency as compared to the bare carbon felt electrode. The wettability of the electrode was improved due to the presence of the sulfonic acid groups. Based on physical and chemical study, the correlation between the presence of the functional group on the surface and electrochemical property of the electrode is discussed. Hence, the synthesized electrode act as a highly efficient electrode for the VRFB as it compensates all drawbacks.

The use of Fiber Reinforced Polymeric Composites in transportation pipelines

abst. 2275
Repository

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These days, the [U+FB01]ber reinforced polymer (FRP) composite entice extra attention in many pipeline industries including water, oil and gas transportation, since they have the ability to resist corrosion and have distinctive advantage of lighter weight to high speci[U+FB01]c strength. Moreover, the FRP composite pipes are becoming even more attractive because of their low installation costs. Therefore, these pipes are favored for many engineering applications. The FRP material has amazing mechanical properties which when combined with other materials will improve the stiffness strength, pressure capacity, durability, the whole-life cost benefit and the environmental impact. The main aim of this review paper was to address the different applications of the FRP composites in pipeline applications, and their development over time. The paper also reviews the types of pipelines based on the transported fluid. It reviews the developed composite pipelines as well as the repaired conventional pipelines against corrosion or leaking using different FRP. The review includes the most common way to employ FRP composites in different pipeline applications. All the different designs and applications of FRP composites in pipelines were presented towards achieving enhanced properties. Future challenges and research directions were discussed in details.

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abst. 2087
Repository

Study of a 3D additevily printed polymeric auxetic structure under impact conditions

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There is an ever-increasing need for stronger, lighter, tougher, cheaper and more ductile materials that should have a strong combination of multiple material properties. Composite materials are a step in the right direction concerning those criteria, however they do not fully fulfil the increasing need for better materials. Metamaterials are a solution to these demands, as metamaterials are engineered to have properties not found in naturally occurring materials. This work is focused in a metamaterial type called auxetic materials. The word auxetic is derived from the Greek word ιο (auxetikos), which means "that which tends to increase" [1]. An auxetic material is in simple terms a material with a negative Poisson's ratio. This fact provides them an excellent shear strength [2,3], indentation resistance [2], high fracture toughnes [4,5] and a high energy disipation capacity [6,7] which makes them specially suitable to certain aplications such as shock absorbers, filters, composites, biomedical implants or protective elements. The objective of this work is to develop, manufacture and analyse an auxetic structure in order to be used as an impact protection. The auxetic protection is manufactured by means of an SLA (stereolitography) 3D printer using a polymeric resin. Once the auxetic cell is defined and manufactured, three different tests were performed: quasi-static compression tests, Split Hopkinson Pressure Bar (SHPB) tests and Drop tower tests. The results obtained allow to know the behaviour of the auxetic protection at different strain rates as well as its energy absorbtion capability in order to broaden the knowledge of this kind of structures and hence being able to design lightweight protections. Bibliography [1] Y. Prawoto, "Seeing auxetic materials from the mechanics point of view: A structural review on the negative poisson's ratio", Jun. 2012. doi: 10.1016/j.commatsci. 2012.02.012 [2] R. Lakes, foam structures with a negative Poisson's ratio, Science 27 235 (4792) (1987) 1038-1040. [3] F. Scarpa, P. J. Tomlin, On the transverse shear modulus of negative Poisson's ratio honeycomb structures, Fatigue Fract Eng M , 23 (8) (2000) 717-720 [4] R.S. Lakes, 1993. Design considerations for materials with negative Poisson's ratios. J. Mech. Des. 115 (1993) 696–700. [5] M. Bianchi, F.L. Scarpa, C.W. Smith, Stiffness and energy dissipation in polyurethane auxetic foams, J. Mater. Sci. 43 (2008) 5851-5860. [6] A. Bezazi, F. Scarpa, Mechanical behaviour of conventional and negative Poisson's ratio thermoplastic polyurethane foams under compressive cyclic loading, Int. J. Fatigue 29 (2007) 922-930. [7] F. Scarpa, P. Pastorino, A. Garelli, S. Patsias, M. Ruzzene, Auxetic compliant flexible PU foams: static and dynamic properties, Phys. Status. Solidi (B) 242 (2005) 681-694.

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abst. 2155
Room 1
Tuesday
June 15
08h30

Characterization of Mechanical Properties and Multiscale Topology Optimization of Auxetic Honeycomb Cellular Structures with Various Microstructures

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Nowadays, cellular structures are becoming increasingly popular due to their excellent characteristics such as lightweight, large variations of Poisson's ratios, and minimum material requirement. Further, higher weight-to-strength ratios and capability in energy absorption make honeycomb cellular structures ideal for various applications in aerospace, automotive and sports industries. There exist a number of normal and re-entrant honeycomb cellular structures with distinct geometries which provide larger varieties in Poisson's ratios. However, if such cellular structures are to be utilised for the construction of structural load-bearing elements, understanding the effect of Poisson's ratios and determining the

homogenized in-plane elastic properties are of paramount importance for selecting the most efficient microstructure. The final objective of this study is to identify the most efficient microstructure for honeycomb cellular structures in terms of the stiffness and the load-bearing capacity. Therefore, the present study examined the effect of microstructures on the mechanical properties of auxetic honeycomb cellular structures. Moreover, homogenized in-plane elastic properties of honeycomb cellular structures have been determined. Furthermore, multiscale topology optimization was carried out and the relationship between the geometrical parameters of microstructure and the elastic properties has been obtained. An energy-based method was used to determine the homogenized in-plane elastic properties, and then the stiffness matrices were obtained for each honeycomb cellular structure. An analytical approach was used to derive the stiffness matrix. Simply supported beams with uniformly distributed load were modelled using shell elements, and the homogenized in-plane elastic properties of different honeycomb cellular structures and their Poisson's ratios were incorporated into the simulations. The beams' dimensions, support conditions and applied load were kept constant with different microstructural properties. The stress distributions and the maximum deformations of the beams under different Poisson's ratios and microstructural properties were obtained from the numerical analysis. Moreover, the variation of mechanical properties was plotted against the Poisson's ratios and the geometries to discuss their influence on the structural behaviour of the beams extensively. These findings strengthen the fact that the re-entrant honeycomb structures exhibit enhanced stiffness due to the negative Poisson's ratio.

On the effect of different geometrical parameters of polymeric 3D manufactured auxetic lattices in their mechanical performance

abst. 2218
Repository

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Nowadays there is a great demand to achieve stronger, lighter, tougher and cheaper structures which fulfil the high requirements for specific applications, such as: bio-scaffolding, energy absorption, impact protection... According to these noticeable needs, the called metamaterials appeared as a solution to these demands, impossible to be manufactured using traditional processes and achieved through the use of additive manufacturing. Metamaterials are engineered to own and provide properties that could never been found in naturally occurring materials. The current study shows an approach to study the mechanical properties optimization for an auxetic metamaterial lattice. An auxetic material is in simple terms a material with a negative Poisson's ratio. This fact provides them an excellent shear strength [1,2], indentation resistance [1], high fracture toughness [3,4] and a high energy dissipation capacity [5,6] which makes them specially suitable to certain applications such as shock absorbers, filters, composites, biomedical implants or protective elements. The main aim of this work is to design, manufacture and analyse a lattice auxetic structure in order to be used as an impact protection. These protective structures have been manufactured by means of an SLA (stereolitography) 3D printer using a polymeric resin. Several auxetic lattices structured were settled, designed and manufactured to afterwards submit all of them to compression tests. The obtained results of force/displacement and an optical observation contributed to improve the understanding of the behaviour of these auxetic lattices as a possible light-weight protection. The study focuses on the dependence of several geometrical parameters in the mechanical properties of the lattices, such as the critical load drop, the global buckling of the lattice and the absorbed energy. All these points are considered as the key factor for the knowledge and future enhancement of this kind of structures to ensure a better lightweight efficiency and performance. Bibliography [1] R. Lakes, foam structures with a negative Poisson's ratio, Science 27 235 (4792) (1987) 1038-1040. [2] F. Scarpa, P. J. Tomlin, On the transverse shear modulus of negative Poisson's ratio honeycomb structures, Fatigue Fract Eng M , 23 (8) (2000) 717-720 [3] R.S. Lakes, 1993. Design considerations for materials with negative Poisson's ratios. J. Mech. Des. 115 (1993) 696–700. [4] M. Bianchi, F.L. Scarpa, C.W. Smith, Stiffness and energy dissipation in polyurethane auxetic foams, J. Mater. Sci. 43 (2008) 5851-5860. [5] A. Bezazi, F. Scarpa, Mechanical behaviour of conventional and negative Poisson's ratio thermoplastic polyurethane foams under compressive cyclic loading, Int. J. Fatigue 29 (2007) 922-930. [6] F. Scarpa, P. Pastorino, A. Garelli, S. Patsias, M.

Ruzzene, Auxetic compliant flexible PU foams: static and dynamic properties, Phys. Status. Solidi (B) 242 (2005) 681-694.

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abst. 2219
Room 1
Tuesday
June 15
08h50

Novel auxetic crushable structure with enhanced impact protection range

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Over the last decades, the development of crash worthiness structures has gained a notorious importance. Increasing research on new polymers and composites spurred the obtention of enhanced mechanical properties for impact protection materials. Conventional hierarchical cellular structures, such as honeycomb panels, are widely used by top tier industries as crushable structures due to their high specific stiffness [1] and efficient energy dissipation mechanisms [2]. If subjected to uniaxial impact force, the materials flow away from the impact point, expanding laterally when compressed in the longitudinal direction and shrinking when stretched. However, there are some metamaterials that exhibit the opposite behaviour, the so-called "auxetics". To date, auxetics have shown a unique mechanical behaviour whereby an imposed local displacement generates a diffused strain distribution throughout the structural network, resulting in higher shear resistance [3], fracture toughness, crack growth resistance [4] and energy absorbance properties [5]. This work aims to provide an improved low-cost crushable structure design based on the combination of negative and positive Poisson Ratio cellular re-entrant geometries. It tackles the main source of honeycomb failure, identation [6], by using auxetics to increase the relative material density and contact area in a localized impact point, while maintaining the highest levels of global energy absorption. Even though the first man-made auxetic materials were designed to work in 3D, many of the existing systems are limited to 2D due to their manufacturing complexity. However, this design presents a novel layout made of 3D folded metals and composite materials easily manufacturable that can be implemented in various current applications at negligible cost. All in all, this study has obtained a novel design for an enhanced impact protection auxetic structure which was studied through theoretical, numerical and experimental models. The results obtained propose a safer lightweight crashworthiness structure for aerospace, automobile, packaging or sport protection applications. Bibliography [1] L. Peroni, M. Avalle, V. Petrella, and G. Monacelli, "Strain-rate effects on the energy absorption capability of crash boxes with different geometry", Structures and Materials, vol. 11, pp. 259–268, 2002. [2] Honeycomb Technology - Materials, Design, Manufacturing, Applications and Testing | T.N. Bitzer | Springer. [3] K. E. Evans and K. L. Alderson, "The static and dynamic moduli of auxetic microporous polyethylene", Journal of Materials Science Letters, vol. 11, no. 24, pp. 1721–1724, Jan. 1992. [4] A. Alderson and K. E. Evans, "Microstructural modelling of auxetic microporous polymers", Journal of Materials Science, vol. 30, no. 13, pp. 3319–3332, Jan. 1995. [5] Y. Li, Z. Chen, D. Xiao, W. Wu, and D. Fang, "The Dynamic response of shallow sandwich arch with auxetic metallic honeycomb core under localized impulsive loading", International Journal of Impact Engineering, vol. 137, no. March 2019, pp. 1–13, 2020. [6] L. U˘ gur, H. Duzcukoglu, O. S. Sahin, and H. Akku¸ s, "Investigation of impact force on aluminium honeycomb structures by finite element analysis", Journal of Sandwich Structures and Materials, vol. 22, no. 1, pp. 87–103, 2019

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abst. 2239
Repository

Axial compressive behavior of 3D printed novel auxetic lattice structures

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Wang Kui (kui.wang@csu.edu.cn), Central South University, China
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In this work, a kind of novel auxetic lattice structure (NAL) was proposed. The NAL was developed based on a hyper-elastic feature of soft photopolymer by stereolithography (SLA) technique. The axial compressive behavior of NAL was investigated under quasi-static (2 mm/min) and dynamic impact (10 m/s) by an MTS machine and a drop hammer test machine. The results showed that NAL could present

the negative poisson's ratio in all impact directions of X, Y, and Z axes under quasi-static and dynamic impact conditions. At the beginning of the compression, the hyper-elastic characteristic was found due to the accumulation of infinitesimal deformation. The negative poisson's ratio reached the highest value of -0.3 after the structural densification strain. Then NAL exhibited transition of deformation mode from total structural collapse to lattice cell collapse. The energy absorption capacity was improved due to the large effective plastic deformation of each single lattice cell. The critical structural parameters such as the size of the lattice cell and thickness can significantly influence the negative poisson's ratio. Compared with quasi-static compression, the NAL under dynamic impact presented a higher level of crushing force. It was observed that a significant influence of the strain rate on strength and strain hardening for NAL. This work offered a new insight into designing the novel meta-lattice structures with improved mechanical properties and energy absorption.

Beam, Plate and Shell Theories and Computational Models for Laminated Structures

abst. 2026
Room 2
Tuesday
June 15
11h00

A finite element approach for studying the size dependent effect of laminated micro-nano plates

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The influence of the micro defects on the mechanical behaviors is quite trivial for macro structures but is very significant for micro structures. Since the classic theory of continuum mechanics is based on the assumption that materials are continuous distributed, it is no longer applicable to describe the mechanical behavior of micro structures. In this paper, buckling and free vibration of laminated micro-nano plates are studied using numerical approach. Based on the couple stress theory and the shear deformation theory, constitutive relations for laminate micro-nano plate are derived. To establish a finite element analysis in which the size dependent effect is considered, a user subroutine is developed. The new constitutive model is defined in the user material subroutine UMAT of ABAQUS software to compute the equivalent material properties, including the membranous stiffness, the bending stiffness as well as the higher order membranous stiffness, the higher order bending stiffness, etc. The influence of the volume fraction and the material length scale parameter of the fiber and the matrix on the material properties of laminate micro-nano plates are considered. With the developed user subroutine, eigenvalue buckling and free vibration of the micro-nano plates are studied using ABAQUS software. Parametric studies are carried out to evaluate the effect of scale ratio, aspect ratio, length-to-thickness ratio, material properties and stacking sequence on the critical buckling load and on the natural frequency of laminate micro-nano plates.

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abst. 2029
Repository

Thermal-mechanical coupling analysis of laminated composite plates using wavelet finite element method

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This paper presents a new wavelet finite element method for thermo-mechanical coupling analysis of laminated composite plates. The laminated composite plates are modeled based on simple first-order shear deformation plate theory (FSDT) and the initial thermal effects are also considered in constitutive equation by generalized Hook's law. The governing differential equations are yielded by implementing the principle of virtual work. Due to the good characteristics of compact support, smoothness, symmetry as well as explicit expression, the two-dimensional BSWI scaling function is selected as the interpolating basis for the thermo-mechanical wavelet-based BSWI element. Different mechanical and thermal loads containing constant, linearly and nonlinearly varying temperature fields are also considered in the proposed thermos-mechanical wavelet-based BSWI element. Serval numerical examples are provided to demonstrate the accuracy and effectiveness of the proposed wavelet-based method for thermo-mechanical coupling analysis of laminated composite plates comparing with published literatures. This paper also extends the application fields of wavelet finite element method to thermal-mechanical analysis of composite structures.

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abst. 2039
Room 2
Tuesday
June 15
12h20

Bending analysis of FGM magneto-electro-elastic plates by a meshless method

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In the last decades the monitoring and selfmonitoring of engineering structures is in the focus of the engineers and scientists. The development of various smart materials, such as magneto-electro-elastic materials leads to their widespread application in various branches of engineering practice, mainly as actuators and sensors for operation of engineering structures. Such a smart structures are usually made as laminated composites from ceramic slices. Discontinuities of material coefficients on the interfaces between two or more layers lead to concentrations of gradient fields, which can play crucial role in failure of the laminated composite structures. This problem can be solved by using functionally graded (FG) magneto-electro-elastic materials. The functional gradation of material coefficients yields new coupling effects between the in-plane deformation and bending modes. Besides the magneto-electro-elastic coupling in such a plates, one could expect some additional coupling effects. In this paper the unified formulation for bending of magneto-electro-elastic plates is derived with incorporating the assumptions of the Kirchhoff-Love theory as well as the 1st and 3rd order shear deformation plate bending theories. Completely 2D formulation is developed for this multifield problem. By proper selection of two key factors and material coefficients, we can switch between various theories. The governing equations which are given by the 4th order partial differential equations (PDE) are decomposed into the 2nd order PDEs in order to overcome the inaccuracy of approximation of high order derivatives of field variables. The strong form meshless formulations for solution of the considered multifield problem is developed in combination with Moving Least Squares (MLS) approximation scheme. Several numerical examples are presented to study of the influence of various parameters of gradations of material coefficients on the coupling effects within the magneto-electro-elastic FGM plate. ACKNOWLEDGEMENT The financial support of the Slovak Research and Development Agency under the contract No. APVV-18-0004. and of the grant agency VEGA 2/0046/16 is greatly acknowledged.

On the dynamics of rotating matrix cracked blades reinforced with graphene nanoplatelets

abst. 2053
Repository

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Graphene nanoplatelets (GPLs) reinforced composites (GPLRCs) have attracted the attention of numerous researchers due to its desirable mechanical properties. Rotating blades are one of the potential applications of GPLRCs. Stiffness degradation due to matrix cracks is the main initial form of damage in laminated composites. Moreover, the vibration characteristics change due to the degradation of blade stiffness caused by the matrix cracks. This study is concerned about the effect of matrix cracks on the dynamic characteristics of rotating pre-twisted blades made of GPLRCs using the element-free IMLS-Ritz method. The effective material properties of GPLRPC layers are obtained via the modified Halpin-Tsai micromechanical model and Voigt's rule of mixtures. The energy functional of rotating pre-twisted GPLRC blades are obtained using the first-order shear deformation theory, including the rotational effects. Based on the IMLS-Ritz approximation, the discrete vibration equations of rotating pre-twisted GPLRC blades are derived. The accuracy of the IMLS-Ritz results is examined by comparing the natural frequencies with those presented in the previously published papers. A comprehensive parametric study is carried out, with a particular focus on the effects of crack density parameter, GPLs parameters, rotating speed, pre-twisted angle, presetting angle, and aspect ratio of the blade on natural frequencies of matrix cracked rotating pre-twisted GPLRC blades.

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abst. 2059
Repository

Nonlocal analytical solution for multilayered composite shells

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Abstract In this work, an advanced nonlocal analytical formulation for the static analysis of composite shell structures is proposed. The governing equations are derived from the Principle of Virtual Displacement (PVD) [1] and are solved by the use of the Navier solution [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 nonlocal behavior based on the work of Eringen [3]. In order to take into account the nonlocality of the material, the Eringen's stress-gradient model is employed [4]. The novelty and innovation of this work is related to the development of an advanced nonlocal analytical formulation for static analysis of composite shells structures by the use of stress-gradient model combined with Layer-Wise kinematics. The accuracy of the present analytical formulation is validate through various assessments. Isotropic, cross-ply composite and simply-supported shell structures are considered. 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] A.C. Eringen, D.G.B. Edelen, On nonlocal elasticity, International Journal of Engineering Science, 10 (1972) 233–248. [4] J.N. Reddy, Nonlocal theories for bending, buckling and vibration of beams, International Journal of Engineering Science, 45 (2007) 288–307.

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abst. 2061
Room 2
Tuesday
June 15
11h20

Determination of bifurcation shortening of the real thin-walled laminated column with initial imperfections under compression

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A problem arises how to estimate a value of the bifurcation shortening for the real structure, in which inevitable geometrical imperfections are embodied. In this case, an effect of bifurcation is not observed and it is impossible to define directly a value of the bifurcation shortening. In the present study, a methodology for determination of an approximate value of the bifurcation shortening for the real thin-walled column under compression has been developed, employing an axial shortening-squared deflection amplitude plot. It has been shown that the applied method can determine the bifurcation shortening with satisfactory accuracy. The obtained results have been compared to the FEM results. Detailed calculations have been conducted for short angle columns. The eigenvalue problem and the nonlinear post-buckling problem have been solved with the perturbation method based on Byskov-Hutchinson's method and the finite element method using an Abaqus software package. The axial shortening - squared deflection amplitude plots have been determined and an effect of the imperfection amplitude on the post-buckling behaviour of laminated thin-walled angle columns has been analysed. General configurations of the laminate plies have been selected. All columns have been simply supported at both ends. Because of the computations conducted, it has been found that a value of the shortening corresponding to the bifurcation shortening of the real laminated thin-walled structure can be determined from the shortening - squared deflection amplitude plot, assuming that the post-buckling state is described with a linear relationship on this plot, whereas the value of the bifurcation shortening corresponds to a free term of the straight line approximating the post-buckling mode on the plot. The

proposed procedure has been positively verified with the finite element method. The presented method based on the shortening-squared deflection amplitude plot underestimates the bifurcation shortening and the error does not exceed several percent for all cases. If an amplitude of initial deflections is very low, the error is the lowest and does not exceed 1.5%. An increase in the initial deflection amplitude is followed by a quick increase in the error up to a few percent. A further increase in the initial deflection amplitude does not result in a fast growth of the error. Comparing all the results, one can state that the proposed method enables estimation of the bifurcation shortening with a high accuracy in a broad range of initial deflection amplitudes in the case of real structures. The proposed method is by far more accurate than the already known methods. In all cases of the initial deflection amplitude, the error is acceptable and it is less than 12.3%. In the case of the load-shortening method or the load - squared deflection method, the estimation error of the bifurcation load is twice as high, whereas an application of the intersection method causes that the error grows sharply and it is four times higher.

Asymptotic homogenization of magnetoelectric and thermoelastic composite and reinforced shells

abst. 2068
Repository

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A comprehensive asymptotic homogenization model for the analysis of structurally periodic and fully coupled magneto-electric and thermo-elastic thin smart composite and reinforced shells is developed in this work. The microscopic problem entails the solution of twenty unit cell problems that eventually yield the effective coefficients of the homogenized shell structure. These unit cell problems can be grouped into 4 sets. The first set of 6 problems stems from static force balance while two further sets of six problems relate to Gauss's Law for electricity and magnetism respectively. The last set of 2 problems is derived from quasi-static thermal balance. The effective coefficients are universal in nature and, once determined, can be used to examine a broad range of boundary value problems associated with the given geometry. These coefficients then enter a system of seven governing equations that permit the determination of as many macroscopic variables related to mechanical displacement, electric and magnetic potential and temperature. Once these variables are obtained one proceeds to the macroscopic analysis which pertains to the asymptotic solution of all desired field variables (stress, electric and magnetic displacement, electric and magnetic field, heat flux and so on). The developed model is illustrated via interesting examples that relate to magnetoelectric laminated and wafer-reinforced shells. It is shown that the curvature of the middle surface plays a prominent role in both the microscopic and the macroscopic problems so that after homogenization the effective shell may exhibit structural inhomogeneity even if the original structure was homogeneous. Thus, the effective coefficients of reinforced shells may vary from one macroscopic point to another which is in sharp contrast to reinforced plates where they are constant between different unit cells. A further practical importance of the model is related to the fact that it generates closed-form expressions for the effective coefficients and can thus be successfully employed to tailor the properties of a smart composite shell to the requirements of a particular engineering application by changing certain geometric, physical or material parameters of interest. It is shown in this work that in the limiting case of a thin elastic shell whereby any magnetoelectric and thermal behavior is suppressed, the derived model converges to the familiar classical shell model. Finally, it is shown that the results of the model constitute an important refinement over previously established work.

Discontinuous Galerkin models for composite multilayered shells with higher-order kinematics

abst. 2106
Room 2
Tuesday
June 15
12h00

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abst. 2112
Room 2
Tuesday
June 15
11h40

Higher-order modelling of latticed-structures and doubly-curved sandwich plates and shells with a honeycomb and grid core

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In the last decades, the fundamental properties of lattice components have increased the attractiveness of lattice metamaterials. The large variety of applications stems from the versatility of several lattice types, e.g. open-cell or closed-cell lattices; periodic, pseudoperiodic, disordered or randomized lattices; homogeneous or heterogeneous lattices; non-hierarchical or hierarchical lattices [1]. This has increased the attention of many scientists and engineers for the development of refined approaches and computational methods to handle even more complicated structural problems. In such a context, a Higher-order Shear Deformation Theory (HSDT) is here combined with some homogenization procedures [2,3] and a high-performance computational method based on a generalized differential quadrature method [4], to study the mechanical behavior of different latticed members and sandwich structures with a soft core featuring different cell units (grid, hexagonal, rectangular and re-entrant cells). 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, in a context where an optimized modelling procedure (model generator/design modeler) can increase significantly the mechanical performances of a structure. 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. 200-207, 2018. [2] S. Sorohan, D.M. Constantinescu, M. Sandu and A.G. Sandu, On the homogenization of hexagonal honeycombs under axial and shear loading. Part I: analytical formulation for free skin effect. Mech. Mater., Vol. 119, pp. 74–91, 2018. [3] K. Torabi, H. Afshari and F.H. Aboutalebi, Vibration and flutter analyses of cantilever trapezoidal honeycomb sandwich plates, J. Sandwich Struct. Mater., Vol. 21, pp. 2887–2920, 2019. [4] 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.

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abst. 2143
Repository

Incorporation of Higher Order Stress Fields into Beam Mechanics

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Slender prismatic beam structures made of homogeneous or inhomogeneous materials are typically analyzed by means of Classical Beam Mechanics (CBM), where the cross-section is assumed to be undeformeable in its projection plane, i.e., in-plane deformations (distortions) are neglected, while out of plane warping deformations are only included in non-uniform warping torsion. Further, CBM only accounts for axial normal stresses and transverse shear stresses, while all other stress components are neglected. It is shown in recent papers [1,2] that these assumptions may lead to erroneous deformation results especially for torsion of beams with thin-walled box-type cross-sections, where cross-sectional distortions may lead to considerable reductions of the global stiffness. Consequently, novel approaches regarding a Generalized Beam Theory (GBT) are proposed in [1,2] which lead to accurate deformation results even for moderately short beams. However, if distortions and accompanied warping fields influence the global stiffness, it has to be expected that the stress fields from CBM are not conservative.

This means that stress fields, which are neglected in CBM, turn out to be significant and in the same order of magnitude as those of CBM. Additionally, strain fields which are assumed to vanish in CBM, might also influence the stress distributions due to Poisson coupling of normal strains to normal stresses. (LINEFEED) In order to extract the fully three-dimensional stress state, we model the cross-sectional deformations as pairs of distortion and warping fields found from a modal decomposition of a Reference Beam Problem (RBP). Within such an approach it suffices to discretize the cross-section only [1,2] using semi-analytical plane finite elements with a single wave number, where inhomogeneities can be resolved by discretization. Each pair of warping and distortion fields is weighted by two independent kinematic degrees of freedom, which serve as generalized coordinates of the physical beam problem. The global displacement and stress fields are then obtained from a superposition of all relevant modes. This contribution provides a detailed insight into the coupling of such modes and into coupling with respect to non-vanishing off-diagonal terms in constitutive relations. Finally, the stress distributions from challenging benchmark problems are compared to CBM solutions as well as reference results from fully three-dimensional continuum solutions. These comparisons will prove the significance of these higher order stress components, which are disregarded in conventional beam theories.
(LINEFEED) Acknowledgments:
(LINEFEED) The authors gratefully acknowledge financial support by the Slovak Grant Agency of the project VEGA 1/0416/21.
(LINEFEED) References:
(LINEFEED) [1] St. Kugler, P.A. Fotiu, J. Murin, Beam Dynamics Using a Generalized Beam Theory Based on the Solution of a Reference Beam Problem. In: Altenbach H., Chinchaladze N., Kienzler R., Müller W. (eds) Analysis of Shells, Plates, and Beams. Advanced Structured Materials, vol 134, 2020, Springer
(LINEFEED) [2] St. Kugler, P.A. Fotiu, J. Murin, A Novel GBT-Formulation for Thin-Walled FGM-Beam-Structures Based on a Reference Beam Problem, Composite Structures (2021), in press
(LINEFEED)

Asymptotic homogenization of geometrically non-linear electroelastic composite and reinforced plates

abst. 2171
Repository

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A dramatic increase in the use of composites, smart composites and multifunctional composites in an ever-widening range of applications in lightweight construction, aerospace and automotive engineering, naval architecture and marine engineering, nanotechnology, biomedical engineering have been shown in the last decades. The properties of the various types of composite materials that are of interest with respect to practical applications include strength, stiffness, energy harvesting and storage, electrical and thermal conductivity, sensing and actuation. Exploitation of these properties is essentially tantamount to incorporation of the aforementioned materials in novel and emerging technologies and fields; in this respect, the implementation of appropriate micromechanical or nanomechanical models is critical. Currently, the preponderance of uses of composites is in the form of laminated or reinforced beams, plates and shells. It is clear that the elaboration of micromechanical models that accurately predict the properties of these structures at the design stage, preferably by means of closed-form design-oriented equations, offers significant advantages to the designer. Since laminated and reinforced plates, and shells are often characterized by a periodic or nearly periodic configuration, the method of asymptotic homogenization is an effective method that can be used to successfully decouple the microscopic (fast) and macroscopic (slow) scales characterizing the aforementioned structures; the microscopic scale deals only with the geometrical and structural features of the periodicity unit cell whereas the macroscopic scale treats the global formulation of the problem. In this work, a geometrically nonlinear model for an electroelastic thin composite plate with rapidly varying thickness is developed using a modified asymptotic homogenization approach. The "rapidly varying thickness" allows the model to be tailored towards thin plates with a periodic arrangement of reinforcements or actuators attached to the surface of the plate (in addition to being embedded within the plate). The asymptotic homogenization model is developed using static equilibrium and the quasi-static approximation of Maxwell's equation for electric

flux (in the reference configuration) and the work generates unit cell problems consisting of a set of differential equations and associated boundary conditions. The solution of these systems of equations yields the effective (or homogenized) coefficients. In this model new effective coefficients are obtained which relate to nonlinear displacement terms. In addition to the microscopic problem the model gives accurate asymptotic expressions for the macroscopic variables of mechanical stress and strain as well as electric field and displacement. Because the model generates closed-form expressions for the effective coefficients (elastic, piezoelectric, dielectric permittivity), which may be used in a broad range of boundary value problems, it constitutes a useful tool in engineering analysis and design. In particular, it can be used to tailor the effective properties of a structure according to the specific requirements of different applications by changing some material or geometric parameters of interest. The applicability of the model is illustrated by means of a 3-layer anisotropic plate consisting of an elastic middle layer sandwiched between two thin piezoelectric laminae. For the sake of generality all constituents are taken to be generally orthotropic. Finally, it is shown in this work that if the piezoelectric effects are ignored the model converges to that of a geometrically nonlinear purely elastic plate and when nonlinear terms are further suppressed the model then reduces to its classical thin composite plate counterpart.

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abst. 2199
Repository

A Study of vibration damping performance on the Laminated Structure Clamp Using Wire Rope

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The gas distribution layer (GDL) of polymer electrolyte membrane (PEM) fuel cell is assembled in a laminated structure and has an effect on fuel cell performance. GDL assembly of PEM is conducted by applying clamping force through-bolts to end plates located at both ends of the fuel cell. When the clamping force that connects the GDL increases, the electric conductivity of the GDL increases, but the permeability decreases as the cavity for fluid penetration decreases. Therefore, in order to optimize the performance of the fuel cell, an appropriate clamping force must be selected. In order to achieve optimal efficiency, the proper bolt clamping force is selected for proper GDL assembly, but the clamping force decreases over time due to vibration fatigue occurring during fuel cell operation, which lowers the fuel cell efficiency. In this study, a study was conducted on the GDL assembly method using wire rope to reduce the fuel cell vibration fatigue phenomenon. The vibration response characteristics of the fuel cell with the proposed wire rope structure were analyzed. Vibration damping performance between bolt clamping structure and the wire rope clamping structure was compared using fatigue damage spectrum.

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abst. 2277
Repository

A new method of shear stiffness prediction for periodic beam-like structures

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Based on the self-equilibrium equation of a unit cell, this paper presents a new method for shear stiffness prediction of periodic beam-like structures. In this method, actual displacements of a composite beam are separated into homogenized displacements and warping displacements. The effective stiffness matrix of a periodic heterogeneous beam is explicitly formulated according to the energy equivalence or the internal force equivalence of the unit cell at both macroscopic and microscopic levels, and it follows

that the two approaches of the energy equivalence or the internal force equivalence are equivalent in essence. In addition, six normalization constraints used to determine the unique solution of the self-equilibrium equation of the unit cell are introduced and well elaborated from physical interpretations. Furthermore, a standard finite element formulation for calculating the warping displacements is established by using the principle of the minimum potential energy. This method can be easily implemented in commercial software Comsol. Finally, numerical comparisons with the results in literature validate the effectiveness and accuracy of the proposed method.

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abst. 1017
Room 3
Tuesday
June 15
14h20

The effect of metallic additives on the mechanical and thermal properties of poly ether ether ketone.

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Poly ether ether ketone (PEEK)/Fe composites were prepared by a melt blending process to disperse micro fillers and improve on the original properties of PEEK. Polymer composites were produced by twin screw extrusion to mix and disperse iron microparticles at loadings of 5-35 wt.% before moulding to final shape by an injection moulding process. In this study the composites were investigated for thermal and mechanical properties. Mechanical properties show a decrease in elongation via the addition of metallic particles and an increase in modulus properties of the composite material. Thermal analysis shows that the addition of the iron microparticles has minimal effect on crystallisation up to loadings of 15% and no nucleation effect on the base polymer; however above 15% the crystallisation is hindered by additive particles which start to reduce the crystallisation of the final polymer composite, a 12% decrease is observed. Thermal gravimetrical analysis shows normal degradation of PEEK and weight loss from 600-800°C and then the iron particles remaining present up to 1000°C. The paper investigates the relationship between filler material and the effect on mechanical and thermal properties.

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abst. 1021
Room 3
Wednesday
June 16
15h00

Composite strut reinforcements in foam core sandwich panels: Analysis of weight-related stiffening effects and free edge effects

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Hybrid core sandwich panels - meaning a sandwich composition with a foam core reinforced with composite struts - represent a highly efficient lightweight construction concept. They share the advantages of classical sandwich panels in terms of high flexural stiffness while at the same time improving the out-of-plane shear stiffness. Industrial fields such as aerospace, wind energy, transportation systems, ship building as well as architectural components are among their current and potential fields of application. Based on a specific example, we will quantify the potential of hybrid core sandwich panels. The investigated configuration represents a sandwich panel with quasiisotropic composite face layers and a foam core with anisotropic 1D reinforcements oriented at plus/minus 45 degrees. Aim of the present study is to numerically investigate the influence of specific core reinforcement design parameters on the membrane, bending and out-of-plane stiffness, taking into account the weight increase due to the built-in stiffeners. In addition, the influence of free edge effects on the results of standardized sandwich compression tests are studied numerically as well as semi-analytically. Core elements of the numerical analysis are unit cell investigations and simulations of standardized compression tests. Finite Element unit cell analyses are performed employing the homogenization software MEDTOOL [www.dr-pahr.at]. Due to the periodic boundary conditions, the results reflect the stiffness values of sandwich panels of infinite size. 3D-continuum FE models are analyzed to study the changes in the stiffness behavior due the following variation of parameters: * change of the reinforcement material from UD-composite to pure matrix material, * the presence of matrix joints at crossing points of adjacent stiffeners, * interpenetration of stiffeners at the crossing point, and * removal of the foam core. A significantly different behaviour is observed for the weight-related inplane and out-of-plane stiffness responses. Compared to the results from unit cell analyses of non-stiffened foam core sandwiches, the values of the membrane and bending stiffness of the hybrid core panels are up to 17 % lower, depending on the parameters selected. In contrast, the use of struts can increase the out of plane normal and shear stiffness values by up to 16 and 60 times, respectively. Subsequently, FE analyses of compression tests of sandwich test samples of standardized size were carried out. The numerical results show a significant influence of the free edge effects on the out-of-plane normal stiffness values. Deviations of up to 23 % from the

results of the unit cell studies are observed. One reason for this is that the tests are carried out on sandwich panels, in which, due to the different Poisson's ratio between the face layers and the core, edge effects are present even for non-stiffened foam core materials. Furthermore, in the case of stiffened foam cores, the struts which are cut through at the free edges no longer contribute to the out-of plane normal stiffness. This leads to a significant reduction of the out-of-plane normal stiffness in the vicinity of free edges. As a result the edge effects are considerably more pronounced. It is obvious that this effect decreases with increasing specimen size. However, for numerical investigations the size of the specimens cannot be increased arbitrarily, due to limitations in computer capacity. Therefore, based on the numerical results of a compression test of hybrid sandwich test specimens of standardized size, a semianalytical approach is developed to predict the dependence of the free edge effects on the test specimen size in terms of out-of-plane normal stiffness values. The comparison of these semi-nanalytical values with the corresponding results of the unit cell analyses allows the evaluation of the experimental results.

Investigation of wavelength resonator using helical structure for harmonic noise reduction

abst. 1032
Room 1
Monday
June 14
14h20

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In this study, sound absorption structure based on wavelength resonator with medium of helical structure is proposed. At the low frequency, damping capacity can be achieved by applying the larger resonant systems. It is unacceptable to employ the absorbing system in mechanisms with spatial limitation. The proposed resonator structure consisted of half-wavelength resonator, helical chip wrapped by foam material. acoustic properties at specific frequency could be controlled by changing internal conditions of the resonator. The noise absorption coefficient was measured by using transfer function method of two-microphone and impedance tube. Acoustic impedance models of resonance mechanism were established and compared with the experimental results to confirm effects of the inherent helix chip on acoustic characteristics. Under same specification conditions, the proposed structure showed better noise reduction performance at low frequencies than the resonator filled with air layers. To achieve ultimate sound absorption ability, the case study was conducted on parameters related to inner structure of the resonator.

A Preliminary Analytical Approach To Model The Low-Velocity Impact Behavior Of Flax, Basalt and Hybrid Composite Laminates

abst. 1044
Room 3
Wednesday
June 16
14h40

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Since natural fibers show high potential as an alternative to synthetic ones, their mechanical properties need to be investigated under different loading modes. This research studies the behavior of flax, basalt and hybrid flax-basalt/epoxy resin composite laminates under low-velocity impact conditions. While the literature already presents many experimental and numerical tests on natural fiber composites, analytical models able to predict their energy absorption capabilities have not been addressed yet. For their part, theoretical models represent a cheap and low time-consuming tool to draw preliminary considerations on the mechanical behavior of these relatively new composite materials in load-bearing applications. As such, analytical models previously introduced for synthetic-fiber laminates

and afterwards adapted to natural-fiber ones are used in this work to predict the critical load of delamination onset, the indentation as a function of absorbed energy, as well as the approximation of the load-displacement curve resulting from a low-velocity impact on flax, basalt and hybrid-fiber reinforced plates. In particular, an attempt to predict the descending phase of the load-displacement curve is done. In order to validate the theoretical results, an experimental campaign has been performed using different impact energies ranging from the barely visible impact damage threshold up to perforation. The results confirmed that the analytical models have good capabilities to predict the response of natural fiber composite laminates during the loading and unloading phases.

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abst. 1062
Room 3
Tuesday
June 15
08h50

OPTIMUM DESIGN OF WATER-LUBRICATED COMPOSITE JOURNAL BEARING BASED ON ELASTO-HYDRODYNAMIC ANALYSIS

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As eco-friendly technologies have come up as the paradigm, there are many trials to replace oil lubrication to water lubrication in marine propulsion systems. However, low viscosity and high density of water result in turbulent flow and dominant inertial force, which cause low load-carrying capacity and high-power consumption. Applying the polymer composites to water-lubricated journal bearings has received a great deal of attention for new alternatives owing to their high tribological behaviors, and high damping characteristics. In particular, the composite bearings have high design flexibility, which can be attributed to increasing the load-carrying capacity in response to the distribution of lubricant film pressure by adjusting elastic constants. Some researchers investigated the effect of elastic constants of the bearing materials on the elasto-hydrodynamic lubrication to improve the bearing performance. However, most of them focused on the variation of the Poisson's ratio and elastic modulus in thickness direction only and considered the localized deformation, which always gives low load-carrying capacity. Accordingly, optimum design regarding elastic constants for water-lubricated composite journal bearings is required to ensure the high bearing performance and expand the application of water lubrication to various rotary systems. In this study, the elastic constants and stacking sequence of laminates in composite journal bearing are controlled to increase the load-carrying capacity in water lubrication. To estimate the bearing performance, Reynolds equation coupled with the elastic constitutive equation of the composite bearing liner is solved by using finite difference method, including effect of turbulence and inertial force of the lubricant. Based on the numerical results, optimum design of the composite liner is suggested for the working condition of the journal bearing.

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abst. 2016
Repository

Compressive Behavior of FRP-Confined Elliptical CFST Columns with a High-Stength Steel Tube

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Elliptical concrete-filled steel tube (CFST) columns have been widely accepted in applications. However, while they suffer deterioration due to various reasons. On the other hand, the concrete and the steel in CFST columns subjected to compression are effectively confined due to the non-uniform confinement in an elliptical CFSTs and the steel tube in CFSTs is easy to experience buckling failure. To this end, fiber-reinforced polymer (FRP) jackets are proposed to strengthen the elliptical CFST columns in the present study. By strengthening CFST columns with FRP jackets, it is expected that strengthened CFSTs exhibit a monotonic ascending load-strain behavior under compression. An experimental study on axial compressive behavior of FRP-confined elliptical CFST (FCECFST) columns is carried out and the effects of the FRP jacket thickness (0, 2, 3, 4 layers) and the cross section aspect ratio (1, 1.5 and 2) on the axial compressive behavior of FCECFST columns are investigated in this study. The experimental results show that FRP jackets substantially enhance the ultimate load capacity of elliptical

CFST columns. The load carrying capacity and ultimate axial strain of FCECFST columns increase with the FRP thickness. Comparisons between predicted ultimate axial stresses and axial strains of concrete in CFST specimens based on existing models and experimental results show that the existing stress-strain model is inaccurate.

Flexural behaviour of hollow concrete-filled rectangular GFRP tube beams

abst. 2017
Repository

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This paper investigates the flexural behaviour of hollow concrete-filled rectangular glass fiber reinforced polymer (GFRP) pultruded tubes beams. The beam specimens consist of an outer GFRP pultruded tube and the infilled hollow concrete. The main parameters investigated included the hollow ratio (0%, 5.7%, 12%, 27%) and the hollow shapes (circle and rectangle). A total of six beam specimens were cast and tested by using four-point bending test. The experimental results in this study show that the hollow ratio had little influence on the flexural stiffness of the beam members, however, the flexural strength was significantly affected. For the beam specimens with the circular hollows, the larger hollow ratio caused the reduction of the flexural strength. The composite beam specimens with a rectangular hollow showed superior flexural behaviour in this study, and the flexural stiffness and strength almost were not affected although the hollow ratio had reached to 27%. Therefore, the rectangular hollow was believed to be a more reasonable design compared with the circle hollow. The height of the hollow was suggested not more than 3/5 height of the beam specimens, to ensure the full use of the compressive behaviour of the concrete.

Towards modelling of beam-like structures considering flexoelectricity and flexomagneticity

abst. 2030
Room 3
Tuesday
June 15
10h10

Eremeyev, Victor A. (eremeyev.victor@gmail.com), Don State Technical University, Russia
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The aim of this lecture is to discuss modelling of beam-like structures considering electromechanical coupling of higher order that is flexoelectricity and flexomagneticity. These phenomena relate strain gradients with electric polarization and magnetic polarization, respectively. Despite a magnitude of these effects at the macroscale could be very small, they may be very pronounced at the small scales. In particular, flexoelectric structures can demonstrate essential apparent piezoeffect even for non-piezoelectric materials. So such materials could be used in NEMS and MEMS such as energy harvesters. Using Euler-Bernoulli-type and first-order kinematics we introduce 1D models of beams considering non only electromagnetic and mechanical couplings mentioned above and stress-driven nonlocality and viscoelastic properties. To this end we utilize variational approach and discuss some particular problems as static bending, oscillations and buckling as described in [1-4]. Acknowledgement. V.A.E. acknowledges the support of the Government of the Russian Federation (contract No. 14.Z50.31.0046). 1. Malikan, M. and Eremeyev, V.A., 2020. On the dynamics of a visco–piezo–flexoelectric nanobeam. Symmetry, 12(4), 643. 2. Malikan, M., Uglov, N.S. and Eremeyev, V.A., 2020. On instabilities and post-buckling of piezomagnetic and flexomagnetic nanostructures. International Journal of Engineering Science, 157, 103395. 3. Malikan, M. and Eremeyev, V.A., 2020. On the geometrically nonlinear vibration of a piezo [U+2010] flexomagnetic nanotube. Mathematical Methods in the Applied Sciences. (in press). 4. Malikan, M. and Eremeyev, V.A., 2020. Free vibration of flexomagnetic nanostructured tubes based on stress-driven nonlocal elasticity. In Analysis of Shells, Plates, and Beams (pp. 215-226). Springer, Cham.

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abst. 2033
Repository

Study of effect eccentricity load of compress thin-walled CFRP Z-profiles

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The study concerns the effect of eccentric load on the stability and postcritical states of thin-walled CFRP laminate Z-profiles under compression. The boundary conditions applied in the study reflected articulated, simple support of the column's ends. In the tests, loading force, deflection and strains of the Z-profi walls and web are measured. The experiments involve examination of the operating performance of the structure undergoing buckling and determination of its postcritical equilibrium paths describing the relationship between force and deflection. Based on the experimental results, numerical models of composite structures are designed and verified by the FEM. The scope of the numerical analysis includes performing a linear analysis of stability, which allows for determination of the buckling mode depending on the amplitude of compressive load eccentricity and the corresponding critical loads. The non-linear numerical analysis of the compressed profiles was performed by the Newton-Raphson method. The numerical results and experimental findings show a satisfactory agreement. Research funding: The project/research was financed in the framework of the project Lublin University of Technology-Regional Excellence Initiative, funded by the Polish Ministry of Science and Higher Education (contract no. 030/RID/2018/19).

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abst. 2034
Repository

Stability and Limit States of Thin-Walled Composite Plates with Cut-Out Subjected to Compressive Load

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The objective of this study was to investigate the influence of matrix couplings on the buckling, post-buckling and load-carrying capacity of thin-walled composite plates weakned by cut-out. The CFRP plates were manufactured by the autoclave technique. The scope of the study involved performing experimental tests on real structures as well as numerical calculations by the finite element method. The experimental tests were conducted in the full range of loading, until the structure's failure. Post-buckling equilibrium paths and acoustic emission signals were measured in order to determine actual condition of the composite material. Non-linear numerical calculations were carried out using the Newton-Raphson incremental iterative method. The numerical simulations were performed using the commercial software ABAQUS®. High compatibility of numerical calculations with the results of experimental studies has been obtained, which confirms the adequacy of the developed numerical models. Research funding: Results presented in the paper was conducted under the project UMO-2017/25/N/ST8/01066 financed by the National Science Centre Poland. The project/research was financed in the framework of the project Lublin University of Technology-Regional Excellence Initiative, funded by the Polish Ministry of Science and Higher Education (contract no. 030/RID/2018/19).

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abst. 2044
Room 3
Wednesday
June 16
16h00

Investigating the mechanical properties of polymer samples from different additive manufacturing processes using ultrasonic phase spectroscopy (UPS)

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Additive manufacturing processes have been recently used more frequently since they offer a high design freedom and an easy individualisation of the components. The processes have been optimised in order to improve the mechanical performance. Nevertheless, properties of components made by means of injection moulding could not be reached yet. Ultrasonic phase spectroscopy (UPS) allows a prompt determination of the Young's modulus and therefore could give a first evaluation of the mechanical

properties of homogeneous specimens. In the study at hand, the aforementioned method is used to compare the elastic properties of specimens manufactured by injection moulding, by fused filament fabrication (FFF) and by piezo controlled injection moulding. In the end, results of UPS are compared with properties derived by usual uniaxial tensile tests in order to validate the UPS as a test method for prompt determination of mechanical properties.

Axial Compressive Behavior of FRP-Concrete-Steel Double Skin Tubular Columns with a Rib-Stiffened Q690 Steel Tube and Ultra-High Strength Concrete

abst. 2045
Repository

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Fiber-reinforced polymer (FRP)-concrete-steel double skin tubular columns (DSTCs), which possess an outer FRP tube, an inner steel tube and sandwiched concrete between both tubes, are a kind of hybrid column with a particular merit of lightweight. It is expected that using high-strength materials (i.e., ultra-high strength concrete (UHSC) and high-strength steel (HSS) tubes) in DSTCs magnifies the merit of DSTCs. This paper presents an experimental study on axial compression behavior of DSTCs with ultra-high strength concrete and a rib-stiffened Q690 steel tube. The rib-stiffened steel tubes, which are less susceptible to local buckling compared with those without stiffeners, were used in the present study. The parameters including the quantity of stiffeners, the length of stiffeners, the FRP tube thickness, the steel tube diameter and the concrete strength were carefully designed and investigated through the experimental study. The test results demonstrate that DSTCs with UHSC and HSS tubes exhibit a ductile behavior and the axial load-axial strain curves exhibit an ascending-descending-ascending-failure behavior. Additionally, the stiffeners are beneficial in enhancing the performance of DSTCs. The comparisons between the test results and theoretical results show that the existing model of Yu et al. is inaccurate in predicting the ultimate axial stress and the ultimate axial strain of HSC and UHSC in DSTCs.

Effect of kaolin modified by microwave radiation on rheological, mechanical, and structural properties of polymer composites.

abst. 2063
Repository

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A kaolin clay was modified with copper acetate solution, and with activated silane under heating in microwave reactor. The experimental conditions for reaction were: 10 mL of 0.5 M copper acetate (CuA-K) and/or 10 mL of activated silane (3-aminopropyl-triethoxysilane) (APT-K) per gram of kaolin, heating time 30, 60 and 120 min. at temperature of 80 °C. Different techniques, such as scanning electron microscopy (SEM), Fourier transformed infrared spectroscopy (FT-IR) and thermogravimetry, were used to characterize modified kaolin samples. Significant structural and spectral changes of kaolin samples were observed by the proposed procedure even at short time (30 min.) of microwave heating. FT-IR spectroscopy and TG analysis confirmed that the treatment has occurred mostly on the external

surface kaolin clay. Furthermore, kaolin and its modified forms can be used as an environmentally friendly filler for the preparation of polymer composites with the desired properties. The given prepared modified MW kaolin samples were used for investigation of its effect in model rubber composites. The effect of 10 phr of modified kaolin on the curing characteristics, mechanical properties, and structural changes in natural rubber (NR) composites was investigated. A lower viscosity of the rubber composites was achieved throughout the CuA-K fillers used, but when APT-K filler was added, the viscosity and the cure time of the composites increased. The decrease of the maximum torque (MH) value indicates a lower stiffness of the compounds at the end of vulcanization. Scanning electron microscopy (SEM) confirmed that the kaolin particles show good physical dispersion in the NR polymer matrix. The uniform distribution of particles in the polymer matrix is visible with the modified kaolin, but their number in the analyzed area is smaller. Evaluation of interfacial adhesion provides information on the occurrence of empty microspaces around the modified kaolin compared to the standard. However, the mechanical properties of the vulcanizates with CuA-K and APT-K showed comparable values of tensile strength and elongation at break, compared with standard mixture filled only with carbon black. The microwave assisted modified forms of kaolin can have positive effect on the properties of NR composites, especially APT-K form. Acknowledgements The authors would like to thank the Slovak Grant Agency for financial support (Grants KEGA 003TnUAD-4/2019, KEGA 002TnUAD-4/2021. This publication was created in the frame of the project: Advancement and support of RD for "Centre for diagnostics and quality testing of materials" in the domains of the RIS3 SK specialization, ITMS2014+:313011W442.

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abst. 2065
Room 3
Tuesday
June 15
14h00

Structural testing of large notched composite specimens under combined shear and pressure

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The VIRTUOSE project aims at reducing the number of experiments from the test pyramid that is necessary to certify aeronautical composite structures. Thanks to the VERTEX test rig [1], a combined loading of tension/compression-shear-pressure can be applied on large specimens (400*400mm^2 area of interest). Around the world, only few test rigs allow testing of structural specimens under multiaxial loadings. At a component level, between the coupon level and the assembly level, representative loadings are enforced on a large notched specimen representative of a composite fuselage section. The specimens are manufactured with 13 plies of unidirectional carbon/epoxy prepreg. Three notched panels with various stacking sequences are submitted to shear until failure. Three matching specimens are tested under shear up to failure with an additional initial internal pressure. Based on previous studies [1-2], methods of measurement have been developed to characterise global strains and loads fluxes undergone by the structure. Digital image stereo-correlation on the upper skin of the specimen is used to get full displacements fields. Once the curvature has been computed, the laminate theory allows the assessment of the fields of membrane stresses, in-plane loads and moment fluxes. Fluxes characterization on the specimen ends is of the utmost importance for industrial partners because the load cases used to size such panels are based on maximal allowable fluxes. The influence of the additional internal pressure on the failure scenario of the three different stacking sequences has been thoroughly analysed. Infrared thermography helped to clarify the failure chronology. [1] Serra, J., Pierré, J.E., Passieux, J.C., Périé, J.N., Bouvet, C., Castanié, B., Petiot, C., 2017. Validation and modeling of aeronautical composite structures subjected to combined loadings: The VERTEX project. Part 2: Load envelopes for the assessment of panels with large notches. Composite Structures 180, 550–567. https://doi.org/10.1016/j.compstruct.2017.08.055 [2] Trellu, A., Pichon, G., Bouvet, C., Rivallant, S., Castanié, B., Serra, J., Ratsifandrihana, L., 2020. Combined loadings after medium velocity impact on large CFRP laminate plates: Tests and enhanced computation/testing dialogue. Composites Science and Technology 196, 108194. https://doi.org/10.1016/j.compscitech.2020.108194

Band Gaps for Flexural Waves in Periodic Composite Plate Structures with Star-shaped, Transversely Isotropic, Magneto-electro-elastic Inclusions

abst. 2070
Repository

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Increased efforts have been made in recent years to explore elastic wave band gaps in periodic composite structures with a piezoelectric/piezomagnetic/magnetoelectric phase. These periodic composite structures can find important applications in vibration isolating, wave filtering and energy harvesting. Band gaps in elastic wave propagation mainly arise from local resonance and Bragg scattering. At small length scales, such band gaps are microstructure-dependent and cannot be captured using the wave equations in the classical elasticity theory. Hence, non-classical wave equations need to be applied in determining these microstructure-dependent band gaps. In this study, a new model for predicting elastic flexural wave band gaps in periodic composite plate structures containing star-shaped, transversely isotropic, magneto-electro-elastic (MEE) inclusions is developed using a microstructure-dependent Mindlin plate model. Bloch's theorem and the plane wave expansion method for periodic media are employed to solve the non-classical wave equations and determine the band gaps incorporating the microstructure effect. The current new model recovers its classical elasticity-based counterpart as a special case if the microstructure effect is suppressed. A parametric study is performed to demonstrate the newly developed model. The numerical results show that the microstructure effect on band gaps is large when the plate is very thin. In addition, it is found that the unit cell edge length, inclusion geometry and volume fraction of the MEE inclusion phase all have significant effects on band gap sizes, and large band gaps can be generated by tailoring these parameters.

Hybrid aluminum alloy and thermoplastic CFR-PA12 joints manufactured by IR-irradiation: Influence of pre-treatment and ageing on the mechanical properties

abst. 2074
Room 3
Wednesday
June 16
14h20

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Hybrid compounds made of metal and fiber reinforced plastics, e.g. carbon-based, are used today across all industries. That is why innovative joining processes are being researched to produce hybrid structures that contribute significantly to resource efficiency in various sectors such as the automotive and aircraft industries by reducing weight. For such innovative multi-material designs the assembling of the different materials is critical because for each of the different material combinations a specially adapted and efficient joining technology is required. For state-of-the-art joining technologies, such as mechanical joining by screws or rivets and adhesive bonding, specific restrictions can be found with the use of additional material, limitations in the geometric flexibility or comparable long bonding times. For mobile applications, the long-term resistance of hybrid multi-material systems such as those made of metal and CFRP is a decisive criterion for ruling out premature failure under operating conditions. To this end a process to manufacture SLJ was developed in order to investigate the influence of process parameters (e.g. t-T) and surface pretreatment of the Al on the mechanical strength as well as aging. The heating by a high performance infrared radiator is also introduced. Prior to joining, different surface topographies with a characteristic aspect ratio range of 0.1 to 2.0 were created on the aluminum by using a short pulse near-IR-beam laser. The surface conditions achieved were characterized by optical methods and correlated with the mechanical properties of the single-lap joints produced. The results

indicate that by usage of a specific range of N-IR-laser parameters the shear strength under tensile load can be increased up to a maximum value corresponding to the interlaminar shear strength value of the starting CFR-PA12. This means that the composite failure no longer takes place in the interface between the materials but in the CFR-PA12. In addition, the hybrid compounds produced in this way were exposed to different artificial ageing regimes such as temperature conditioning at T = 40 °C and r.H. > 95 %. It can be shown that high strength in the initial state of approx. 14 MPa can be maintained over a long period of up to 1,500 h. A critical influence is shown during the neutral salt spray test according to DIN EN ISO 9227, which leads to a decrease of the bond strength depending on the structuring. To summarize, it has been shown that the manufacturing of hybrid compounds using IR emitters leads to compounds that have a strength that corresponds to the material strength of the CFR-PA12 used. Secondly, these hybrid compounds have shown different strength degradation under varying climatic and corrosive stress.

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abst. 2077
Room 3
Tuesday
June 15
09h30

Finite-element modelling, analysis and design of anisogrid composite lattice spoke of an umbrella-type deployable space reflector

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Deployable umbrella-type reflectors are widely used in the antenna systems of modern spacecraft. Such reflectors consist of radio-reflective lightweight knitted mesh and radial cantilever spokes attached at one end to the central hub. The spokes are the main load-carrying structural elements in such designs. These elements should have sufficient bending stiffness for the reflector deployment and ability to sustain the mesh tension in both the orbit operation and ground testing. In addition, the spoke dimensions should not vary much under thermal loads on orbit. Currently, the straight anisogrid lattice spokes made of high-modulus composite materials are gaining popularity in the umbrella-type reflector designs. Such spokes are composed of two identical groups of helical ribs and the system of hoop ribs. Conventionally, the lattice spokes have round cross-sections. However, the designs of the spokes with rectangular cross-sections having the rounded corners (fillets) are of substantial practical interest. Such designs have certain advantages related to the improved bending stiffness and compact and convenient attachment to the central hub of reflector. In this paper, results of analysis of dynamic behaviour, buckling, and deformation due to actions of local and thermal loads of anisogrid lattice spokes having rectangular cross-sections and made of carbon fibre reinforced polymers (CFRP) are presented and discussed. The study was performed using the finite-element modelling and analysis procedures realised in MSC Nastran. In the modelling, the lattice structure was treated as a three-dimensional frame, which was approximated using two-node beam elements. Each node had six degrees of freedom. Derivations of the formulas linking the height and width of the spoke cross-section, fillet radius, the number of helical ribs and angle of their orientation are presented. These formulas enable the geometry parameters of the spoke required for the creation of finite-element model to be determined. A specialised algorithm has been developed to form the finite-element model for the lattice spoke using a model developed for a typical segment of the lattice structure. Using the internal programming language of MSC Nastran, the macros was created to form the finite-element model of the spoke for a given combination of its geometric and elastic parameters. The finite-element model developed in this work was employed to perform a number of analyses for a cantilever spoke, one end of which was fully clamped. First, the fundamental frequency of the anisogrid lattice spoke was determined. The value of fundamental frequency allows the bending stiffness of the spoke to be assessed. Secondly, the buckling behaviour of the spoke under axial compression, transverse load, pure bending and torsion was investigated. Then, the spoke displacements caused by a tensioned tie cable network of the reflector have been calculated. The cable network exerts local loads on the spoke ribs at the points of attachment at the stage of the reflector deployment. In addition, the thermal deformations caused by heating and cooling cycles the spoke is normally subjected to at the orbit have been analysed The analyses performed allowed the effects

of geometric and structural parameters on the value of fundamental frequency, critical buckling forces and moments, and thermal displacements to be identified and assess. The data obtained were used in the design optimisation of anisogrid composite spoke with the rectangular cross-section. In this process, the mass of the structure was taken as the objective function with the functional constraints represented by the allowable value of fundamental frequency, safety factors under buckling, and maximum values of thermal displacements.

Identification of strain gradient continua of heterogeneous materials with homogenization methods and applications to 2D and 3D composites

abst. 2081
Repository

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The objective of this work is to establish strain gradient models of fibers reinforced periodic composites in the elastic range showing strong gradients of the microscopic properties of their constituents, motivating the need to recourse to higher strain gradient models at the level of a homogeneous substitution medium. The use of such homogenized models will alleviate the huge numerical cost of fully resolved FE simulations at the macroscale, while accounting for microstructural effects in a average sense. Moreover, since the reinforcement is made of fibers prone to large rotations, the overall behavior exhibits geometrical nonlinearities. In this work a strain gradient model in 3D has developed based on variational principles, the strong point of this model is that it is applicable on 3D structures which cannot be realized and analyzed in 2D, such as thin-walled materials, and some composite materials. The homogenization of heterogeneous materials towards strain gradient effective continua have been developed in the literature from a mathematical viewpoint in the small strains regime (Maurice et al., 2018), or using the so-called discrete homogenization method suitable for architected materials (El Nady et al., 2016; Rahali et al., 2017), and more recently for composite structures in both the static and dynamic regimes (Ayad et al., 2019a, 2019b). Key to the proposed homogenization method is the existence of a minimization principle of the mesoscopic energy with respect to all periodic displacement fluctuations. This result in the proposed formulation in a unit cell BVP for the strain localizators in the context of Cauchy homogenization. The homogenized constitutive law is evaluated from the writing of Hill macrohomogeneity condition, stating that the average of the microscopic strain energy is identical to the mesoscopic strain energy of the effective continuum. The designed variational method has been implemented into the open source Finite element code Freefem++ written in C language. The Cauchy type response is determined at the leading order by sequentially solving a set of unit cell BVP's over the loading path. Moving to strain gradient homogenization, the linearity of the BVP to be solved leads to two sequential unit cell problems which are solved for a controlled kinematic loading applied over the unit cell boundary, including the macroscopic strain and strain gradient tensors. The proposed homogenization method is illustrated by the computation of the strain gradient response of fibers reinforced 3D Interlocks. The internal length that quantify the importance of strain gradient effects is computed, allowing the comparison of the mechanical performances and responses of different architectures of composites. The homogenization method delivers effective strain gradient response that prove to be size-independent. Virtual bending tests are performed and compared with real tests from the literature to provide insight into the accuracy of numerical predictions. References: Miehe, C., Schotte, J., Lambrecht, M., 2002. Homogenization of inelastic solid materials at finite strains based on incremental minimization principles. Application to the texture analysis of polycrystals. J. Mech. Phys. Solids, 50, 2123-2167. Maurice, G., Ganghoffer, J.F., Rahali, Y., 2018. Second gradient homogenization of multilayered composites based on the method of oscillating functions. Math. Mech. Solids 24(7):108128651882008. DOI: 10.1177/1081286518820081 Rahali, Y., Dos Reis, F., Ganghoffer, J.F., 2017. Multiscale homogenization schemes for the construction of second order grade anisotropic continuum media of architectured materials. DOI: 10.1615/IntJMultCompEng.2017016848. ElNady, K., Goda, I., Ganghoffer, J.F., 2016. Computation of the effective nonlinear mechanical response of lattice materials considering geometrical nonlinearities. Comput. Mech. 58(6). DOI: 10.1007/s00466-016-1326-7. Ayad, M., Ganghoffer, J.F., 2019a. Higher-gradient and micro-inertia contributions on

the mechanical response of composite beam structures. Int. J. Engng Sci. 154: 103318. DOI: 10.1016/j.ijengsci.2020.103318. Ayad, M., Karathanasopoulos, N., Ganghoffer, J.F., 2019b. On the role of second gradient constitutive parameters in the static and dynamic analysis of heterogeneous media with micro-inertia effects. Int. J. Solids Struct., 190. DOI: 10.1016/j.ijsolstr.2019.10.017

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abst. 2108
Room 3
Wednesday
June 16
16h20

Variability in the response and failure of composite tubes subjected to combined axial and torsional loadings due to non-deterministic in-situ material properties

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Tubes made with polymer-matrix fiber-reinforced composite materials are widely used in automobile, mechanical and aerospace engineering applications. In engineering practice, such composite components are often subjected to multiple simultaneous service loadings. Composite tubes are manufactured mainly using filament winding and automated fiber placement techniques. The ply manufacturing parameters and the tube manufacturing parameters have considerable influence on the in-situ material properties of the composite material in the manufactured tube. Hence, the in-situ material properties of the composite materials in the manufactured tubes are not necessarily deterministic. The unavoidable variations in the in-situ material properties of the composite material, which are random in nature, affect the response and failure of the composite tube. In the present work, the response and failure of uniform-diameter composite tubes with random material properties and subjected to combined axial and torsional loadings are determined considering the stress distributions and First-Ply Failure (FPF) characteristics. The stiffness and strength properties of the composite ply are represented as random variables. The stress distributions and the first-ply failure envelopes of the composite tube are determined based on the Classical Laminate Theory and 3D Finite Element Modeling and Analysis considering the Tsai-Wu 3D first-ply failure criterion. Existing works in the literature are used to validate the three-dimensional finite element model of the composite tube developed using the commercial software ANSYS®. The variations in the first-ply failure loading limits of the uniform-diameter composite tube made of a Carbon Fiber Reinforced Polymer (CFRP) composite material are investigated using the Monte Carlo Simulation (MCS) method, considering the random variability in the in-situ material properties. A sample ensemble of the first-ply failure envelopes of the uniform-diameter composite tube is shown in Figure 1. The probabilistic distributions of the first-ply failure loads are determined. Design aspects are brought out.

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abst. 2132
Room 3
Tuesday
June 15
08h30

A study on the curing process of epoxy molding compound encapsulation to reduce the warpage of ultra-thin semiconductor packages

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Recently, the importance of semiconductor packaging technology has been increased due to the demand for miniaturization and high performance of semiconductor products. The semiconductor packaging composed of epoxy molding compound (EMC) plays an important role in protecting semiconductor components such as silicone chips, lead frames, wires, and substrates from external environments. However, the warpage in the semiconductor packaging has been the critical issue during the semiconductor packaging process as multilayer structured semiconductors comes to be thinner. The warpage is caused by mismatch of coefficient of thermal expansion (CTE) of the semiconductor components and the residual stresses induced by the EMC curing process as well. The warpage not only decreases the reliability of the semiconductor package but also lowers the production rate yield, which results in increase of the semiconductor price. In this study, the multifunctional cure monitoring system was constructed by using an interdigital dielectric sensor and a fiber bragg grating (FBG) sensor. The purpose of this system is to monitor and control the cure cycle to reduce the thermal residual stresses of the EMC package

during the compression molding process using a hot press machine, which results in reduction of the warpage in the package. Dissipation factor during the curing process was measured with the interdigital dielectric sensor and the internal strains changed by the CTE mismatch and chemical shrinkage of EMC during the curing process were measured with FBG sensor. Also, the voids inside the EMC packaging were investigated by using a C-scanning acoustic microscope equipment. The data obtained from the multifunctional cure monitoring system were used to analyze the initial point of the adhesion between the substrate and the EMC, and the internal strains depending on the dissipation factor and cure cycle. Finally, the die shear tests were conducted to investigate the effect of thermal residual stresses of the EMC on adhesion strength of EMC packaging and the quantitative warpage analysis of semiconductor packaging was conducted using 3D-dimensional digital image correlation system.

TESTING OF THERMOMECHANICAL PROPERTIES OF EPOXY INTERFACE COMPOSITES CONTAINING MONTMORILONITE AND TITANIUM NANODIOXIDE

abst. 2140
Repository

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Sandwich construction provide adequate stiffness and strength with a significant reduction in weight. Compared to a solid structure of the same weight, the sandwich structure has a similar tensile strength and a much higher bending strength. An important advantage of such a structure is also its energy consumption, which significantly increases the impact resistance of the sheathing. A composite with a sandwich core does not soak up water even with minor damage. Due to these features, elements with a honeycomb structure are used, among others, in the construction of aircraft hulls, in the construction of hulls of sea yachts or, for example, in the construction of car trailers. These structures are exposed to various forms of failure which depend on a number of elements. One of the most important ones is the material from which the cladding and the core are made. Repeated loads, aging or sudden intensive loading of these structures can lead to the formation of detachment along the interface of the sheathing-core, which may compromise the safety and integrity of the entire structure. The article presents the results of research on the individual and total impact of environmental influences, such as temperature and load variability, on the existing hidden detachments between the sheathing and the core in composite honeycomb structures. The influence of the phase composition and the presence of the spacer on the thermodynamic properties of composites was investigated. Montmorillonite K10 powder and nano-titanium dioxide (TiO2) were used as fillers to modify the composites. Honeycomb Aramid 5 mm XO spacers with a basis weight of 48 kg / m3 and a honeycomb structure, made of Kevlar paper saturated with phenolic resin, were used in the research.

The equivalent thermal conductivity of C/SiC pyramidal lattice core composite sandwich structures

abst. 2141
Room 3
Tuesday
June 15
09h50

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An analytical model for predicting the equivalent thermal conductivity of C/SiC pyramidal lattice core composite sandwich structures by considering the radiation emitted from the struts is proposed. The Monte Carlo method is used to determine the configuration factors of the sandwich structures. The numerical results are compared with the literature results. The proposed model is proven to be an accurate method for estimating the equivalent thermal conductivity of C/SiC pyramidal lattice core composite sandwich structures. The effects of solid emissivity, temperature and lattice core geometry on the equivalent thermal conductivities are discussed. The equivalent thermal conductivity increased with increasing solid emissivity and temperature. The effect of the solid emissivity on the radiative conductivity becomes more significant at higher temperatures. The equivalent thermal conductivities of the pyramidal lattice sandwich panels linearly increase with the core height and strut diameter.

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abst. 2166
Room 3
Wednesday
June 16
15h40

On the efficiency of some analytic wrinkling models

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The design of very lightweight aircraft sandwich structured composites requires a deep knowledge to tackle the failure modes. In this paper, we focus on the wrinkling which may be the primary cause of failure of such structures. Currently, lightweight sandwich structured composites are more and more used in the aeronautics industry and extend to primary structures such as control surfaces. The engineer therefore needs an efficient and effective tool to prevent the occurrence of wrinkling. The ideal, from the engineer's point of view, would be to define the local buckling phenomenon using an analytical formulation with as few parameters as possible. As a result, the formulation proposed by Hoff and Maunter in 1945 [1] for wrinkling in sandwich beams is still widely used today as it only depends on 3 parameters. However, modelling the complex behaviour of local buckling in a sandwich structure using a simple analytical formulation is not easy. Strong assumptions are required to linearize the system of equations and obtain a simple form expression. A telling example is the approach of Douville and Grognec (2013)[2]. The authors start from a complex 3D base and then linearize their system by reporting the problem in an isotropic 2D framework. It is understood that analytical modelling allows a simple and quick use, which ideal for the engineers. However, this comes at the price of important assumptions, sometimes far from reality. Here, a critical literature review of analytical wrinkling formulations is done (for example [1][3][4][2]), and the equations are compared first to 3D finite element models and then to a coupon's tests campaign. About fifty sandwich coupons panels, with a design consistent with those used in lightweight aeronautics sandwich structured composites, were tested. The onset of wrinkling under compressive uniaxial loading, thanks to Digital Image Correlation (DIC) and high-speed camera were captured. Finally, the limitations and approximations of the models are identified and the relevance of simple wrinkling formulas for the design of sandwich structured composites (anisotropy, defects etc...) are discussed. References: [1] N. . Hoff and S. . Mautner, "The Buckling of Sandwich-Type Panels," J. Aeronaut. Sci., vol. 12, no. 3, pp. 285–297, 1945, doi: 10.2514/8.11246. [2] M. A. Douville and P. Le Grognec, "Exact analytical solutions for the local and global buckling of sandwich beam-columns under various loadings," Int. J. Solids Struct., vol. 50, no. 16–17, pp. 2597–2609, 2013, doi: 10.1016/j.ijsolstr.2013.04.013. [3] K. Niu and R. Talreja, "Modeling OF wrinkling in sandwich panels under compression," J. Eng. Mech., vol. 125, no. 8, pp. 875–883, 1999, doi: 10.1061/(ASCE)0733-9399(1999)125:8(875). [4] L. Léotoing, S. Drapier, and A. Vautrin, "Nonlinear interaction of geometrical and material properties in sandwich beam instabilities," Int. J. Solids Struct., vol. 39, no. 13–14, pp. 3717–3739, 2002, doi: 10.1016/S0020-7683(02)00181-6.

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abst. 2167
Repository

An analysis of ablative and strength properties of a powder composite reinforced with montmorillonite

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The authors investigated the strength of the composite material depending on the amount of an reinforcement additive in the form of montmorillonite, as well as ablative properties - exposing the composite to a stream of hot combustion gases. The parameters are crucial in the process of constructing and building thermoprotective shields for applications in aerospace, aviation and construction. In order to check the possibility of using the montmorillonite additive in a powder form added to the matrix base of the polymer composite, a quantitative and qualitative analysis of experimental studies was conducted. For the needs of the study, nine batches of samples were manufactured for strength and ablation research. 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 montmorillonite additive (between 0 to 16.3% volume share). The samples were prepared for tensile testing (5 pieces per batch), bending (1 piece per batch - only for control purposes) and the ablative properties (2 pieces per batch - fundamental investigation of the project subject), which were then subjected to a further optical analysis. Flammability testing of the composites was carried out for approximately 120 seconds. The composites were exposed to an impact of a mixture of combustible gases at a temperature of approximately 1,000°C. In order to measure the temperature of the rear surface of the sample, the authors fitted temperature sensors in the form of thermocouple types J and K. Moreover, a thermal camera was used to measure the temperature distribution on the rear surface. Conducting experimental research made it possible to specify the distribution of temperatures occurring on the rear surface of the samples, determining the ablation weight loss, the rate of ablation as well as the basic strength properties of the material. On the basis of the conducted research, it can be concluded that the application of the reinforcement in the form of montmorillonite significantly improved the thermoprotective properties of the composite in relation to the base material and slightly worsened the strength properties (for the amount of the additive of approximately 9% and above, they significantly deteriorated, especially with regard to tensile strength), as follows: • the temperature of the rear surface from 60.6° C to 48° C; • the ablation weight loss from 66% to 33%; • the rate of ablation from 61µm to 26µm; • the tensile strength of 47 MPa to 37 MPa (for approximately 9% of the additive), and to 24 MPa (for 16.3% of the additive); • the bending strength from 55 MPa to 40 MPa.

Additive manufactured composite with fibre Bragg grating sensors

abst. 2179
Repository

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Fibre Bragg grating (FBG) sensors have been known as one of the smart localised and globalized structural health monitoring (SHM) devices for various structural applications specifically those utilise composite materials. In recent decades the use of advanced composite materials green manufacturing methods has increased the requirement to provide effective means of performing experimental investigations to support analytical and numerical analyses. The main objective of this article is to analyse the performance of additive manufactured (AM) carbon fibre reinforced polymer (CFRP) sample with FBG sensors under environmental factors (temperature, relative humidity) influence. The sample was manufactured using continuous carbon fibre. During the AM process one FBG sensor was embedded in the middle of the sample, while the second FBG sensor was attached to the finished sample surface. The environmental tests were conducted to investigate the durability of AM elements and influences of embedded FBG sensors on the composite specimen. Additionally, the behaviour of composite materials under environmental loading was modelled using the finite element method (FEM) in Abaqus. It allows to achieve a more complex picture of embedded fiber optic influences on AM composite material durability.

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abst. 2181
Repository

Temperature influence on additive manufactured carbon polymer composites

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The popular applications of Additive Manufactured (AM) polymer materials in engineering, medical, and industrial fields have been widely recognized due to their high-speed production despite their complex design shapes. Fused Deposition Modeling (FDM) is the printing technique included in material extrusion and it has become the most renowned AM process due to its simplicity and least-cost than other methods. However, under various thermal conditions, AM materials may possess some mechanical changes. Over time, a constant change in temperature will also cause degradation in the structural chains of the materials. The main objective of this research is to perform a numerical simulation of the thermo-mechanical behaviour of AM polymers with continuous carbon fibre reinforcement with different thickness. The samples, with the same alignment of the layers, were exposed to elevated temperature. The influence of global thermal loads on AM materials will be focused on mechanical properties changes at the microscale (level of fiber–matrix-interaction). The determination of mechanical behaviour (strain and stress distribution) due to applied temperature loading for printed AM materials will be modelled using Abaqus, the 3D finite element analysis software. This relationship will be approached using the coupled thermal-displacement analysis. The numerical results will be compared with the experimental results achieved for the samples under the same thermal conditions. The measurements will be performed in an environmental chamber. In order to analyse the properties changes in structural level a microscopic testing techniques will be used.

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abst. 2217
Room 3
Tuesday
June 15
14h40

Effect of low oxidation graphene oxide on physical, dynamic and mechanical properties of MCC type refractory castable

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The present work investigates medium cement content (MCC) refractory castable modified by graphene oxide (GO) having oxidation degree of 4. For the evaluation of GO effect on the hydration kinetic and structure of the castable, the SEM and XRD analyses along with calorimetry measurements were performed. To determine the physical properties of the obtained castables the dynamic measurements applying modal analysis method were curried out (Ahmed, 2018; Choe et al., 2020). The study included thermal cycling, corrosion and mechanical testing as well. It was found that the addition of GO changes the hydration of aluminate cement (AC) and the structure of AC stone: the peak intensities corresponding to CAH10 hydrates were found to be higher and those of unreacted CA and CA2 – lower, as compared with un-modified samples; the duration of the hydration induction period was shortened and formation of new crystallization centers were observed. The addition of GO affects the physical and mechanical properties of MCC specimens: regardless of the heat treatment temperature, which varied from 110 °C to 1200 °C, the density of the specimens does not change but the compressive strength of the specimens increases by 4%, thermal resistance increases from 26 to 52 heating-cooling cycles. Dynamic measurements by modal analysis method were performed on an experimental bench employing the "Brüel Kjær" equipment for vibration measurement, which consists of portable equipment 3660-D for processing, storage and handling of measurement results with PC, "Lion precision" position measurement sensors U20B and U3B with amplifiers, excitation vibrator 4810 with amplifier.

As a result of dynamic measurements, the physical characteristics of the obtained castables were established, such as Young modulus, Poisson coefficient, etc., which are important for solving various tasks of materials modeling by digital methods. According to the results of dynamic measurements, the difference in values of the first mode resonant frequency for the samples containing various amount of GO was from 3.31 % to 11.39 %, indicating that even very small GO additions applied in the present research (0.01–0.10 %) have the effect on the modified material properties. References Ahmed, L., 2018. Dynamic Measurements for Determining Poisson's Ratio of Young Concrete. Nordic Concrete Research 58, 95–106. https://doi.org/10.2478/ncr-2018-0006 Choe, G., Kang, S., Kang, H., 2020. Mechanical Properties of Concrete Containing Liquefied Red Mud Subjected to Uniaxial Compression Loads. Materials 13, 854. https://doi.org/10.3390/ma13040854

Research on the mechanical properties of a composite based on a polymer matrix with the addition of aerogel particles

abst. 2227
Repository

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In order to check the possibility of using the powder aerogel as an additive to the matrix of the polymer composite, experimental tests of the material strength (static tensile and bend test) of the composite as well as tests of tribological properties and Shore D hardness depending on the amount of the dispersed phase in the form of powder aerogel were carried out. In order to perform the tests, were prepared samples divided into twenty series, differing in the percentage of the amount of aerogel addition (0-6%) and the temperature of cross-linking of the composite before the test (20, 55, 80 and 100° C). The L285 MGS aviation resin with the H285 MGS hardener was selected as the matrix of the tested composites. The conducted experimental tests allowed to determine the effect of the amount of powder additive and the cross-linking temperature on the properties of the composite. Based on the study, it can be concluded that the use of an aerogel additive deteriorated the mechanical properties of the composite in relation to the base material (without the additive). The tensile and bending strength of the material decreased by about 60% (for the 6% additive). Young's modulus in tensile decreased by about 20% and in bending by about 25%. No effect of increasing the amount of additive on hardness was observed, but only the influence of the cross-linking temperature (higher hardness for temperatures of 80 and 100 °C). A uniform decrease in mass was noted during the abrasion tests, only samples that were cross-linked at elevated temperature showed reduced wear. As a result of adding aerogel, the structure of the composite changes. A material with slightly reduced strength properties is obtained, but with additional properties that will be the subject of further research by the authors. The composite with the addition of aerogel also benefits from the reduced density, which is very important when using such a material in aircraft construction.

The correlation of the physical properties of the surface of aluminum and titanium with selected strength properties of fibre metal laminates

abst. 2235
Room 3
Wednesday
June 16
14h00

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Fiber metal laminates (FML) are a group of hybrid materials composed of alternating layers of metal and polymer-fiber composites. They are characterized by their favorable strength properties like impact resistance, high fatigue resistance or corrosion resistance. Due to their properties, they have found their application mainly in the aerospace industry. One of the most important issues in fibre metal laminates is the designing of the metal-composite interface. Properly prepared the metal surface allows to obtain specific physicochemical properties, surface morphology, and appropriate topography and has a decisive influence on obtaining in FMLs a high adhesive strength and durability. An effective methods of surface pretreatment allows for the production of laminates capable of transferring high stresses. While the lack of a good adhesion at the metal-composite interface may lead to the formation of structural discontinuities such as delamination, which affects the quality of FML laminates. The subject of the study was aluminium alloy 2024-T3 and titanium Grade 2 which surface was prepared using several treatment methods: mechanical, chemical, electrochemical to improve the metal-composite interface strengths. The purpose of the work was to assess the possibility of increasing adhesion at the metal-composite interface in FMLs by applying various surface modifications on aluminum and titanium. The study was conducted using the following techniques: surface roughness, surface wettability and microscopic tests using scanning electron microscopy (SEM) and atomic force microscopy (AFM). For the properties assessment, the single-lap shear test has been conducted. It was shown that there is possibility to substitute the anodizing of aluminum alloys with chromic acid while maintaining high strength parameters for example using sandblasting and covering with a sol-gel coating. It is also promising method in titanium alloys. It seems that plasma treatment is another promising method because it is economic and environmentally and user friendly.

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abst. 2246
Room 3
Tuesday
June 15
09h10

Strength and ductility of a functionally graded reinforced concrete beam

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The use of concrete is synonymous of CO2 release due to the use of cement. Hence, researchers have focused on finding alternatives to cement with limited successes. Another way to tackle this problem is to optimise the use of concrete. This paper tries just that by developing and analysing the performance of a functionally graded concrete beam comprising of three-layers of different concretes properties. The concrete in the compression zone was High Strength Fibre Reinforced Concrete (HSFRC) with an average compressive strength of about 80MPa. The HSFRC had fibre content of 1% and 2% steel fibre by weight of concrete. The middle layer was a softer concrete containing jute fibre with an average compressive strength of about 40MPa and the bottom layer was conventional concrete, with an average compressive strength of 45MPa. A series of beams with dimension 130 x 160 x 1.2 m long were casted and tested in flexure under three-point bending configuration. The results were promising and it revealed that the beams with 60mm top HSFRC concrete with 1% steel fibre had an increase of 6% in strength and 1.7 times enhanced ductility.

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abst. 2263
Repository

Multi-functional honeycomb core sandwich composite with microwave heating elements

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In this paper, multi-functional honeycomb sandwich composite with the heating function was investigated. The sandwich structure consisting of core and skins was fabricated by using a nickel-coated glass fabric via an electroless plating technique. The fabricated structure exhibited over 99% absorption and heating performances in 2.45 GHz. This multi-functional sandwich structure was transformation of microwave energy to thermal energy through molecular frictional force and dielectric loss. The heating performance was evaluated using horn antenna machine. The heating test results demonstrated that the proposed multi-functional sandwich has microwave absorption performance and heating performance.

On the basis of test results, it was proved that the sandwich structure proposed in this paper can be a promising candidate for heating technology of microwave-absorbing honeycomb sandwich structure.

Design Optimization of Dynamic Scaled Models of Composite Structures

abst. 2282
Repository

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The aeroelastic behavior of an innovative aircraft designs should be investigated throughout the flight envelope. This can be achieved by either experimental or computational work. Experimental wind tunnel and scaled flight test models need to exhibit similar aeroelastic behavior to the full-scale air vehicle. In this research, the main goal of the optimization is to produce a scaled model that has the same dynamic behavior as the full scaled model. This means that the eigenvalues and corresponding eigenvectors of each model must match. To this end, the variable stiffness composite structures are designed to meet pre-defined dynamic performance objectives. Here, the variable stiffness composite structures are achieved by using different materials and fiber paths to adapt the composite structure according to the specified design driver. A computational design optimization framework is developed by using a modified Particle Swarm Optimization (PSO) for large-scale optimization problem. Therefore, the objective function is the desired eigenvalues, the design variables are the fiber orientations and materials in each layer of composite laminates, and the constraints are the desired eigenvectors in the optimization problem definition. The Modal Assurance Criterion (MAC) is also evaluated to track the desired modes since the structural configuration is changing at each step of the design configuration.

Experimental and Numerical Analysis of Braided Box Section with Optimised Axial Reinforcement

abst. 2283
Room 3
Wednesday
June 16
15h20

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Composite box section beams are widely used in lightweight primary structures as load-carrying members, such as automotive chassis, wind turbine blades and propeller spars in aerospace/marine applications. The composite box beams develop unique failure modes due to competing failure mechanisms under service loads such as bending and torsion. In addition, dry-fibre preform technology has a significant influence on the failure onset and evolution as well as determining the quality, speed, and automation of manufacture. This study develops a novel preform using $\pm 45^{\circ}/0^{\circ}$ triaxial carbon fibre tows braided over rectangular box section foam core. Two configurations have been set up for braiding: a) evenly distributed $\pm 45^{\circ}/0^{\circ}$ reinforcement around the beam cross-section, and b) localised axial reinforcement on the top and bottom surface of the beam only. Instrumented quasi-static bending and torsion tests have been performed to evaluate the beams with different braiding configurations. An efficient 2D numerical model developed to analyse the behaviour of the beams using ABAQUS software. Experimental characterisation results such as fibre volume fraction, the dimension of fibre tows, stress, and strain have been used to develop and validate the numerical model. The numerical results were compared with the experimental load-displacement curves as well as the damage evolution under bending and torsion loads.

Structural performance of composite tubes developed using 3D complex winding in comparison to braided and filament wound architectures

abst. 2284
Room 3
Tuesday
June 15
15h00

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Three-dimensional (3D) winding is a novel winding technology that uses multiple winding rings with fibre packages to wind onto a traversing part. The method produces fibre architecture similar to that of braiding and conventional filament winding. The fibre float length is comparatively shorter than that of filament winding, however, considerably longer than that of typical regular (2/2) braid architecture. Also, while braiding has multiple interlacements within a single pitch length, the filament wound structures consist of quasi-interlacement that appears only at the middle of the pitch length. For 3D wound structures, there is no interlacement between layers. However, as the layers stacked on top of each other, cross over points appear in the form of quasi-interlacement. This cross over points are more frequent than that of filament wound structure but less than that of braided structure. This unique pattern will have the advantage of longer float length like filament winding to contribute to the composites' in-plane properties. Also, the more frequent interlacement pattern will contribute to the impact-damage resistance. In this study, braided, filament wound, and 3D wound composite tubes are investigated for bending after impact loading. Fibre preforms were produced onto a cylindrical mould with $\pm 45^{\circ}$ orientation, and composite tubes were manufactured using resin transfer moulding process. Two sets of tubes are used for testing with and without impact. Low-velocity impact test showed the impact force of the 3D wound structure was between braided and filament wound structure. This observation was similar in the case of four-point bending loading as well. Further analysis will be carried out to study the failure phenomenon along with the mechanical properties such as strength, modulus and energy absorption.

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abst. 1068
Repository

Flexoelectric effect in dielectrics under a dynamic load

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Monitoring of high-performance structures is very important since their collapse can lead to disasters. Damages in structures are detected in the real time mainly in case of strong dynamic loads like at natural disasters such as hurricanes, tornadoes and earthquakes. It requires developing sensing method for in-situ monitoring of the onset and growth of cracks at the early stage, especially near the severe strain gradient fastener areas is of growing interest. Nowadays used sensing technology (e.g., strain gauges, accelerometers, linear voltage displacement transducers) is not effective for monitoring damage because of its limited sensitivity, bandwidth, and accessibility to the hidden localized areas, let alone damage initiation and progression. Structures with ability to sense and assess the damage are referred as intelligent structures. The materials that perform the sensing and reacting (actuating) tasks are called smart materials. The structural health monitoring (SHM) system is utilized to prevent catastrophic failure of structures, decrease maintenance cost and guide construction. Piezoelectricity is the most exploited electromechanical coupling that links the electric polarization and strain. A uniform mechanical strain can induce an electric polarization and conversely, a uniform electric field can cause mechanical deformations in piezoelectric materials. It is observed in materials with non-centrosymmetric crystal structures. The polarization vector in natural piezoelectric material is related to the second order strain tensor through the third order piezoelectric material property tensor. Tensor transformation properties require that under inversion-center symmetry, all odd-order tensors vanish. Thus, most common crystalline materials are not piezoelectric if their structure is centrosymmetric. Physically, however, it is possible to visualize how a non-uniform strain or the presence of strain gradients may potentially break the inversion symmetry and induce polarization even in centrosymmetric crystals. Then, the polarization is proportional to the strain gradients. The [U+FB02]exoelectricity is the electro-mechanical coupling de[U+FB01]ned as the generation of electric polarization by a strain gradient (direct effect) or

stress by an electric [U+FB01]eld gradient (converse effect) in solid dielectrics. Even a centric material can exhibit a piezo-electric-like response if the material has special geometries or structures to convert the applied stress into a strain gradient or electric potential into an electric [U+FB01]eld gradient. The flexoelectric effect has been experimentally observed by the non-uniform straining of a graphene nanoribbon, which is a manifestly non-piezoelectric material. Many literature sources show that gradient elasticity theory have been well used to model and analyze the mechanical behavior of small-scale structures. However, most of the existing works ignore the contribution of inertia gradient effect on structural kinetic energy. Baroudi et al. (2018) have analyzed the dynamic problems for flexoelectric nanobeams without dynamical scaling parameter. Only harmonic oscillations of nanobeams are considered there. The first effort to examine the influence of the dynamic flexoelectricity on natural frequency is performed for the simply supported beam by Nguyen el. (2018). That 1-d model is extended here for a general 2-d boundary value problem of flexoelectricity on a piezoelectric structure under an impact load with a dynamical scaling. The influence of flexoelectricity on in-plane cracks in piezoelectric solid under an impact load is investigated. The direct flexoelectricity with strain gradients in the constitutive equations for electric displacements and the higher-order stress tensor is considered. The Hamilton's principle is applied to derive equations of motion. The variational formulation of considered initial-boundary value problems has been used to develop the mixed finite element method (FEM), where the C0 continuous approximation is applied independently for displacements and displacement gradients. The kinematic constraints between both approximated fields are satisfied by collocation at some internal points of elements. Numerical examples are presented and the influence of flexoelectricity on the elastic wave propagation is discussed. References: Baroudi, S., Najar, F. Jemai, A. (2018) Static and dynamic analytical coupled field analysis of piezoelectric flexoelectric nanobeams: A strain gradient theory approach. International Journal of Solids Structures, 135, 110-124. Nguyen, B.H., Nanthakumar, S.S., Zhuang X., Wriggers, P., Jiang, X., Rabczuk, T. (2018) Dynamic flexoelectric effect on piezoelectric nanostructures. European J. Mechanics –A/Solids 71, 404-409. Acknowledgements: The financial supports of the Slovak Research and Development Agency under the contract No. SK-CN-RD-18-0005 and of the grant agency VEGA-2/0061/20 are greatly acknowledged.

Elastic properties of heterodesmic composite structures: the case of calcite CaCO3 (space group R-3c)

abst. 2294
Repository

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In nature, there are several minerals presenting a composite-like structure. Among them, calcite (CaCO3, space group R-3c) is made of alternately stacked layers of Ca2+ amd triangular CO32- ions. Hence, this mineral has an heterodesmic structure, because the carbonate ions are made up of covalent bonds (acting along the crystallographic a- and b-axes) and the positive and negative layers are held by electrostatic interactions (along the c-axis) [1], resulting in a highly anisotropic material. In the present work, the elastic properties of calcite have been investigated by means of the Density Functional Theory. Different computational settings were considered, in particular the choice of different Hamiltonians (LDA, PBE, M06L, B3LYP, PBE0 and M06) and the use of a posteriori corrections (DFT-D2 and DFTD3 [2,3]) to treat the weak long-range interactions. Both second-order elastic moduli and the equation of state of the calcite were obtained and compared to well-established experimental data [4-6] to assess which quantum mechanical approach is more suitable in the treatment of such heterodesmic structure. The results of this in silico work could be of use to both experimentalists and theoreticians

for the characterization of the elastic properties of other similar minerals/crystal structures used in composites. References 1. Markgraf, S.A.; Reeder, R.J. High-temperature structure refinements of calcite and magnesite.American Mineralogist 1985, 70, 590-600. 2. Grimme, S. Semiempirical GGA-type density functional constructed with a long-range dispersion correction. Journal of Computational Chemistry 2006, 27, 1787-1799, 10.1002/jcc.20495. 3. 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, 154104, 10.1063/1.3382344. 4. Dandekar, D.P. Elastic constants of calcite. Journal of Applied Physics 1968, 39, 2971-2973, 10.1063/1.1656709. 5. Redfern, S.A.T.; Angel, R.J. High-pressure behaviour and equation of state of calcite, CaCO3.Contr. Mineral. and Petrol. 1999, 134, 102-106, 10.1007/s004100050471. 6. Chen, C.C.; Lin, C.C.; Liu, L.G.; Sinogeikin, S.V.; Bass, J.D. Elasticity of single-crystal calcite and rhodochrosite by Brillouin spectroscopy. American Mineralogist 2001, 86, 1525-1529, 10.2138/am-2001-11-1222.

Composite structures in civil engineering

On the effectiveness of composite layers reinforcements on the static behavior of damaged civil structures through unified formulation.

abst. 1027
Room 1
Tuesday
June 15
15h00

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Over the past few years, civil engineering has encountered a sudden groowth in the design of constructions that would likely have seemed unimaginable only a few decades ago. For example, long span bridges and skyscrapers have appeared increasingly in modern times. This has been possible thanks to modern structural computer aided tools, which made possible the development of advanced mathematical models and the accurate prediction of particular phenomena which may occur within the structure. The improvement of computational methods, such as Finite Element method (FEM), has remarkably contributed to expand the knowledge in structure engineering. The present work focusses on the analysis of civil engineering structures that may have suffered deterioration. In fact, due to corrosion or extreme weather conditions, a drop on the mechanical properties may arise within the structures. Repair and rehabilitation of the civil structures needs an enduring repair material. The ideal durable repair material should have low shrinkage, good thermal expansion, substantial modulus of elasticity, high tensile strength, improved fatigue and impact resistance. Reinforcing the civil structures with composite fiberssuch as polypropylene or fiber glass is one of the possible ways to provide all the criteria of the durable repair material. The main disadvantage of this technique is that it may results to a costly process, both in terms of fabrication and installation. Then, an accurate design and prediction on their structural behavior results to be mandatory. The proposed methodology for the structural analysis of composite reinforcements for damaged civil structures has been built in the framework of the carrera Unified Formulation (CUF). This methodology, according to which the three-dimensional displacement field can be evaluated as an arbitrary expansion of the unknowns evaluated through FEM, is extremely suitable for this analysis. In fact, every component or layer within the structure can have its own kinematic described independently from the others, without the need of any ad-hoc theory implementation. As a matter of fact, one can evaluate the infleunce of thickness, material properties and fiber direction of reinforcements in a unified manner. Arch-type structures are analyzed, comparing obtained results with those provided from literature and experimental tests. The results estabilish and reports graphs showing the effects of the reinforcements on the overall behavior of the components, with the aim of providing a reliable starting point for future design of civil structures.

Design of locally resonant metamaterial curved double wall with embedded resonators to improve sound insulation

abst. 1059
Room 1
Tuesday
June 15
14h40

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A locally resonant metamaterial curved double wall is proposed and studied, with the aim of improving broadband noise insulation in the low frequency range. This metamaterial is realized by applying periodically distributed resonators to a curved double wall. The sound transmission loss properties of a curved double wall are first investigated by using the concept of 'apparent impedance', which expresses the properties of the whole structure in terms of the impedances of the constituting panels and air cavity. The apparent impedance derivation is validated against Finite Element models. It is shown that, instead of a dip in the sound transmission loss around the ring frequency of a single curved panel, the curved double wall may exhibit a broad 'valley' with low sound transmission loss, whose bandwidth is determined by the spacing between the two characteristic frequencies of the structure (ring frequency and mass-spring-mass resonance of the curved double wall). The curved double wall is then specifically designed by adjusting the two characteristic frequencies to be close to each other

in order to narrow the region associated with a poor transmission loss. This enables, subsequently, to improve the transmission loss in this region by effectively inserting tuned local resonators. The design principles are discussed, and applications of double walls consisting either of the same curved panels or different curved panels are both included. Curved double walls or similar structures are among the commonly used structures in modern industries such as the aerospace industry. However, the combination of curved panels, and a double wall arrangement may exhibit poor acoustic insulation properties at specific frequencies. For curved acoustic panels, the ring frequency is one of the frequencies where poor acoustic insulation properties occur. Double-wall structures, on the other hand, may be strongly affected due to the mass-spring-mass resonance effect, which may result in a low sound transmission loss. Extensive research has been conducted in order to improve the acoustic properties of curved panels alone [?, ?, ?, ?, ?, ?, ?, ?, ?, ?] or double walls [?, ?, ?, ?, ?]. However, the sound insulation performance for curved double-wall structures may be even more critical since the sound transmission loss is not only affected by the ring frequency effect, but also by the mass-spring-mass resonance effect. Research with respect to the acoustic properties of such curved double-wall panels may be found in [?, ?, ?]. However, to the authors' knowledge, limited contributions have focused on the specific improvement of sound insulation performance of such structures around the critical frequencies mentioned above. In recent years, numerous studies have been devoted to the development of locally resonant metamaterial acoustic panels for sound insulation purposes [?, ?, ?, ?, ?, ?, ?, ?]. These metamaterial acoustic panels sometimes exhibit excellent sound insulation in certain frequency bands due to the presence of internal resonances. For example, locally resonant metamaterial panels have shown to be effective to overcome the coincidence effect [?, ?, ?]. However, on the other hand, the resonance only results in a narrow working frequency range and may sometimes even lead to an adverse effect, *e.g.*, when tuning the resonance frequency at the ring frequency [?]. In general, the sound insulation effect of the metamaterial panel is strongly influenced by the resonance of the resonator, and such resonance may only occur in a very narrow frequency band, thus limiting the application potential of such metamaterial design. On the basis of these limitations, a specific design is investigated in this paper, where the ring frequencies of the outer curved panels, and the mass-spring-mass resonance frequency are tuned to be close to each other, such that their bad acoustic performance may be dealt with simultaneously. In particular, the combined effect of the ring frequencies and the mass-spring-mass resonance frequency may be addressed using localized resonators. The present paper focuses on studying the sound insulation properties of such metamaterial curved double walls, exploring the possibility to achieve broadband acoustic insulation in the low frequency range. A more general description of curved double walls is considered in this work, compared to concentric double-wall cylindrical shells, generally suitable for ducts, as may be found in [?, ?, ?]. The investigation conducted is based on an impedance approach and the Finite Element method. The impedance approach is used to predict the sound transmission loss of infinite panels. In order to estimate the sound transmission loss of the double wall, an 'apparent impedance' is introduced, which is then extended to the case of the curved double wall and the associated metamaterial design. The impedance approach not only provides clear physical insight, but also provides a fast and reliable tool prior to a time-consuming and computationally expensive numerical simulation. The Finite Element model is established for panels infinitely long in one direction and bounded in the other direction. It is used not only to validate the impedance approach, but also to provide additional detailed results corresponding to a more realistic configuration.

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abst. 2005
Repository

Self healing capacity of hybrid PE and PVA fiber-reinforced slag-based composite

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The purpose of this study is to investigate the self-healing capacity of hybrid polyethylene (PE) and polyvinyle alcohol (PVA) fiber-reinforced slag-based composite. Three kinds of mixtures were designed and manufactured according to types of reinforcements. Test results showed that hydrophilic PVA fiber is not beneficial to improve mechanical properties. However, self-healing capacity of mixture incorporating PVA fiber showed excellent performance.

Durability of constituent materials in externally-bonded FRP system under chloride environment

abst. 2009
Repository

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The strengthening technique of externally-bonded fiber reinforced polymer (FRP) composites in civil structures has many advantages, such as high-strength/weight ratio, good corrosion resistant, ease of handling and application, and the elimination of the need for heavy equipment. This has led to numerous studies on the mechanical properties of constituent materials i.e. FRP and adhesive in the externally-bonded FRP system. However, the majority of these studies focused on with the short-term performance, and limited information is available for the durability of externally-bonded FRP system which is of dominate importance in cases such as serving in the marine environment. To this end, an experimental study was conducted to investigate the durability of constituent materials in externally-bonded FRP system under chloride environment in this work. Two types of FRP sheets (CFRP and BFRP), two types of epoxy adhesive (epoxy value was 0.40 and 0.53) and conventional concrete were exposed to a laboratory-accelerated chloride environment with a temperature of 40 °C and a chloride ion concentration of 5%, and then were tested under axial force after different exposure duration to evaluate the residual mechanical properties. In addition, the microstructure of the exposed specimen was examined, and the deterioration mechanism was discussed. The results show that the tensile strength of CFRP sheets initially increase by 10% after a exposure of less than 180 days and then slightly decreased after a 360-day exposure, while the strength of BFRP sheets reduced by 69% after a 360-day exposure, indicating that the CFRP sheets has a significant better durability than the BFRP sheets under chloride environment. In addition, the epoxy adhesive with a lower epoxy value may have better corrosion resistant, although it had a lower strength in ambient environment. The residual strength model based on Arrhenius theory could predict the relationship of FRP strength and exposure time in the accelerated chloride environment.

Experimental Study on Flexural Behaviors of Concrete Beam Reinforced with Steel-Fiber Composite Bars

abst. 2013
Repository

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Steel-fiber composite bars (SFCBs) are a type of composite reinforcing bar, which consists of a steel core and a fiber-reinforced polymer (FRP) pultruded protective coating. In SFCBs, FRP pultruded coating not only serves as protective layer for the core steel, but also takes loadings. Due to the presence of the steel core, the tensile stress-strain behavior of SFCBs exhibits a linear ascending segment and a hardening second segment, and they are superior to FRP bars in terms of tensile and shear behaviors. The distinctive mechanical properties of SFCBs may allow better flexural behavior of concrete beams reinforced longitudinally with SFCBs (referred to as SFCB beams) than those reinforced longitudinally with FRP bars. Against this background, an experimental program on flexural behavior of concrete beams reinforced with SFCBs and GFRP bars (referred to as GFRP-SFCB beams) was conducted. GFRP-SFCB beams are not susceptible to corrosions and are expected to be cast by sea sand concrete. Also, concrete beams reinforced with FRP bars or steel bars were also included in the experimental so as to make comparisons. The test results including the failure mode, the load-deflection behavior, the moments, the ductility and the energy absorption capacity of the beams were presented and discussed. The test results showed that SFCB beams showed a favorite behavior with a post-yield hardening load-deflection curve. The ultimate load, moments, ductility and energy absorption capacity of SFCB beams generally increase with an increase in thickness of FRP protective layer.

abst. 2015
Room 1
Tuesday
June 15
11h40

Experimental Study on the Flexure Response of CFST Beams using Normal and Recycled Aggregate

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Concrete-filled steel tubes (CFSTs) are recently considered as possible and promising alternatives to reinforced concrete structures because of their improved structural properties and economic advantages. Recent research investigated replacing natural aggregate concrete (NAC) infill with recycled aggregate concrete (RAC) and utilizing the confinement provided by the steel tube as a method to overcome any mechanical properties drawbacks of using RAC. Previous research focused on the performance of RACFSTs in compression. This study aimed to expand the research by investigating the flexural performance of RACSFTs experimentally. The experimental program consisted of testing a total of 20 CFST beams, of which 12 are circular and 8 are rectangular, under four-point bending. The parameters considered in this study included Diameter-to-thickness (38, 42, 56), depth-to-thickness (50 67) ratios, concrete compressive strengths (30 50 MPa), and recycled coarse aggregate replacement percentages (50 100%). The test results revealed promising outcomes on the feasibility of using RAC in CFST systems under flexure. The flexural response of CFSTs filled with NAC and RAC were very similar in terms of load carrying capacity, moment-displacement response, moment-strain response, and failure mode. Moreover, it was observed that changing the concrete compressive strength and the recycled coarse aggregate percentage had a slight effect on the flexural behaviour of RACFSTs.

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abst. 2018
Repository

Comparative mechanical and fracture properties of self-compacting concrete containing basalt and polypropylene fibers

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Self-compacting concrete (SCC) has different properties compared with the normal concrete regarding its fresh and mechanical behaviour. A number of studies have been carried out to determine the benefits of incorporating various cement replacement materials into the self-compacting concrete. These materials reduce the cost of the SCC resulting from the significant amount of cement that is necessary to provide the required SCC flow ability. Decreasing or eliminating the use of cement in SCC seems imperative for both economical and environmental reasons. This study investigates fresh, mechanical and fracture properties of sustainable SCC in which 86% of the cement is replaced by ground granulated blast furnace slag (GGBS) with six different polypropylene and basalt fiber volume fractions (Vf = 0%; 0.025%; 0.05%; 0.075%; 0.125%; 0.25%) within an identical SCC matrix. The water to binder (w/b) ratio of SCC mixtures is maintained at 0.32. Two aspects of fresh SCC properties including filling ability (slump flow, T500) and passing ability (L-box) of the mixtures have been investigated. SCC with fiber reinforcement fulfil the fresh concrete properties requirements of the EFNARC guideline. In this research, the compressive, tensile splitting and flexural strengths of fiber reinforced SCC have also been compared with plain SCC. The study proposes empirical relationships to predict 28-day compessive, tensile splitting and flexural strengths based on 7-day strengths, respectively. In addition, the fracture properties of various sustainable fiber reinforced SCC mixtures were determined at 7 and 28 days after the moist curing of concrete. The higher amount of basalt and polypropylene fiber resulted in an improvement of strengths, flexural toughness, fracture energy and rigidity of the SCC up to 0.25 vol.% of fibers and thus, the use of these fibers would enhance overall SCC performances. The experimental studies show that fiber reinforced SCC with the use of GGBS as 86% replacement to the cement weight is potentially a sustainable alternative construction material. The mechanical and fracture properties of the sustainable SCC mixtures containing fibers falls within ranges suitable for structural engineering applications.

Durability of BFRP bars wrapped in sea-sand seawater concrete in laboratory accelerated simulation marine immersion environments

abst. 2019
Repository

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In this study, the long-term durability of basalt fiber-reinforced polymer (BFRP) bars wrapped in sea-sand seawater concrete (SSC) in laboratory accelerated simulation and natural marine immersion environments was studied. The laboratory accelerated simulation marine immersion environments were set at 26, 40, and 60 °C. The natural marine immersion was set in Zhanjiang, Guangdong province, China. The wrapping thickness were 10 and 20 mm. A set of bare BFRP bars and alkaline solution/distilled water immersion were investigated for comparison. After one year, the shear strength degradation of BFRP bars immersed in laboratory accelerated alkaline solution shows the most degradation, and the degradation in 26 °C simulated marine environment is higher than that of natural marine immersion environment. This study indicated that laboratory accelerated simulation marine environment results are conservative due to the high pH value in the laboratory environment, and the results of directly immersed BFRP in alkaline solution is too conservative. The additional chemical reaction at the interface between BFRP and concrete should be considered when its used in SSC. The relationship between the thickness of protective layer and the interlaminar shear properties was proposed.

RC Beams with an FRP-strengthened web opening: Moment-rotation model

abst. 2020
Repository

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The strong column-weak beam design philosophy has been widely used in the seismic design of reinforced concrete (RC) frames, in order to achieve their good seismic performance. However, a number of existing RC frames violate the strong column-weak beam requirement, due to the inadequate stipulations in the design codes (generally previous codes). Particularly, the contribution of cast-in-place floor slabs to the flexural capacities of the supporting RC beams was not considered in the previous versions of design codes (e.g. previous Chinese seismic design codes). Against this background, a novel seismic retrofit technique (i.e., the beam opening technique or BO technique) for RC frames which violate the strong column-weak beam requirement was proposed. The BO technique involves the creation of a web opening in the T-section beam to weaken the flexural capacity of the beam and shear strengthening of the opening area using fibre-reinforced polymer (FRP) to avoid shear failure of the weakened beam. Extensive experimental and numerical studies on the structural performance of RC beams with an FRP-strengthened web opening have been conducted and the effectiveness of the proposed BO technique has been preliminarily verified. In order to more comprehensively investigate the effectiveness of the BO technique, studies on the structural behaviour of RC frames with beam web openings are indispensable. For the assessment of the seismic performance of RC frames with beam web openings using finite element (FE) methods, the moment-rotation (M-[U+03F4]) relationships at the plastic hinges of RC frame beams with web openings are essential and need to be determined first, and then incorporated into beam elements as the property of plastic hinges in the FE simulation of RC frames. The present study aims to establish an M-[U+03F4] model for the plastic hinges of RC beams with an FRP-strengthened web opening. Firstly, the M-[U+03F4] relationships at the plastic hinges of RC beams with an FRP-strengthened web opening are extracted from experimental results. Based on a series of theoretical studies and the experimental findings, a simplified M-[U+03F4] model is proposed. The proposed M-[U+03F4] model is then employed in the FE modelling of RC beams with an FRP-strengthened web opening using beam elements, and its accuracy is verified with test results.

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abst. 2036
Room 1
Monday
June 14
15h00

Accurate multi-level model for creep of micro-cracked masonry

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This paper aims to prove the accuracy of a recently proposed multi-level model (Rekik 2020) available for creep of microcracked masonry based on periodic homogenization and the coupling between the brittle Griffith theory (Huy Duong 1978) and a rigorous homogenization scheme (Ponte Castañeda Willis 1995) accounting for both microcracks states (open or closed (Deudé et al. 2002)) and interactions. Accordingly, results provided by Rekik's multi-level model are compared to "exact" ones (up to numerical accuracy) provided by full finite element method for masonry structures submitted to compressive loadings. Before carrying full computation of masonry creep, only the behaviour of the microcracked viscoelastic mortar is homogenized. Two cases are considered for comparisons: masonry with rigid bricks and viscoelastic ones. Creep functions of bricks and mortar joints are assumed to follow the Generalized Maxwell (GM) model.

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abst. 2058
Room 1
Tuesday
June 15
12h20

A non-invasive reinforcement solution of power transmission monopoles

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This communication introduces a non-invasive reinforcement solution of power transmission monopoles and its merits when compared with other existing solutions. The mechanics principles of the non-invasive reinforcement solution: 1) increase the section inertial moment of monopole to resist lateral loads, i.e., wind load and earthquake. 2) expansive cement concrete with / without steel fiber produces high pressure between the steel-bar reinforced concrete and monopole shaft so that the lateral load is transferred from monopole shaft to base disk and the weld crack propagation is prevented.

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abst. 2079
Room 1
Tuesday
June 15
14h20

Material characteristics of Carbon Fiber Reinforced Polymer Matrix Composites and their application for the Strengthening of Reinforced Concrete Structure

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The paper presents the determination of material properties of carbon fiber-reinforced composite materials (carbon/epoxy) by numerical homogenization and experimental investigation. A periodic square array model of microstructure with and without pores is utilized for the homogenization. In the FEM software ANSYS, the numerical homogenization, as well as simulation of the experiment are performed. At first, to investigate the material characteristics of the carbon/epoxy composite laminate, a unidirectional quasi-static tensile test was conducted. The comparison of the results gathered from the numerical and experimental investigation followed. Secondly, we dealt with the application of FRP composite lamella for strengthening of the reinforced concrete structure. The high-strength glue epoxy used at the beam bottom in the milled slot, the composite lamella was fixed to the beam. In this application, firstly the reinforced concrete flexural four-point beam with steel bracing was evaluated and then the bonded lamella effect was considered. MSC MARC and Mechanical APDL ANSYS software were used for the analysis. The Von Mises stress and deflection of the concrete reinforced

beam without and with lamella bracing was examined numerically, as well as experimentally. The results revealed that using of the lamella influenced the reduction of maximum tensile stress in concrete and concrete reinforcement.

Influence of nanometric C-S-H phase on cementitious composites modified with siliceous fly ash.

abst. 2136
Repository

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Currently, different types of mineral additives and chemical admixtures are increasingly used in cementitious composites. One of the most commonly used additives is siliceous fly ash (FA). They are waste produced by burning coal in power plants. Their storage degrades the environment. The use of this supplement has both an economic and an ecological aspect. Replacing cement with FA, which is a combustion waste, lowers the price of the cementitious composite. On the other hand, the worldwide production of cement contributes to the release of compounds that negatively affect the environment into the atmosphere. Therefore, the use of substitutes for cement is beneficial from the ecological point of view. However, despite the many advantages associated with the use of FA as substitutes for cement composites, such actions also have a negative impact on main parameters of composites with cement matrices. It has been found in numerous studies that the addition of FA significantly delays the hydration process of the mixture and slows down the increase in strength of cementitious composites in the first days of curing. The strength increase is an important feature because its reduction significantly limits the possibility of using modified composites in some industries. Therefore, the neutralization or reduction of this negative impact can significantly increase the scope of application of ash concretes in the construction industry. In order to improve the strength processes in the material, admixtures accelerating setting and hardening are commonly used in concrete technology. One of the solutions is the "seeding" technology consisting in adding to the composite of synthetically produced crystals of hydrated calcium silicate. Seed crystals do not require energy to nucleate as is the case with conventional cement hydration, and existing nanocrystals only need to grow in a supersaturated solution in the pores. The setting of the cement binder is thus much faster. The use of this technology in concretes with FA could significantly improve their early strength parameters and at the same time increase the possible scope of their application. In the paper, the Authors conducted research on cement composites modified with the addition of FA (10%, 20% and 30%) and nanoadmixture (NA). The use of FA allows to reduce the amount of cement in the composite, the use of NA has a positive effect on the increase in strength in the first hours of the composite curing. In order to determine the influence of the applied modifications, the following tests were performed on cement composites: compressive strength test, bending strength test, setting time test, SEM-EDS test with elemental composition ratio analysis. All test carried out after 8, 12, 24, 72 hours. Strength test were also carried out after 28 days. Based on the conducted research, it was found that the negative impact of FA on cementitious composites and its course could be neutralized. The use of NA in modified composites allows for their wider use in composite industry.

Influence of elevated temperatures on the mechanical properties of glass fibre reinforced polymer produced by vacuum infusion

abst. 2144
Repository

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Fibre reinforced polymer (FRP) materials are being increasingly used in civil engineering structures (e.g. profiles, plates, shells, sandwich panels), mainly due to their advantages over traditional materials, such as high strength to weight ratio, durability, customised anisotropy and lightness. Nevertheless, concerns have been raised regarding their behaviour when subjected to elevated temperature and under fire exposure. In fact, even at moderately elevated temperatures (e.g. 100-200 ºC), FRP materials present considerable reductions of their strength and modulus, mainly due to the softening of the organic matrices caused by the glass transition process. Most previous studies on the influence of elevated temperatures on the mechanical properties of FRP materials focused on quasi-unidirectional composites, namely pultruded profiles, rebars and strips; much less information is available about FRP materials with more balanced fibre architectures. This paper aims at fulfilling the above-mentioned gap by presenting experimental and analytical investigations about the effects of elevated temperatures on the mechanical behaviour of glass-FRP (GFRP) laminates produced by hand lay-up, with a fibre architecture that is typical of what is used in sandwich panels for civil engineering structural applications. The experimental programme included: (i) tensile and compressive tests up to 300 ºC, and (ii) shear tests up to 200 ºC on such GFRP laminates. The thermo-physical properties of the GFRP laminates were also studied by means of dynamic mechanical analysis (DMA) and thermogravimetric analysis (TGA). The results obtained confirm that the mechanical properties of the GFRP laminates are severely affected by the temperature increase: compared to room temperature, at 200 ºC the shear modulus was reduced to 88%, whereas the reductions of the compressive strength and modulus were 96% and 67%, respectively. The tensile properties were less affected by temperature - at 300 ºC the residual tensile strength was 54%. These figures were compared with data available in the literature for quasi-unidirectional composites and the main differences were duly highlighted and explained. Finally, based on the test results, the accuracy of a temperature conversion factor and four empirical models to simulate the variation of the GFRP mechanical properties with temperature was assessed. The temperature conversion factor and the empirical models were able to provide good estimates of the experimental results obtained in the presented study, as well as those available in the literature.

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abst. 2145
Room 3
Tuesday
June 15
15h20

Investigation on economic notch connections for composite UHPC-CLT floor

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In modern construction, timber-concrete composite (TCC) structures are becoming a promising solution in terms of lightness, reduced use of materials and environmental impacts. In particular, the connection system plays an important role in ensuring the overall rigidity and strength, decreasing the slenderness and avoiding the uplift between the two materials. Among the types of connectors offered, the notched connector is appealing for its stiffness and capacity and competitive cost. By further optimizing TCC composite floor made of thin Ultra High Performance Concrete slabs connected with CLT slabs, which have been lately developed at Université Laval, this article aims at investigating the effect of different notch connection configuration. Four types of notch connector shapes were investigated: (i) rectangular with screw (ii) open trapezoidal shape with screw (iii) dovetail shape notch connection without screw. In addition, a glued connection was also investigated for comparison. The shear behavior of the connection was tested by push-out tests. All connectors showed a high shear stiffness in compared with previous experimental tests. While the notch connections exhibited a ductile shear behavior due to timber plasticization in the longitudinal direction of the wood fibers, the post-peak response of the glued connection was rather fragile. The connectors were compared in terms of key performance w such as stiffness (Ks), strength (Vmax) and ductility (Ds). The structural response of a UHPC-CLT floor was statistically estimated from the experimental shear law by means of a well-validated TCC FEM model. Finally, the latest TCC code was applied to evaluate their applicability to UHPC-CLT floor design prediction with developed connections.

The description of the adhesive properties of the composite, made of the epoxy resin coatin modified with waste feldspar-quartz powders and concrete substrate, by means of microstructure analyses.

abst. 2214
Repository

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In civil engineering, one type of coatings commonly used in industrial flooring are epoxy resin coatings. Unfortunately, relatively not much research has been done to date related to the properties of the epoxy resin coatings, in particular modified with waste powders. It should also be emphasized that epoxy resins are very expensive and harmful to the environment. Long-term work on the production and application of these resins can cause severe allergies to workers. Compounds contained in epoxy resins can persist in the environment for a very long time. Therefore, there is a need to find a solution to reduce the total mass of epoxy resins used to make such coatings. An ideal solution could be the addition of waste powders, e.g. waste feldspar-quartz powders. Waste feldspar-quartz powders come from the extraction and processing of mineral resources. Mineral waste is one of the largest waste streams in the European Union. These fine feldspar-quartz powders, are extremely hazardous in this form because they are often float in the air, get into the soil and water. Thus, these waste powders have the potential to cause pneumoconiosis, respiratory failure and affect the nervous system in animals. These powders will not be harmful when incorporated in solid epoxy resin. Therefore, the main goal of this research was to reduce the amount of epoxy resin in the coatings and to reduce the amount of waste feldspar-quartz powders stored on landfills. The addition of waste feldspar-quartz powders should improve, or at least not deteriorate, the properties of the epoxy resin coating. Considering the durability of the coatings, it is particularly important that these resins are characterized by high pull-off strength (minimum 1.5 MPa). Therefore, the specific goal of these research were, at first analyzing the pull-off strength of the epoxy resin coatings modified with waste feldspar-quartz powders. Another specific research goal was analysis of the microstructure and chemical composition within the interphase zone between epoxy resin and the substrate. The tests were carried out on a large concrete substrate with a thickness of 15 cm. The concrete substrate was divided into two areas with different methods of substrates surface treatment. Half of the concrete surface was mechanically grinded and then vacuumed. The other half of the surface was only patched after concreting and then vacuumed. On both types of surfaces, five squares with dimensions of 0.20 m x 0.18 m were separated for each type of waste powder and one square for reference sample. To assess the influence of the substrate surface treatment methods on the pull-off strength of the epoxy resin coatings. The morphology of the concrete surface was be examined using a 3D laser scanner and the MountainsMap program. A bonding agent was applied to all measurement squares. The epoxy resin coating was then applied with a gradually increasing content of waste feldspar-quartz powders. Two series of the tests were carried out for two selected types of feldspar-quartz powders with different grain sizes. Reference squares with the epoxy resin coating were also made without any waste feldspar-quartz powder addition, on the both types of the surface. The pull-off strength tests of the epoxy resin coatings were taken after the coating hardened. The measurements were made at three points for each square, using the pull-off method. Then, the chemical composition of the material was analyzed in the interface between epoxy resin and the substrate using a scanning electron microscope (SEM) and X-ray micro CT. Finally, the analysis of the porosity of the surface zone of the substrate were performed. The samples were evaluated for non-destructive evaluation of the microstructure using a micro-computed tomography. Analyzing the obtained data in ImageJ and Mathematica, graphs of fractional share of pores along the sample's height of the subsurface zone were obtained.

The thermal and mechanical analysis of polymer-cementitious floor composite made of epoxy resin and concrete substrate

abst. 2236
Room 1
Tuesday
June 15
12h40

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The concrete elements exposed on chemical aggression are often covered by epoxy resin coating. Preparation of composite made of polymer and cementitious materials allows to enhance the durability of the concrete. The epoxy resin layer covers the cementitious substrate and protects it against chemical aggression, abrasion or some low dynamic loads. The concrete substrate is still the construction element which is designed for external mechanical loads. The pull-off strength is the weakest point of the composite which guaranty the durability of the material. The pull-off strength of the material can be affected by exceeding its thermal shock resistance. The floor elements are exposed on mechanical loads of working forklifts. Many load situations are taken into account during design process. However, the forklift can cause the failure of the floor by affecting it with spinning wheel, what is not taken into account in design calculations. During this process the friction between the wheel and composite generates rapidly growing temperature. The friction also wears the composite. The high rise and fall of the temperature can exceed the thermal shock resistance of the composite. The performed studies focus on analysis of the temperature parameters of three different epoxy resins applied on concrete substrate and their correlation with mechanical properties such as pull-off strength test. The epoxy resins were analyzed with LFA, DIL and DSC methods. The studies were focused to analyze the impact of exceeding of thermal shock resistance on pull-off strength of the composite.

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abst. 2242
Room 1
Tuesday
June 15
12h00

Random Vibration of Composite Saddle Membrane Structure under Dynamic Impact

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Large-span composite membrane structure is light in weight and small in stiffness, which may produce violent random vibration under the random impact, such as wind, rain, hail and windborne debris. In order to accurately understand the random vibration response of membrane structure, the dynamics of composite saddle membrane structure under the random impact load is studied in this paper. Firstly, the governing equation of random vibration of the saddle membrane structure is established based on the large deflection theory of von Karman. The orthotropy of membrane material, the damping of the air and the geometrical nonlinearity of membrane deformation are considered in the governing equation. Then, according to the stochastic characteristics of the random impact velocity difference, the statistical model of the random impact load is obtained. Finally, the perturbation method is used to solve the partial differential equation of vibration analytically. Compared with the simulation and experimental results, the analytical solutions show very good agreement in the random vibration amplitude of the membrane structure. Meanwhile, it is also discovered that the displacement of saddle membrane structure decreases with the growth of the membrane pretension and arch-span ratio, while it increases with the growth of the velocity difference. Finally, the experiments show that even though the composite hail load is not enough to cause direct damage to the membrane, the saddle membrane structure will produce large deformation after the impact of composite hail. The cable tension decreases greatly, and the maximum relaxation rate may reach as high as 25%. Therefore, the relaxation caused by the impact load should be considered in the design of membrane structure. The stiffness and stability of the structure can be improved by increasing the rise span ratio and pretension; meanwhile, the pretension should be regularly detected, and the secondary tensioning can be carried out in time for maintenance.

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abst. 2269
Room 1
Tuesday
June 15
14h00

Dynamic nonlinear analysis and vulnerability protection of structures with base isolation systems

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Cancellara, Donato (), University of Naples Federico II, Italy

A strategy for the vulnerability protection of structures is discussed by presenting a dynamic nonlinear analysis of structures with different base isolation systems. The performance of structural frames is analyzed with different base isolation systems. The dynamic behavior of base isolated structures is studied with respect to multi-storey reinforced concrete buildings. A multi-storey reinforced concrete building characterized by irregularity in plan is considered in the analysis. The performance of different base isolation systems is evaluated by showing the dynamic behavior of the base isolated structure subject to strong seismic actions. In the comparative analysis it has been analysed the behavior of the structure with different base isolation systems. In the first base isolation solution high damping rubber bearing isolators actuated in parallel with friction sliders have been adopted. In the second base isolation solution lead rubber bearing isolators actuated in parallel with friction sliders have been adopted. A dynamic nonlinear analysis is performed for three-dimensional base isolated structural frames of the considered reinforced concrete building. Bi-directional ground motions compatible with the reference elastic response spectrum have been considered in the analysis together with the corresponding recorded accelerograms. The structural assessment and the dynamic behavior of the base isolated structure are evaluated. The behaviour of the structure is described and the dynamic nonlinear analysis is assessed by illustrating a comparative analysis of the seismic performance of a traditional fixed base structure and the seismic performance of a base isolated structure with the different considered base isolation systems.

Synergistic Effect of Addition of Siliceous Fly Ash and Granite Powder in Cementitious Composites

abst. 2291
Repository

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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.

Composites in Innovative Applications (chaired by L. Solazzi)

abst. 2051
Room 1
Tuesday
June 15
16h20

Dynamic Analysis of a Novel Composite Pump

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Pumps are vital components in machines. Pumps may be classified under "rigid-body pumps" and "compliant-body pumps". Compliant or flexible-body pumps have a compliant-body or membrane for generating the pumping action. The heart, the diaphragm pumps, and the actuating fluidic flexible-matrix-composite [1] are examples of compliant-body pumps. They enjoy a more gentle pumping action and forgo the need for bearings and their associated problems. Flexible matrix composites (FMC) possess "amplified" properties, which allow for some "out-of-the-box" unique applications. Exploiting some of these "amplified" properties, Ghoneim et al introduced a couple of compliant-body pumps with high pumping potential (volumetric-ejection efficiency): Barrel-shaped [2], Left-ventricle-like [3], and Hyperboloid [4] compliant-body pumps. They presented neither a dynamic analysis nor an estimation of the energy efficiency. The objective of the current work is to conduct a dynamic analysis, estimate the energy efficiency, and assess the merit and practicability of the novel Hyperboloid flexible-matrix-composite (FMC) pump. We introduce a lumped structural-fluidic model with a FMC tubular chamber, which includes the effects of the negative Poisson's ratio and the high effective coefficient of mutual influence. The model's parameters were estimated using classical fluid dynamics and a modified classical lamination theory of cylindrical laminate tubes [5]. The parameters of the inlet and exit openings were evaluated using classical fluid dynamics. The frequency response function (the applied torque versus the twist response as a function of frequency) as well as the energy efficiency was determined using the complex approach. Results demonstrate that while the pumping potential of the proposed pump is superior, the energy efficiency in general is small. However, at low frequencies the efficiency is high. Consequently, the analysis concludes that the proposed pump has a promising potential at low frequency applications: it enjoys a very high pumping potential (volumetric-ejection ability) as well as a high-energy efficiency, REFERENCES [1] Zhu B., Rahn C. D., and Bakis C. E. Actuation of fluidic flexible composites in structural media. Journal of Intelligent Material Systems and Structures 2012; Vol. 23:269-278. [2] Ghoneim H., Santos D. Evaluation of the pumping action of a barrel-shaped composite shell structure. ASME International Mechanical Engineering Congress Exposition, Proceedings 2010; Vol. 11: 347-355. [3] Chanda A., Ghoneim H. Pumping potential of a two-layer left-ventricle-like flexible-matrix-composite structure. Composite Structures 2015; Vol 122: 570-575. [4] Yen Z., Ghoneim H. A novel compliant-body pump with a high volumetric efficiency. Composite Structures 2016; Vol 153:578-584. [5] Herakovich C.T. Composite laminates with negative through-the-thickness Poisson's ratios. Journal of Composite Materials 1984; Vol. 18: 447-455.

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abst. 2109
Room 1
Tuesday
June 15
11h00

GFRP/CFRP hybrid composites with self-sensing capability for the ankle spring of exoskeleton robot

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Composite materials are expected to be used in diverse industry fields due to their high specific strength and stiffness. In particular, composite materials have been attracting a lot of attention in the robot field for weight reduction and performance improvement. In this study, the ankle spring of the exoskeleton robot for fast running was fabricated by GFRP/CFRP hybrid composites in order to assist the ankle torque of human by inducing high Ground Reaction Force (GRF). In addition, by measuring the capacitance change of the GFRP/CFRP hybrid composites, not only did we intend to identify the dynamic deformation of the structure, but we also intend to analyze the overall running locomotion. As a result, when wearing the exoskeleton robot with a composite ankle spring, the running performance was improved and the metabolic cost was relatively reduced. Moreover, when controlling the actuators at the exoskeleton robot using the running speed and GRF data derived from the change of capacitance of the composite ankle spring, running performance could be further enhanced.

Reusable sand composite mandrels for Multi-Stage Filament Winding

abst. 2169
Room 1
Tuesday
June 15
16h00

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Knippers, Jan (), ,

Multi-Stage Filament Winding allows to produce double curved fibre reinforced polymer components. The fabrication method is being developed by the Institute of Building Structures and Structural Design (ITKE) of the University of Stuttgart in collaboration with the industry partners Maus GmbH, Hähl Gmbh and CirComp GmbH. Multi-Stage Filament Winding mandrels consist of multiple mandrel parts required for multiple stages of winding. Simple mandrel removal is key for the feasibility of the method. The developed sand composites consist of synthetic or mineral sands and the emulsifying salt sodium polyphosphate (NaPO3). Due to the hydrolysis of the binding material, such mandrels can be broken back down into their constituent materials. The sand can be reused after drying. Different mixtures were evaluated by static load testing and prototypical winding. Silica sand composites show sufficient strength and stiffness for Filament Winding. The eco-friendly low-cost winding mandrels can be CNC milled into shape and is therefore free of geometric limitations. Closed laminates and lattice structures were successfully wound using silica sand composites. This publication describes the material development and the experimental evaluation of sand composite winding mandrels.

Integrative structural design of a hybrid coreless filament wound building system for inhabitable spaces: Maison Fibre

abst. 2182
Room 3
Tuesday
June 15
15h40

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The Institute for Computational Design and Construction (ICD) and the Institute of Building Structures and Structural Design (ITKE) of the University of Stuttgart were presented with the opportunity to design a large-scale installation for the 17th International Architecture Exhibition 2021 "How will we live together" in La Biennale, Venice. The Maison Fibre aims to rethink materiality in architecture by showcasing coreless filament wound structures as an inhabitable space. The resulting multi-storey building system consists of 10-wall and 20-slab components with a footprint of 2.5 by 2.5 meters and a total floor area of about 60 square meters. Each of the modules is robotically fabricated by coreless filament winding (CFW), a fabrication method developed by ICD and ITKE, where resin-impregnated glass and carbon filaments are freely spanned between anchor pins on a minimal steel frame or scaffold. The slab is designed as a hybrid structure combining fibre reinforced polymers (FRP) with laminated veneer lumber (LVL) to allow for walkability. During the integrative design process of this novel slab system, the optimum fibre layup was negotiated between the timber support span, load induction, boundary conditions, and material amount required. A total of four design iterations of the hybrid modules were load tested with the maximum enveloped forces resulting from the global structural simulation. The full-scale load tests were used to validate and calibrate the refined structural simulation of the slab components. The experimental process allowed for material reduction and validated the structural system's capability to withstand the design forces. In addition, the fibre layup was tailored and load adapted for the different components of the installation achieving further material optimisation. This publication describes the integrative design process of the hybrid slab system from initial concepts to the iterative optimisation of the structural system, demonstrating its potential for future applications.

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abst. 2200
Repository

STUDY THE FATIGUE PHENOMENON APPLIED TO HYDRAULIC CYLINDER MADE OF COMPOSITE MATERIAL

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This research concerns the fatigue design of a composite material hydraulic double acting cylinder, installed on a medium sized excavator for the bucket handling. The application of composite materials instead of the classic construction steel leads to innovative advantages in terms of lightness of the component itself, which can result in an increase of the performance of the machine on which the components are installed. It is important to underline that the hydraulic cylinders during their exercise life are continuously subjected to fatigue phenomena. The fatigue phenomena occur because the components are subjected to pressurization events at different magnitude. For this reason, it was chosen to address the fatigue phenomena applied to composite material. In order to compare the actual geometrical solution, the first phase of sizing was addressed assuming a hydraulic cylinder made of classical construction steel (S235JR-UNI EN 10027) and statically stressed. The small thickness pressure vessels theory was assumed for the barrel sizing. The next step regards the using of composite material instead of steel. The material adopted is a composite material, made by 40% of epoxy resin and 60% of carbon fiber. In this case the winding angle theory was assumed for sizing the hydraulic cylinder. Regards the feasibility point of view, a barrel realized only by composite material would have given structural problem at the junction level between the cylinder components; in particular between the barrel and cap end. Therefore, a composite barrel with a small thickness inner tube made of aluminium alloy was studied (Ergal 7075-T6), around which the composite material will be wrapped. The ends of the cylinder (end cap) realized in aluminium, will be welded to inner tube of the barrel and, through a specific geometry they will be partially coated by composite material so as to cooperate with the barrel cylinder. Finished this initial phase of static dimensioning and feasibility study, it was possible to appreciate a considerable weight reduction of entire component equal to 86% for hydraulic cylinder made of composite material with respect to the one made of steel material. After a preliminary sizing by static analyses, the fatigue study was performed. Researches show that these components are mainly subjected to pulsating fatigue from zero. The fatigue phenomenon was studied assuming the bibliography information especially in term of fatigue performance of composite materials. In particular, three different approaches were used, highlighting substantial differences between them and the most critical zones of the cylinder. The three theories adopted are the following: 1) micromechanics of orthotropic laminate; 2) carpet plot; 3) winding angle. For each theory implemented it has been obtained the percentage of failure and the relative safety factor. It is important to underline that the three methodologies used for composite materials lead to a very similar result, for example for the barrel thickness (the variation is of the range of few percentages) also if the base assumption and the development is different for the three theories adopted. The obtained analytically results are confirmed by ones obtained by FEM analysis, both for the static analysis and the fatigue one, where the S-N curve were assumed by literature. The analytical and numerical results permitted the correlation between the static and fatigue safety factors. In particular it is important to point out that the mechanical behaviour of the hydraulic cylinder made of composite material is very similar to the one made of steel. The weight of composite material hydraulic actuator is about 13,7 % of the steel one. The next step of the research is related to build the component (scale 1:1), whom will be experimental tested (by strain gauges). This activity will permit to test the analytical and numerical model developed for this research for sizing the hydraulic cylinder.

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abst. 2232
Room 1
Tuesday
June 15
15h20

Coreless Filament Wound Fiber-Polymer Composites Structures in Architecture: a state-of-the-art review

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In the context of architecture and civil engineering, large scale FRP components are mostly produced through manufacturing techniques such as manual layup, closed molding processes and pultrusion. Although very successful and widely used in the production of standardized parts, the high level of customization resulting from the prototypical character of an architectural project renders such fabrication methods not very well suited when complex or bespoke geometries are to be realized. To overcome these issues, the institute for Computational Design and Construction (ICD) together with the Institute of Building Structures and Structural Design (ITKE) of the University of Stuttgart developed several strategies, derived from industrial filament winding processes, for robotic core-less filament winding (CFW). Compared to the aforementioned FRP manufacturing methods this fabrication technique replaces molds with minimal and reconfigurable formwork equipped with winding pins (anchor points), whose position and orientation are fixed in the space. In such fabrication process, resin impregnated fibers are hooked to the anchor points by means of a robotic arm. The component geometry gradually emerges from the interaction of free spanning fibers, and their subsequent deformation, as they are progressively deployed into the system. Over the past decade, several experimental structures ranging different scales, have been realized as research demonstrators by ICD and ITKE, as well as other academic institutions and private companies. The article provides an overview on the coreless filament wound fiber composite structures developed and realized. It examines the specifics of such structures and highlights the novel aspect of the research successively introduced by each case study. It also showcases how in this specific context of coreless filament wound fiber composite structures, both global geometry and details' planning are not merely the result of imposed top-down design choices but instead the complex outcome of a system of interrelations between architectural design, material, fabrication and structural requirements.

Three-point bending of closed profiles with an omega cross-section, made by additive processing, reinforced by glass fiber

abst. 2243
Room 1
Tuesday
June 15
15h40

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Omega profiles are now widespread in a variety of industries. They are often used to make structural elements of aircraft, automotive vehicles, boats, elements used in construction. They are also subject to various types of loads, such as static, dynamic or fatigue. On the other hand, the additive manufacturing technology (3D printing) is relatively young and is not yet widely used in industry. However, 3D printing technology has enormous potential that can be released over time and affect every area of our lives. In the paper, it was decided to test specimens with dimensions of 300x84x36 mm in the shape of a closed omega profile, made in 3D printing technology. Specimens made of plastic were reinforced in the lower plane with stripes of epoxy resin-encapsulated glass fiber to increase strength of them. For comparison, reference specimens were also made without glass fiber reinforcement. The samples prepared in this way were subjected to three-point bending in one plane, and the analysis of the mechanical response of these elements was carried out. The results allowed to determine the legitimacy of the use of reinforcement of elements obtained from 3D printing and allowed to determine the load-bearing capacity and nature of damage to the samples.

The effect of the addition of recycled steel fibers on the properties of ultra-high performance self-compacting cementitious composites

abst. 2289
Room 1
Wednesday
June 16
10h10

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The utilization of waste products is one of the major concerns for many environmental agencies all around the world. Advanced technological achievements and the continuous growth of economy have made the disposal, recycle and reuse of industrial by-products a severe challenge. Utilization of industrial waste materials in cementitious composites compensates the lack of natural resources, solving the disposal problem of waste and to find alternative technique to safeguard the nature. Recently, amount of scraped tyres into the landfill are increasing annually due to increasing tyres production as an ancillary consumables in automobiles. It would be economically and ecologically a great values if extracted recycled fibers from those scraped tyres could be employed as an reinforcement in the production of cementitious composites. Recycled steel fibers (RSFs) were used in fiber reinforced cementitious composites, especially ultra-high performance concrete. Based on this facts, this study addresses a new generation of recycled ultra-high performance self-compacting mortar (UHPSCM) reinforced by recycled steel fibers derived from waste and scraped tyres. The UHPSCM has been designed based on particle packing density model, and modified with different dosages of silica fume and fly ash. Finally, the fresh and hardened properties of the developed cementitious composites are evaluated and analyzed. The behavior of UHPSCM was experimentally studied in the fresh and harden phases. Fresh properties were mainly characterized by slump flow. On the other side, the hardened properties were investigated in terms of compressive, splitting tensile, and flexural strengths. Further, ultrasonic pulse velocity tests were conducted for nondestructive test. To characterize the above properties, a total of six series of cementitious composite mixtures were prepared. Three of those mixtures were proposed as a referenced specimens by varying water to cement (w/c) ratios of 0.17,0.18 and 0.19 without using any reinforcement of RSF. In the next three mixes, w/c ratio was consider as constant to be 0.21 and RSF with the volume fractions of 1%,2% and 3% were utilized. The results highlighted a fairly negligible influence of RSF in terms of compressive strength, whereas a significant decay in the post-cracking behavior was observed in specimens with higher fractions of RSF. However, a significant enhancement in the bending response was observed with respect to the case of referenced specimens, even for specimens reinforced by low content of RSF.

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abst. 1013
Room 1
Tuesday
June 15
11h20

Cement Composites to Detect Elevated Temperature with Colors

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Cement-based materials are widely used in various applications, which exhibit notable resistance under different environmental conditions. At high temperatures, the cementitious materials undergo gradual physical and chemical changes, which result in the cracking and spalling, reduction of strength, increase in deformation, and damage between concrete and steel, even though they can maintain considerable strength to a certain extent. Thus, adequate repair and maintenance should be followed to allow the structure to work properly. In general, several tests, such as core and rebound hammer tests, ultrasonic velocity, petrographic examination, and drilling resistance, are conducted to assess the condition and strength of concrete subjected to high temperatures. These tests usually performed in the field have some issues, such as cost, error, and samplings, and they hardly provide a complete picture of degree of deterioration. Thus, this study developed cement composites which can provide temperature information with color changes on structural elements. For this, the composites were heated in the furnace from room temperature, and the change in the color properties of the cement composites were analyzed using photographs captured at each temperature interval. The results of the study showed light grayish yellow at room temperature but dark grayish orange at 300 °C. The RGB values of the cement composite were stable until 270 °C and increased rapidly at 300 °C where color change was obtained. This research was supported by a grant from Mid-career Research Program (NRF-2019R1A2C1006494) through the National Research Foundation (NRF) of Korea.

Computational Mechanics in Manufacturing of Composite Structure (chaired by Yingjie Xu, Hui Cheng, Yuliang Hou)

An insight into the mechanical behavior of plain-woven-composite adhesively bonded joints using a multiscale approach

abst. 2060
Repository

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The mechanical behavior of plain-woven-composite adhesively bonded joints has been investigated using a multiscale modeling approach. The microscopic and mesoscopic representative volume elements (RVEs) have been constructed using the hierarchical architectures of plain woven composites. Based on the local homogenization of the mesoscale modeling, an equivalent cross-ply laminate (ECPL) cell has been developed to represent the woven architecture. It aims not only to accurately compute the effective properties, but also to efficiently retain the local behavior within composites. The macroscopic models of single-lap joints (SLJs) and donble-lap joints (DLJs) fabricated with plain woven composites, are constructed by topologically arraying the ECPL cells. Combined with continuum damage mechanics (CDM) and cohesive zone model approaches, the mechanical behavior and failure mechanisms are predicted for the SLJs and DLJs subjected to tensile load. Moreover, experimental tensile tests have been performed on the corresponding composite joints, verifying the reliability of the multiscale models. Parametric studies of the overlap length and width, as well as the bondline thickness have been carried out using numerical simulations to analyze their effect on the bonding performance. Finally, this study provides an optimization cafeteria to effectively enhance the load carrying capacity of adhesively bonded CFRP joints based on the simulation results.

A multi-scale modeling framework for low-velocity impact and compression after impact behaviors of plain woven CFRP composites

abst. 2064
Repository

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A multi-scale modeling framework, consisting of microscale, mesoscale and macroscale models, is developed to investigate the low-velocity impact (LVI) and compression after impact (CAI) behaviors of plain woven CFRP composites. Based on the maximum principal stress failure criterion and stiffness degradation method, a microscale representative volume element (RVE) model is constructed to predict the effective properties of fiber tows. To estimate effective properties of the composites, various loading scenarios are performed on a mesoscale RVE model established using the obtained effective parameters and the internal woven architecture. Wherein, the continuum damage mechanics (CDM) approaches are used to capture the damage behaviors. A new equivalent cross-ply laminate (ECPL) cell, including and subcells, is proposed to simplify the mesoscale RVE model based on a local homogenization method. And then, a macroscale model extending the ECPL cells, is established to predict the LVI and CAI behaviors of the plain woven CFRP composites with various impact energies. The ECPL cell can efficiently bridge the mesoscale and macroscale models, significantly reducing the computational but providing high-accuracy. Finally, the corresponding experiments are implemented to validate the effectiveness of the multi-scale model. The numerical results indicated that, the residual compressive strength of plain woven composites is decrease in a nonlinear manner with the increase of impact energy, and the failure is dominated by the delamination rather than the intralaminar damages during the CAI process.

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abst. 2202
Repository

The effect of EMAA self-healing agent on healing performance of CFRP laminates

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Introduction In traditional resin matrix composite laminates, weak resin matrix or interlaminar adhesive layer plays a role of load transfer. When subjected to bending, shear, impact and other loads, the material will produce interlaminar failure. Delamination will decrease the local stiffness of the laminate, forming a potential safety hazard, and then lead to yield and eventual failure. At present, for damaged composite components, the main methods are patching technology, which can restore 70% - 80% strength and impact resistance of components in a short time. However, in practical application, the requirements for repair equipment and condition are high, and the repair quality is difficult to be controlled. How to improve the interlaminar strength and impact damage resistance of composite laminates efficiently is an urgent problem. With the rapid development of intelligent materials and advanced material design concepts, self healing and interlaminar toughening are two ideal ways to solve the delamination damage and improve the impact resistance of composites. Recently, a thermoplastic material is used to heal cracks, delamination and impact damage of epoxy resin laminates after heating and activation. It is proved by researches that using thermoplastic resin as the healing agent of thermosetting materials, the healing efficiency of delamination damage is 200%, and the elastic modulus can be restored by 80%. In this study, the research on the interlaminar toughening and self-healing damage performance of self-healing structure is carried out. Through this study, the healing mechanism of thermoplastic prosthesis is investigated, and the collaborative design of toughening stitch thread and thermoplastic healing agent is performed, which provides references for improving the performance of composite materials and healing material damage. Specimen preparation and numerical simulation Using t300-3k prepreg and EMAA stitch threads, self-healing DCB specimen was made by using hot pressing method. According to ASTM d5528-01 standard, the double cantilever beam experiment was carried out on the composite specimens with or without self-healing stitch threads. A three-dimensional finite element model of self-healing specimen was also established in ABAQUS. The self-healing model consists of composite laminate and EMAA stitch thread through the composite. Eight node hexahedral solid element (c3d8) was used to mesh composite laminates, and zero thickness eight node bonding element (coh3d8) was used to divide interlayer adhesive layer. EMAA stitch thread was simulated by nonlinear spring. Results and Conclusions The results show that the interlaminar fracture toughness of the composite with EMAA can be effectively improved by establishing a bridging area at the intermediate interface compared with that without EMAA. (1) According to the structural characteristics of the specimen with self-healing EMAA stitch thread, a finite element model was established to simulate the self-healing agent and resin matrix. The correctness of the simulation model was verified by comparing with the experimental results. (2) By activating EMAA by heating, the fracture toughness of the specimen after self healing is well restored, which indicates that EMAA self-healing agent provides higher interlaminar toughness than the initial condition without self healing. (3) The low velocity impact finite element model of EMAA self-healing composite structure is established, and the effects of different impact energy and suture parameters on the low velocity impact performance are studied. It shows that EMAA stitched structure can effectively improve the performance of the composite structure against impact damage.

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abst. 2254
Repository

Improving Mode II delamination resistance of curved laminate using z-pin

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In this paper, experimental and numerical studies are conducted to investigate the effects of z-pin on the mode [U+2161] delamination resistance of carbon fiber-epoxy curved laminate. A z-pining process with the pre-hole technique to minimize in-plane damage is firstly developed. Experimental tests of the z-pinned curved sample subjected to End Notched Flexure (ENF) loading are then conducted. The test results show that z-pin increases the stiffness of the laminate, reduces the crack growth rate and improves the fracture toughness. The delamination crack growth rate is reduced with the increase of z-pin diameter and volume fraction and a reduction up to 40% is achieved compared with the sample without z-pin. The Mode [U+2161] fracture toughness is significantly improved with the increase of z-pin volume fraction. It is observed that the fracture toughness increases about 250% with only 1% increase of z-pin volume fraction. In addition, finite element model of the curved laminate with z-pin is developed to investigate the delamination fracture behavior in detail. The FE model adopts nonlinear spring element to represent individual bridging force exerted by z-pin, which can account for large-scale bridging force. The FE model agree well with experimental results. A parametric analysis is then conducted to investigate the influences of z-pin volume fraction and diameter on delamination resistance.

Micro-mechanical modeling study of the influence of cure process on the interfacial cracking of Z-pinned laminates

abst. 2255
Repository

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Cure-induced residual stresses have a great impact on the mechanical behavior the fiber reinforced resin composites. This paper presents a three-dimensional micro-mechanical finite element (FE) modelling strategy for predicting the cure-induced residual stresses and the interfacial cracks around the Z-pin of a Z-pinned composite laminate sample. Based upon the actual microstructural configuration of the sample, a unite cell model is developed and the cohesive element is employed to model the interphase between Z-pin and the laminate. The Benzeggagh and Kenane (B-K) propagation criterion is applied to determine the failure mechanism around the Z-pin. FE modelling results indicate that the thermal expansion and chemical shrinkage mismatch between the Z-pin and laminate can generate large residual stresses in the cure process. The cooling process of the cure has a significant influence on the residual bond strength of the Z-pin/laminate interphase. Numerical simulation results show that the cure-induced residual stresses could even result in the interfacial cracks around the Z-pin, which coincide well with the scanning electron microscopy of the samples. Furthermore, the influences of the cure cycle parameters on the residual stresses and cracking area around Z-pin are discussed.

Process modelling of manufacturing of polyamide 6/carbon fibre by infrared lamp (IR) assisted automated fibre placement

abst. 2261
Room 2
Tuesday
June 15
10h10

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This paper investigates the effect of temperature and pressure of infrared (IR) assisted automated fibre placement on the thermoplastic laminates through ABAQUS simulation and experiments. Manufacturing of thermoplastic laminates with automated fibre placement involves different process parameters, which affects the property of final product. The tape melts when the IR lamp irradiates, and consolidation roller presses the tape onto the substrate or tapes with the pressure. Distribution of temperature and pressure are monitored throughout the process using thermocouple and pressure sensor respectively. A thermal simulation of the process is done with the measured values to understand the effect of temperature and pressure on the bonding between the tapes and also with substrate. Structural analysis and microstructure study are done with manufactured laminates are compared with the simulation results for better understanding.

Delamination and fracture

Telephone cord blisters driven by pockets of energy concentration in multilayer films

abst. 1009
Repository

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Blisters are frequently observed to nucleate and develop, apparently spontaneously, in thin compressed films. For instance, circular and straight blisters that nucleate and grow from a central region or an edge can develop into telephone cord blisters (TCBs) and web blisters, which propagate forward with wavy boundaries between the coating film and the superalloy substrate. Yuan et al. [1–4] modelled the nucleation and growth of TCBs as being driven by pockets of energy concentration (PECs), with primary and secondary buckling subsequently driving the development, and with energy being seamlessly transmitted to the TCB tip to provide the necessary crack-driving force. Yuan et al. [1–4] reported completely-analytical formulae to predict the morphology parameters of TCBs in films with isotropic materials subjected to biaxial compressive residual stresses, that is, local width and height, and global wavelength and transverse amplitude. The current work further develops the authors' PECs theory for TCBs in multilayer films, which are typical of many advanced coating systems, such as thermal barrier coating systems. Variable through-thickness Young's modulus, Poisson's ratio and coefficient of thermal expansion are introduced into the theory, and the resulting equations are valid across the ranges of TCB width and transverse amplitude-to-wavelength ratio. Mechanical conditions for the TCB formation in multilayer films are also presented. The developed theory agrees very well with experimental results. This work provides mechanical understanding on blister development, coating adhesion and blister shape, and can guide improvements in the industrial design of coating material systems.
References: [1] Yuan B, Harvey CM, Thomson RC, Critchlow GW, Rickerby D, Wang S. Spontaneous formation and morphology of telephone cord blisters in thin films: The formulae. Compos Struct 2019;225:111108. doi:10.1016/j.compstruct.2019.111108. [2] Yuan B, Harvey CM, Thomson RC, Critchlow GW, Rickerby D, Wang S. A new spallation mechanism of thermal barrier coatings and a generalized mechanical model. Compos Struct 2019;227:111314. doi:10.1016/j.compstruct.2019.111314. [3] Harvey CM, Wang B, Wang S. Spallation of thin films driven by pockets of energy concentration. Theor Appl Fract Mech 2017;92:1–12. doi:10.1016/j.tafmec.2017.04.011. [4] Wang S, Harvey CM, Wang B. Room temperature spallation of -alumina films grown by oxidation. Eng Fract Mech 2017;178:401–15. doi:10.1016/j.engfracmech.2017.03.002.

Telephone cord blisters in hydrogel films

abst. 1010
Repository

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Hydrogel is finding more applications in biomechanical engineering due to its soft and super elastic nature which provides excellent compatibility with biomaterials [1]. One potential application is to

fabricate functional devices of various surface morphology patterns by using soft hydrogel films instead of hard solid films [2,3]. The latest work [4] reports such an interesting study on the dynamic creation of 3D hydrogel architectures via selective swelling programmed by interfacial bonding.Telephone cord blisters (TCBs) with various morphology parameters in hydrogel films are generated by systematically controlling hydrogel composition, solvent concentration, temperature, etc. The present study is to apply and extend the mechanical model developed in authors' recent work [5] to predict the morphology parameters of these TCBs in hydrogel films [4]. As hydrogel is highly deformable and flexible, these TCBs have very large transverse amplitudes which indicate deep post secondary buckling with large geometrical nonlinearity. The authors' mechanical model [5] for thin TCBs with small transverse amplitude to wavelength ratios still gives accurate predictions for the two local morphology parameters, that is, the height and width; however, it is unable to give accurate predictions of the two global morphology parameters, that is, the wavelength and transverse amplitude. In this work, analytical formulae are derived based on the mechanical model [5] to predict these two global morphology parameters. The predictions are in excellent agreement with the test results [4]. The mechanical model provides a valuable means for the design of functional devices with topological features composing various blisters of straight, circular, TCBs and web blisters by using soft films in biomechanical engineering. References: [1] Zhang YS, Khademhosseini A. Advances in engineering hydrogels. Science 2017;356:eaaf3627. https://doi.org/10.1126/science.aaf3627. [2] Liu Y, Kenry, Guo Y, Sonam S, Hong SK, Nai MH, et al. Large-Area, Periodic, Hexagonal Wrinkles on Nanocrystalline Graphitic Film. Adv Funct Mater 2015;25:5492–503. https://doi.org/10.1002/adfm.201502010. [3] Ren H, Xiong Z, Wang E, Yuan Z, Sun Y, Zhu K, et al. Watching Dynamic Self-Assembly of Web Buckles in Strained MoS2 Thin Films. ACS Nano 2019;13:3106–16. https://doi.org/10.1021/acsnano.8b08411. [4] Takahashi R, Miyazako H, Tanaka A, Ueno Y. Dynamic Creation of 3D Hydrogel Architectures via Selective Swelling Programmed by Interfacial Bonding. ACS Appl Mater Interfaces 2019;11:28267–77. https://doi.org/10.1021/acsami.9b05552. [5] Yuan B, Harvey CM, Thomson RC, Critchlow GW, Rickerby D, Wang S. Spontaneous formation and morphology of telephone cord blisters in thin films: The formulae. Compos Struct 2019;225:111108. https://doi.org/10.1016/j.compstruct.2019.111108.

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abst. 1012
Room 1
Monday
June 14
16h00

Numerical simulation of blister development and spallation in thin coatings

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Blisters of alumina oxide films formed on the surface of Fe-Cr-Al alloy substrates at 1200 °C have been observed to develop and subsequently spall off, apparently spontaneously, after cooling to room temperature. The process is unlikely to be solely buckling-driven as the blisters nucleate and grow below the critical buckling size for the residual compressive stress in the oxide, and after reaching room temperature at constant residual compressive stress. The authors recently hypothesised that pockets of energy concentration (PECs) may be responsible for the phenomenon, whereby concentrations of tensile stress and shear stress on and around the interface between the coating/substrate provide the additional energy source in addition to the residual stress for blisters to nucleate and propagate. That work showed that the mechanical consequences of PECs are in excellent agreement with the observed behaviour, and can predict the unstable growth size, spallation size, and blister morphology very accurately. The latest work now considers the origin of PECs, that is, how can sufficient concentrations of tensile and shear stress on the substrate/coating interface come to exist? The finite element method (FEM) is used to make a numerical study of the development and spallation circular blisters of alumina oxide on Fe-Cr-Al substrate. Various mechanical phenomena are accounted for, including the effects of thermal expansion coefficient mismatch, creep, oxidation, diffusion, thermal cycling, and localised non-uniform temperature during cooling.

Delamination, damage and fracture

Investigation on low-velocity impact damage and CAI characteristics of hybrid normal/thin ply composite laminates

abst. 2052
Room 2
Wednesday
June 16
12h00

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The most common and important damage in composite laminates is low-velocity impact damage which normally results in significant degradation of the load capacity of the compressive strength (CAI) of composite structures. Experimental and numerical investigations on the low-velocity impact damage and CAI characteristics of hybrid normal/thin ply composite laminates are reported in this paper to provide comprehensive understanding of damage evolution and failure mechanisms for optimization design of hybrid composite laminates. Low-velocity impact tests are carried out for composite laminates with normal ply only and different hybrid normal/thin ply staking sequence designs, respectively. Three dimensional numerical models using ABAQUS are developed to simulate the damage evolutions during the low-velocity impact experiments. The in-plane damages are modelled with progressive damage law based on continuum damage mechanics, and the delamination damage initiation and growth by the cohesive elements and a mixed-mode traction separation damage law. The numerical results are compared with the experimental results to validate the models and the different damage mechanisms within the normal and normal/thin ply composite laminates. Subsequently, compressive after impact (CAI) tests are carried to assess the CAI strength of the different composite laminates. The numerical modelling developed for the low-velocity impact simulation is also adapted to simulate the CAI tests with only modification of the boundary conditions. The numerical simulations identified the complex feature of interactions among local buckling and delamination propagation and final global bucking for composite laminates with impact damages under compressive loading. The simulation results are validated by the comparison with the CAI experimental results.

Predictions of Damage in SiCf/SiC Ceramic Matrix Composites by Considering the Coupling of Multiple Failure Modes

abst. 2105
Room 2
Wednesday
June 16
11h40

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SiCf/SiC ceramic matrix composites (CMCs) have the characteristics of high temperature resistance, wear resistance, high temperature creep resistance, low thermal conductivity, low thermal expansion coefficient, chemical corrosion resistance, high strength, high hardness, etc. Excellent oxidation resistance in oxygen environment makes it one of the preferred materials for aero-engines. The toughening mechanism of SiCf/SiC CMCs has been the focus of research, and the theoretical model and simulation of single failure mode are mature, but the coupling between multiple failure modes has not been considered so far. In this paper, fracture mechanics and finite element method are adopted to consider the scale effect according to Weibull distribution, and the equivalent volume element (RVE) modeling and simulation are implemented for the main failure modes, such as SiCf/SiC CMCs matrix cracking, fiber/matrix interface debonding, fiber failure and pulling out. The main failure modes of SiCf/SiC CMCs are predicted according to the properties of interface layer by crack deflection criterion. Considering the contribution ratio of multiple failure modes, the coupling of multiple failure modes is simulated. In addition, the temperature field is introduced to consider the thermal coupling effect of SiCf/SiC CMCs under operating condition. The modeling and simulation of SiCf/SiC CMCs with multiple failure modes are implemented using the multi-scale method to determine the stress at

crack initiation from microstructural flaws and resulting crack pattern, so as to predict the mechanical behavior of SiCf/SiC CMCs.

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abst. 2149
Room 2
Wednesday
June 16
11h20

Impact Damage Morphology of STF-incorporated Sandwich Composite Structures using a 3D X-ray Micro-Computed Tomography Technique

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The susceptibility of sandwich composite structure towards low-velocity impact (LVI) loading might induce barely visible impact damage (BVID) resulting in reduction of residual strength. In this study, the morphology and severity of impact-induced damage in the STF-incorporated sandwich composite structure was analyzed by a 3D X-ray micro-computed tomography (μCT) technique. Three types of sandwich composite structure, namely pristine, with STF-filled core, and with STF-filled facing were subjected to LVI at several energy levels, to investigate the influence of impact energy on the impact behavior and damage of structure. Investigation on impact behavior shows that the incorporation of STF improved the energy absorption of the structure. The μCT was used to examine the cross-sectional views and internal damage of the impacted sandwich structures, showing the damage morphology of carbon fiber reinforced polymer facing and the 3D printed honeycomb core. It was discovered that the impact damage modes in the structure consist of delamination, debonding, fiber breakage, core crushing and core breakage. Based on the surface damage at the point of impact, it was found that the damage severity of the structure grows as the impact energy increased. Acknowledgment. This research was supported by the National Research Foundation of Korea (NRF) Grant funded by the Korea government (MSIT) (No. 2019R1A2C4070280).

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abst. 2186
Repository

Numerical simulation of the compression crushing energy of carbon fiber-epoxy woven composite structures.

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The crashworthy behavior of composite material is investigated in an experimental campaign and then simulated using the explicit Finite Element solver ESI-VPS. The Ladevèze and the Waas-Pineda damage models are implemented here in their modified versions, specifically designed for the use with woven fabric material. The former uses a conventional continuum formulation of damage, while the latter introduces a traction-separation formulation to model virtual cracks with prescribed fracture energy, with the aim to simplify the population of the material card and the calibration of the numerical model. Characterization tests are carried out on a plain weave carbon fiber-epoxy tape, in particular, tensile and compressive tests on notched coupons are conducted and analysed as reliable and representative method to measure the crushing resistance under controlled conditions, which can then be easily extrapolated to be applied to a composite structure under compressive crushing load. Calibration of the numerical models is carried out by simulating the experimental tests of coupons, the models are then validated against the quasi-static crushing of specimens with one reference geometry and two different layups. Results show that the using a non-local damage formulation like in the Waas-Pineda model has advantages over the traditional continuum formulation of Ladevèze, since the definition of fracture energies for the virtual cracks, as well as the stress level in the post-damage state, simplifies the calibration process, and allows to obtain reliable results for all configurations tested.

Mechanical and fracture response of composites based on commingled recycled carbon fibres/PPS fibres

abst. 2213
Repository

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There has been a rapid growth in CFRP applications over the last decade in multiple industries, especially in the aerospace and automotive sectors. This was accompanied by a rapid global increase in the CFRP waste, which includes testing materials from research and design, manufacturing scrap, out-of-date prepregs and end-of-life parts. For this reason, the developments of recycling process and CFRPs based on recycled carbon fibres are attracting considerable attention in recent years. In this work, the mechanical and fracture response of CFRPs produced from non-woven mats containing commingled recycled carbon fibres/PPS fibres were studied. An UV-irradiation process was applied to the mats prior to the laminate manufacturing. This improved the surface functionalisation of the PPS fibres, as well as removed the organic contaminating on the surfaces of the fibres, and hence increased the adhesion between the PPS matrix and the recycled carbon fibres (rCFs) within the laminates. It was found that an improved PPS/rCF adhesion slightly increased the mechanical properties of the laminates, i.e., the modulus and strength of the recycled CFRPs increased by approximately 10%. Moreover, the in-plane and out-of-plane fracture behaviour of the recycled laminates were also studied using a compact-tension (CT) test and a Double cantilever beam (DCB) test. It was observed that the in-plane fracture toughness increased by 25.7% upon applying the UV-treatment to the mats, as a higher fibre pull-out force was required during the CT test. In contrast, an improved PPS/rCF adhesion caused a drop of 22.3% in the out-of-plane fracture energy, owing to the decreases in the fibre bridging mechanism during the fracture process.

Influence of process conditions on hole quality and delamination in drilling of two-layer sandwich structures

abst. 2259
Repository

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Hybrid sandwich structures have been used in many industries. Due to their properties, they are an alternative to solid constructions. One of the difficulties in using this type of material is join sandwiches in large-size structures. Assembling of sandwiches usually needs the high-quality holes. Drilling of the structure consists of dissimilar materials can result in numerous defects. The purpose of the work is to assess the hole quality and the occurrence of delamination during drilling of sandwich structures. Drilling results with a drill and a diamond milling tool were compared. The machining was performed with a variable cutting speed. The tests were carried out for two configurations of the arrangement of the layers – Al/CFRP (aluminium alloy–carbon fibre reinforced polymer) and CFRP/Al (carbon fibre reinforced polymer–aluminium alloy) stacks.

DELAMINATION GROWTH AND POST-BUCKLING BEHAVIOR OF COMPOSITE LAMINATE WITH FLAW UNDER COMPRESSION

abst. 2262
Room 2
Wednesday
June 16
16h00

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Composite laminates contain flaws that are induced during practical manufacturing especially in aerospace engineering applications. The behavior of such laminates under compressive loading is more complex than that under tensile loading. This behavior has not adequately been studied in the existing literature. In the present work, the composite laminate with through-the-width delamination under compressive loading is considered to study its delamination growth and post-buckling behavior based

on the three-dimensional FEA. The commercial software ANSYS® is used for this purpose. The 3D 8-node SOLID185 layered structural solid element with enhanced strain formulation and the 3D 8-node INTER205 element are used in the laminate modeling and interface modeling respectively. The Virtual Crack Closure Technique (VCCT) is used to calculate the Mode I, Mode II and Mode III energy release rates along the delamination front of the laminate. Computed strain energy release rates across the width of the laminate are validated using the results available in the literature. The effect of the ply orientation angle difference at the delamination interface on the energy release rates is quantified. An appropriate linear fracture criterion is used for predicting the delamination growth. The laminate with the delamination is further studied for its post-buckling behavior. The influence of the delamination on the post-buckling behavior is investigated.

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abst. 2267
Repository

Nanoparticle dispersed resin injection repair for the damaged composite structures under low velocity impact

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In this study, the delaminated composite structures under low velocity impact were repaired by resin injection. Injection repair of modified resin was investigated as an effective composite repair method to recover the static strength and stiffness. The carbon nanotubes (CNTs) dispersion was conducted with different contents (0.1, 0.3 and 0.5 wt.%) using a 3-roll mill. A static load was applied to create the delamination in the specimen. The resin injection repair was conducted using custom designed system. The repair performance was evaluated by varying the CNT contents in the resin. The results of C-scan and cross-section analysis revealed excellent resin injection into the delaminated region. The three-point bending tests and Compression after impact (CAI) tests were conducted to verify recovery rate of mechanical properties. The repaired specimens showed improved mechanical properties with increase of CNTs contents. The SEM images of fracture surface were obtained to investigate correlation between mechanical properties and CNT dispersion. It was demonstrated that CNTs acted as efficient filler material in the matrix. The experimental results validate the proposed modified resin injection repair method.

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abst. 2290
Repository

Barely visible impact damage in carbon fibre/epoxy laminates: resin-injection repair method

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Purpose: Several types of repair methods, namely patch, scarf, stepped, and resin-injection method can be employed to repair damaged fibre reinforced composite structures. Here we described a novel portable resin-injection device for composite repair where the damage site was barely visible. Approach: The device featured an enclosed cylindrical chamber, with one inlet for resin injection and two outlets which may be used for driving out air (thus creating a low pressure environment), coupled to a suction cup for mounting onto the damaged site. Low pressure (optional) was intended to extract debris and stimulate the flow of the resin into the crack site. To repair a damaged site under low pressure, a vacuum pump and a hot bonder were attached to the device for air extraction (27 inHg) and low-pressure monitoring in the chamber. A 55-cc syringe barrel, with a 20AWG dispensing tip aimed at the damaged site, was used for dispensing the resin. For high precision resin injection, the syringe could be controlled by a liquid control unit pre-set to an air pressure of 0.3 MPa, by connecting the syringe barrel to the unit by an air hose. The resin-injection operation typically lasted about 5 minutes. The repaired laminates were cure at room temperature over 24 hours. In this study, the device was employed to repair barely visible impact damage (BVID) on rectangular specimens of 16-ply

and 24-ply carbon fibre reinforced polymer (CFRP) composite laminates. The BVID was created by subjecting the specimens to a quasi-static indentation to simulate low-velocity impact. For the purpose of comparison, the repair efficiency of specimens done at low-pressure environment was compared with those done at normal atmospheric pressure. Also, three different types of resins (neat epoxy, E1HNT, and NF100) were studied for repair effectiveness. Here, E1HNT represented epoxy blended with 1% (volume fraction) of halloysite nanotube and NF100 (a commercial product) referred to epoxy resin blended with carbon nanotubes. The repaired specimens were subjected to in-plane compression (at a predetermined strain rate to fracture) to determine the fracture properties. Results: With regard to the 16-ply CFRP laminates, NDT images showed that the resin infiltrated better in the BVID-crack network when repaired at low pressure. However, no appreciable differences in the magnitude of the mechanical properties were observed for specimens treated at low pressure and atmospheric pressure. Apart from the fracture strain and fracture toughness, the fracture strength, energy to resilience and stiffness of the repaired specimens could be restored to almost pristine level. The epoxy shrinkage resulting in poor gap bridging and adhesion between fibres to fibres could contribute to low fracture strain and fracture toughness. With thicker laminates (24 plies), the magnitudes of the mechanical properties were not appreciably enhanced following repair (compared to unrepaired BVID specimens). Interestingly the BVID area was more extensive and there was poorer resin infiltration, which could be due to the presence of more non-interconnecting internal cracks. As to which is the best type of resin to be used out of the three different types (namely, neat epoxy, E1HNT, and NF100), it was observed that there were no appreciable differences in the mechanical properties of the specimens repaired using any of these resins. However, compressive mechanical properties (strength, resilience, fracture toughness, and stiffness) could be restored to almost pristine level. No appreciable differences were observed for the fracture strain of repaired specimens as compared to the unrepaired BVID specimens. Conclusion: It was concluded that low pressure and the type of resin (neat versus nanoparticle-blended resins) may not be an important factor in repairing BVID CFRP laminate by the resin-injection method. Some but not all mechanical properties of the repaired CFRP laminate could be restored to pristine level. The effectiveness of resin infiltration into the cracks of laminates could also depend on the thickness of the laminate.

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abst. 2067
Repository

Analytical and Experimental Axial Crash investigation of the Composite Cylindrical Energy Absorbers Filled with Honeycomb and Foam under Quasi-Static Load

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The collapse behavior of composite cylindrical shells filled with foam and honeycomb materials has been considered in recent years due to their possible applications as crash absorber in vehicles, aircraft, etc. In this study, an analytical model for crushing behavior of the cylindrical composite shell filled with foam and honeycomb materials under quasi-static load is presented. The presented analytical model which is based on the energy method is applied to predict the mean crushing force and crushing length during the collapse process. In this study, according to the experimental observations, the stable mode of collapse (Mode I) which has the ability to absorb the most energy, is considered for composite cylindrical shell. In this analytical method the main contribution of the shell, honeycomb and foam energy absorption which are shell bending, petal formation, circumferential delamination, friction, collapse of honeycomb cell walls, deformation of foam are considered to determine total internal energy during the crash process. This energy is equal to the work done by the external load. Then, quasi static crash tests are conducted on cylindrical composite shells filled with honeycomb and foam. Finally the analytical and experimental results are compared.

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abst. 2085
Room 1
Wednesday
June 16
09h30

DESIGN OF FABRIC RUBBER SEAL BASED ON DEEP LEARNING

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Fabric rubber seals are widely used in aerospace, large ships and other equipment due to their excellent mechanics and sealing performance. The cross-sectional shape and material distribution of the fabric rubber seal have an important influence on its mechanical properties and sealing performance. However, the current design methods of fabric rubber seals were almost based on a large amount of experimental data and finite element simulation results. The design process is cumbersome and the application is limited. It is urgent to develop fabric rubber seal design methods based on intelligent methods such as deep learning to realize the efficient, intelligent and dynamic design of fabric rubber seals. The purpose of this paper is to establish a design and optimize method for fabric rubber seals based on deep learning. The main contents are establishing the relationship between mechanical properties and seal structure through deep learning, and obtaining new seal structures through artificial neural network algorithms in the design stage, and finally realizing the intelligent and dynamic design of fabric rubber seals.

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abst. 2086
Room 1
Wednesday
June 16
09h10

Mechanical Behaviour of GFRP Full Adhesive Connections: Experimental and mechanical aspects

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In the field of the fiber reinforced polymer materials the efficiency of the adhesive technique versus the classical ones, bolting and welding, has been demonstrated by several studies available in the literature [1,2]. The main advantage of adhesive technique are relative to the absence of holes, then

the stresses are more uniformly distributed over the bonded surfaces and stress concentration and damage to the fibers caused by the holes are non-existent. Furthermore, the stiffness and strength of adhesive joints is generally sensibly higher than those of bolted connections [3]. On the contrary, full adhesive joints present a brittle unsolicited behavior as well as an innate absence of plasticity limiting the diffusion on this technique in the field of civil engineering in particular. Within this framework several studies were developed to the study of hybrid connection (bonded and bolted at the same time), using the stiffness of the adhesive and the plasticity of steel bolts [4-6]. The main conclusion of these studies is that the strength of the hybrid connection is strictly function of the adhesive layer while the steel bolts represent a plastic reserve. Relative to the field of full adhesive connection between FRPs members, in the present paper a wide experimental study is presented concerning the study of the mechanical response of a beam-to-column connection. Several parameters were taken into account: the extension of the adhesive surface, the load condition (shear and shear with bending) and the contribution of the GFRP angles. The test set-up was equipped not only with several displacement transducers in order to evaluate the load-displacement and moment-rotation curves but with the Digital Image Correlation system also. The latter allowed to understand the strain/stress distribution inside the adhesive layers giving the possibility to govern the strength and stiffness of the beam-to-column connection in function of the mode II of fracture energy being the only fracture energy considered. Furthermore, two different levels of fracture energy were taken into account: the total fracture energy, corresponding to the complete collapse of the joint; and the fracture energy level corresponding only to the linear behaviour of the connection. The last circumstance was taken into account in order to prevent the brittle fracture of adhesive connections.

3D-printed cuff connection for hollow-section GFRP pultruded profiles

abst. 2271
Repository

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Cavicchi, Mattia (mattia.cavicchi@edu.unife.it), University of Ferrara, italy
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Developing suitable connection systems for Glass Fiber Reinforced Polymer (GFRP) members started at least three decades ago [1] and is continuing today [2]. Based on previous experimental results by Smith et al. [3,4], GFRP profiles with closed cross-sections (i.e., tubular sections) provide certain mechanical properties that are superior to those of open shapes (I-sections), such as higher local flange buckling load, higher torsional rigidity, and higher strength and stiffness in the minor-axis plane. GFRP frames made of hollow-section profiles have been found to have 25% higher connection stiffness and 280% higher connection strength than frames comprised of I-section profiles with the same bending stiffness. Accordingly, the study of the best configuration to connect hollow-section profiles has become the focus of several research. Among several different types of connections, that one which involves a monolithic GFRP member, called "cuff" and firstly presented by Smith et al. [3], is one of the best in terms of stiffness (increment about 90%) and strength (increment about 330%) of the connection compared to the earlier typical seat angle connections used to join GFRP I-beams and columns. The concept of the cuff connection is that the beam and column can fit into the hollow cuff sections, ideally requiring only epoxy to keep them in place. This paper deals with the design of an innovative FRP cuff connection obtained by 3D printing. The manufacturing technique ensures optimization of the connector shape, so avoiding stress concentrations and allowing for the use of a smaller amount of material compared to traditional connectors. Numerical analyses are used to compare proposed and existing connectors in terms of beam-column joint stiffness and strength. [1] Bank LC, Mosallam AS, McCoy GT. Design and performance of connections for pultruded frame structures. Reinf Plast Compos 1994;15:1052–67. [2] Razaqpur AG, Ascione F, Lamberti M, Spadea S, Mirfet M. GFRP hollow column to built-up beam adhesive connection: Mechanical behaviour under quasi-static, cyclic and fatigue loading. Compos Struct 2019; 224: 111069. [3] Smith SJ, Parsons ID, Hjelmstad KD. An experimental study of the behaviour of connections for pultruded GFRP I-beams and rectangular tubes. Compos Constr 1998;42:281–90. [4] Smith SJ, Parsons ID, Hjelmstad KD. Experimental comparisons of connections for GFRP pultruded frames. Compos Constr 1999;3:20–6.

abst. 2272
Room 1
Monday
June 14
12h00

Stretching and Forming Limit Curve of Steel-Glass Fibre Reinforced and Non-reinforced Steel-Polyamide Sandwich Materials

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With the increasing interests on lightweight materials for different fields of application, more attention is drawn on the development of formable hybrid structures, typically as multi-layered metal/polymer sandwich structures. In this paper, two types of sandwich materials based on their core type are introduced: a) steel skin sheets and a thermoplastic polyamide (PA6) core, delivering the so-called steel/polymer/steel sheets (abbreviated as SPS), and b) steel skin sheets and woven glass fibre-reinforced polyamide 6 (GFR-PA6) core layers, so-called fibre metal laminates (FML). The formability of such sandwich sheets, especially of the FML, is a substantial challenge due to the strongly limited forming and flow potential of the fibre reinforcements in the thermoplastic matrix at room temperature (RT). Forming under stretching conditions - taking into account the influence of the forming temperature on the forming limits - is the one selected in this presentation. The sandwich sheets were produced by hot pressing under controlled pressure and cooling conditions. Stretch-forming tests were carried out using 200 mmØ samples and a 100 mmØ semi-spherical punch with heated forming tools. Besides forming at RT, temperatures at forming were selected with 200°C and 235 °C (below and above the melting point of the polymer). The effect of the core layer thickness t on the stretch-forming potential was also investigated for SPS (t: 0.5 and 1.0 mm) and FML (t: 0.5, 1.0 and 2.0 mm). In addition to the stretching tests, the forming limit curves of the monolithic steel sheets, the SPS and FML were determined at these temperatures according to DIN ISO 12004-2. As a result, pre-heating up to 200 °C and 235 °C enables a sufficient flow of the fibre-reinforced thermoplastic matrix. The stretch formability of the FML even reached the level of the pure steel sheet. For example, the forming depth of the FML with a core thickness of 1.0 mm reached 13 mm at RT before cracking and increased up to 34 mm and 32 mm by stretch-forming at 200 °C and 235 °C, respectively. No significant improvement of the forming potential could be stated for the SPS at elevated temperatures compared to RT in terms of the forming depth, but the forming forces were reduced, as expected. The forming depths at 200 °C of SPS - with core thicknesses of 0.5 mm and 1.0 mm - reached 31 mm and 32 mm, respectively. At RT they reached 32 mm (t: 0.5 mm) and 30 mm (t: 1.0 mm) compared to 34 mm for the pure steel skin sheet. So, with the elevated temperatures the stretch-forming limits of the pure metal sheet can be reached for this type of SPS and FML! The results of the FLC revealed that with increasing test temperatures the level of FLC was significantly increased for the FMLs, but the change for the SPS was only marginal.

Hygrothermal durability of epoxy resins used for civil engineering applications: experimental and numerical investigation

abst. 2076
Room 2
Monday
June 14
14h40

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In the recent years, the use of adhesives in the construction sector increased, especially relating to the use of composite materials, considered a valid and alternative solution to traditional ones, with the aim to realize structures more durable and with lower maintenance requirements [1]. However, a wider use of bonded joints is pending on obtaining a better understanding of their long-term behaviour. Within this scope, several studies were recently conducted relative to the study of the influence on the strength and stiffness of a bonded joints by different parameters such as: temperature [8] and hygro-thermal and outdoor ageing as well as moisture [15]. More in details, the environmental temperature may exceed the glass transition temperature (Tg) of the adhesive formulation entailing relevant changes in its properties, determining, for instance, a transition from a hard to a rubbery behaviour, thus compromising its specific application [22]. While, due to different environmental parameters experienced by the assembled structures during the employment, among which the temperature values, the structural adhesive can be naturally subjected to a delay or increase in the curing degree. Hence adverse or positive changes in strength and stiffness can be manifested. Speed and extent of the changes depend on the magnitude and duration of the temperatures experienced by the adhesive [23]. To design and verify the bonded connections, it is crucial to know the fracture energies in mode I and in mode II taking into account durability and the relative interface laws as requested by standards [24]. Relative to the fracture energies, the authors of the present paper started in the recent past with the study of the hygro-thermal durability of epoxy resins used for civil engineering applications [30]. In particular, the authors focused their attention on the study of the influence of two types of conditioning (immersion in tap water and sea water for a period of fifteen months at the temperature of 30°C) on the mode II fracture energy of two commercial epoxy resins cured at room temperature (about 23±2°C). Near to the classical fracture energy (defined as the area under the interface law function of limit values in terms of stress and relative displacement), the authors investigated about a different fracture energy value, lower than the classical one, corresponding to the end of the elastic stage relative to the P-curve of the End Notch Failure test, selected by standards [24] as reference test for the evaluation of fracture energy in mode II. Relative to the interface bonding law, the authors implemented also a Finite Element Model (FEM) model, by using the commercial Abaqus code, able to describe perfectly on one hand the End Notch Failure (ENF) test used to evaluate fracture energy in mode II as indicated by standards [24], and on the other hand, to evaluate the stiffness of elastic and softening stages in case of ageing. [1] Bakis C, Bank L, Brown V, Cosenza E, Davalos J, Lesko J, et al. Fiber-reinforced polymer composites for construction - state-of-the-art review. J Compos Constr 2002; 6: 73–87. [2] Michels J, Sena-Cruz J, Christen R, Czaderski C, Motavalli M. Mechanical performance of cold-curing epoxy adhesives after different mixing and curing procedures, Compos Part B Eng. 2016; 98: 434–443. [3] Bowditch MR. The durability of adhesive joints in the presence of water, Int J Adhes Adhes 1996; 16: 73–79. [4] Michels J, Widmann R, Czaderski C, Allahvirdizadeh R, Motavalli M. Glass transition evaluation of commercially available epoxy resins used for civil engineering applications, Compos Part B Eng 2015; 77: 484–493. [5] Sousa JM, Correia JR, Cabral-Fonseca S. Durability of an epoxy adhesive used in civil structural applications. Constr Build Mater 2018; 161: 618–633. [6] Report EUR 27666 EN (CEN TC/250). Prospect for new guidance in the design of FRP. JRC Science for Policy Report (https://ec.europa.eu/jrc/en/publication/eurscientific-and-technical-research reports/prospect-new-guidance-design-frp). [7] Ascione F, Granata L, Guadagno L, Naddeo C. Hygrothermal durability in terms of mode II fracture energy of epoxy adhesives used in civil structural applications. Submitted to Compos Struct Journal.

abst. 2091
Room 2
Monday
June 14
15h00

Adhesively bonded hybrid Al-CFRP joints: Influence of pre-treatment, adhesive chemistry as well as corrosion and ageing processes on the mechanical properties

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Lightweight structures are more and more used in all kinds of transportation vehicles. Due to their high production costs, monolithic carbon fiber reinforced polymer (short CFRP) structures are used exclusively for the highest quality applications such as aeronautics. For general usage, hybrid structures combine the properties of metals with FRP and open access to lightweight structures at a lower cost. This is possible through functional integration, which reduces the assembly's complexity and therefore, compensates for the high production cost of FRP. However, these hybrid components rely on successful adhesive joining strategies between metal and FRP. The aim of this work was to investigate the influence of pre-treatment strategies as well as adhesive composition on the aging behavior of hybrid single-lap-joints. The test specimens were manufactured in accordance with the DIN EN 1465 standard and are based on EN AW 5754 aluminium and aircraft grade HexPly® M21/T800s CFRP by Hexcel. Prior to the particular joining process, two different laser sources – near-IR and UV – with different energies were applied to clean, activate and structure both materials. As a reference a solvent based cleaning process was used. The surface topology was characterized quantitatively using micrographs, showing on the one hand that the ablation depth in the matrix (initial median depth of 22 μm) of the CFRP could be adjusted in a range from 0 – 35.2 μm and on the other hand a structure in the aluminium was introduced allowing a significant surface enlargement. Subsequently, the pre-treated specimens were bonded with two 2k epoxide adhesive from Henkel. Hygrothermal ageing was performed following the PV 1200 standard of Volkswagen AG. In addition, these hybrid joints were subjected to corrosive conditions in two different tests in accordance with the DIN EN ISO 12944-6:2018-06 standard. Finally, the mechanical shear strength was determined and compared to unaged samples. In hygrothermal tests the first 26 cycles, corresponding to 13 days of ageing, the shear strength decreases significantly by 12% of the initial value. By doubling or quadrupling the aging period to 50 and 100 cycles the shear strength value shows no significant further change. Fiber exposure through high energy laser pretreatment did neither increase the bonding strength, nor did it accelerate the ageing effects. Higher energy densities weaken the CFRP material to become the weakest link of the bond. In a corrosive environment it can be observed that the adhesive acts as an insulator and the mechanical strength of the hybrid compound decreases linearly and slowly by 20% of the initial value over the length of 1,500 hours. The predominant form of damage was not contact corrosion but crevice corrosion due to initial infiltration of the adhesive on the aluminium side. This reduced the joining surface and thus explains the strength degradation. In summary, it can be said that hygrothermal ageing as well as the selected corrosion system are suitable for simulating accelerated ageing scenarios for these hybrid aluminum/adhesive/CFRP material systems.

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abst. 2135
Room 2
Monday
June 14
14h20

Coupled thermomechanical, creep and degradation behaviour Carbon PEKK composites for aircraft applications above the glass transition temperature

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In the past 30 years, the possibility of replacing thermoset matrix inside the composite with thermoplastic polymers was investigated, due to the property of the latter of potentially extend the maximum operative temperature to higher temperatures with respect to thermoset polymers, potentially above their glass transition temperatures (Tg). Moreover, thermoplastic polymers can be recycled, property which, for the nowadays higher sensitiveness towards environment issues, increased the interest towards this class of materials. High performance polymers of the PAEK family where studied, in particular the Poly-Ether-Ether-Ketone (PEEK), and employed for aircraft applications and, amongst them, the PAEK family polymers, in particular the PEEK and PEKK, show excellent corrosion and water absorption resistance. For this reasons, other polymers were developed, as the Poly-Ether-Ketone-Ketone (PEKK), manufactured by Arkema with the commercial name of KEPSTANTM. In the literature there are very few studies concerning the behaviour of Carbon/PEKK composites above the glass transition temperature. The present work focuses on the characterisation and modelling of the coupled thermo-mechanical, creep and degradation behaviour of Carbon/PEKK composite materials above the glass transition temperature (close to 160°C for this material) and up to 200°C. Several thermomechanical and creep tests were carried out in a temperature range between 160°C and 200°C. Tests results discussion was supported by DMA and DSC scans. Coupled oxidation-thermomechanical-creep tests were also carried out on C/PEKK samples under a 5 bar O2 environment, by employing a test setup capable of carrying out mechanical test in a controlled thermo-oxidative environment, up to 350°C and 5 bar 02. X-rays μ-tomography scans were performed on the tested specimens to investigate the possible occurrence of degradation and damage. Acknowledgements This work pertains to the French government program ANR IMPEKKABLE (reference ANR-15-CE08-0016), in collaboration with AIRBUS GROUP SAS Département Innovations, ARKEMA France, Ecole Nationale Supérieure d'Arts et Métiers - Laboratoire de Procédés et Ingénierie en Mécanique et Matériaux, Paris.

Thermal and thermo-mechanical investigation of an interpenetrating metal-ceramic-composite

abst. 2150
Room 2
Monday
June 14
15h20

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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 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. This is due to the hybrid microstructure of IPCs with both phases building up a complex 3D structure with two continuous constituents. By combining a metallic and ceramic interpenetrating phase, the interaction of both phases in a thermal environment and under thermo-mechanical load is a crucial influence on the performance of the material system. Therefore, thermal treatment as influence on the microstructure in the metallic phase and the linked mechanical strengthening of the composite is investigated systematically and carried out via compression testing. The thermal properties of the composite over a range of the relevant temperature from 20 to 500 degrees centigrade are investigated to get information about the interaction of the two materials in the interpenetrating composite. Cyclic testing of the thermal load with microstructural investigation gives an first insight into the damage behavior. Thermo-mechanical load experiments, carried out in an universal testing machine combined with a mirror furnace, can clarify the material durability and damage behavior and give a closer understanding of the properties of this material system.

abst. 2157
Room 2
Monday
June 14
14h00

Corrosion effect on mechanical performance of self-prestressing ultra-high-performance concrete-steel tubular columns.

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The corrosion of steel reinforcements in concrete is one of the major reasons for the strength degradation and deterioration of reinforced concrete structures. These structures are usually exposed to mechanical loading conditions which cause the concrete cracking at load levels well below the yielding of the conventional steel reinforcement. However, until now there are limited studies for the enhancement of the durability performance of reinforced concrete structures by the improvement of concrete matrix exposed to the severe corroding environment. In this study, the novel incorporation of expansive agent (EA) and steel fibers (SF) in the concrete is proposed to improve the durability performance of the structures. To evaluate the durability performance of this concrete, the effect of corrosion on the mechanical performance of concrete-steel-tubular columns (CSTCs) were examined. CSTCs were consists of hollow steel tubes reinforced with different concrete mixes. EA and SF were used together due to the restraining action of SF against the autogenous expansion of concrete yielding active confining stress, during which fibers are prestressed, producing self-prestressing ultra-high-performance concrete (SPUHPC). Four different concrete mixtures made with no EA and SF, single use of EA, single use of SF, and the combined use of them were studied. Meanwhile, various cover thicknesses (33.7, 45.3 and 59.9 mm) were considered. For all of the scenarios, an accelerated corrosion test (ACT) under a constant anodic current has been performed for 672 h consistently followed by an axial compression test. The axial compression behavior of un-corroded CSTCs was also assessed and compared with corroded counterparts. Test results showed that the CSTCs suffer a deterioration in load-carrying capacity after being subjected to ACT. During the compression test, failure occurs due to the main crack developed during the ACT. Meanwhile, it is observed that the CSTCs with the incorporation of EA and SF have higher load carrying capacity both before and after corrosion. Furthermore, scanning electron microscopy (SEM) revealed improvement in the fiber-matrix interface by the combined addition of EA and SF. Moreover, SEM/EDS analyses were performed to characterize the corrosion products and to observe the real state of corrosion. This work shall be beneficial to improve the durability performance of the steel-concrete composite structures.

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abst. 2158
Repository

Performance of the reinforced polymer composite with different proportions of the quartz addition

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In the paper, effect of quartz additions on the durability of a polymer composite was investigated. The tested material was based on a resin MC-DUR 1200VK reinforced with two layers of E-type glass mat of a weight 300 g/m2 with an emulsion binder. The quartz was added in form of powder of fraction 0.1-0.3 mm. Its chemical composition was 99.57% SiO2, 1.12% Al2O3, and 0.31% other oxides. The samples were made with following proportions of the quartz powder: 0%, 1%, 3%, 6%, and 10% by mass. Durability was measured in terms of specific wear work in J/g obtained from the novel tribological tester TT-4. Its important feature was the application of friction belt instead of disc or plate, which made it possible to avoid undesirable impact of the used friction surface and wear debris on the measurement results. Apart from that, standard measurements of flexural strength, shear strength

between the layers, tensile strength, proof resilience, and microhardness were performed. It was found that the examined polymer composite increased its wear resistance when it contained 1% of the quartz powder. However, further increase of the addition caused decrease of the wear resistance. Interestingly, in case of similar composite with reinforcement of glass mat with a powder binder, the best results were achieved for 6% of quartz addition. Similarly, the best results were achieved for the composite with 1% addition of quartz for the shear strength and proof resilience. Compared to the composite with no quartz powder added, its respective characteristics improved by 20% and 40%. On the other hand, all other properties worsened after the quartz powder was added in any proportion. Despite no clear trends in characteristics after quartz addition was present, important finding was that it was disadvantageous to increase above 1% addition of quartz powder in the composite of resin MC-DUR 1200VK reinforced with two layers of E-type glass mat of a weight 300 g/m2 with an emulsion binder. Initial researches also demonstrated that quartz additions may have different effect on the similar composite with other sort of reinforcement.

Finite element analysis of the hygroscopic and the coupled hygroelastic behaviours of flax-epoxy composite using Fick's and Langmuir's models.

abst. 2176
Repository

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Abstract Nowadays, natural fibre reinforced composite materials attracts more and more attention in several sectors thanks to their interesting specific mechanical properties combined with their low impact on the environment. However, the anisotropic nature of natural fibres and especially their degradation in humid atmosphere might limit the growing use of natural fibre composites in some sectors like automotive and construction. Accordingly, it is essential to investigate and understand the moisture diffusion kinetics inside natural fibre reinforced composites when exposed to humid environments in order to firstly estimate their durability and secondly suggest possible ways of improvement. Within this context, several research studies have considered the analytical solution of Fick's model to analyse moisture diffusion kinetics in natural fibre reinforced composite materials like flax-epoxy composites [1,2]. In addition, the finite element method based on Fick's model has been considered to predict the hygroscopic behaviour of flax-epoxy composite [3] and also to estimate the internal stress induced by moisture absorption [4]. Fick's model assumes that all water molecules are free to move in the aged composite material without considering the molecules that may be bound to hydroxyl and oxygen groups in the fibres and matrix. This may explain the overestimation of the hygroscopic stress obtained with finite element simulations based on Fick's model [4,5]. Accordingly, the use of a more general diffusion model like that of Langmuir could result in a more accurate estimation of the internal hygroscopic stress. The aim of this work is to conduct a numerical study of the hygroscopic and hygroelastic behaviours of unidirectional flax fibre-reinforced epoxy composite, whose samples were aged in tap water until saturation, using Fick's and Langmuir's models. To this end, a three-node triangular hygroscopic membrane finite element based on Langmuir's model is firstly proposed. A heterogeneous plane finite element modelling of moisture diffusion in the aged flax-epoxy samples is then presented and the obtained results are compared with those of the three-node triangular element based on Fick's model developed by Zouari et al. [3]. Secondly, to analyse the hygroelastic behaviour of the studied materials and to relate the water diffusion parameters to the stress state, coupled hygroelastic three-node triangular membrane finite elements based on Fick's and Langmuir's models are developed. The obtained results show that despite the difference in the formulation of Fick's and Langmuir's models, the water diffusion parameters identified by the optimisation procedure correctly describe the experimental curves. Besides, the hygroelastic finite element simulations show that the diffusion phenomenon is affected by the stress state in the aged flax-epoxy composite samples and that the internal hygroscopic stress estimated by Fick's model seems to be higher than that obtained by Langmuir's model. 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. Composites Part A: Applied Science and Manufacturing 2017;95:75–86. [2] Saidane EH, Scida D, Assarar M, Ayad R. Assessment of 3D moisture diffusion parameters on flax/epoxy composites. Composites Part A: Applied Science and Manufacturing 2016;80:53–60. [3] Zouari W, Assarar M, Chilali A, Ayad R, Kebir H. Numerical Modelling of the Transient Hygroscopic Behavior of Flax-Epoxy Composite. Journal of Renewable Materials 2019;7:839–53. . [4] Chilali A, Assarar M, Zouari W, Kebir H, Ayad R. Analysis of the hydro-mechanical behaviour of flax fibre-reinforced composites: Assessment of hygroscopic expansion and its impact on internal stress. Composite Structures 2018;206:177–84. [5] Peret T, Clement A, Freour S, Jacquemin F. Numerical transient hygro-elastic analyses of reinforced Fickian and non-Fickian polymers. Composite Structures 2014;116:395–403.

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abst. 2287
Repository

Effects of moisture ingress on the mesoscale mechanical properties of epoxy adhesives under elevated temperature

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This work aims to investigate the relationship between local moisture concentration and mesoscale mechanical properties of epoxy adhesive under elevated temperature. Araldite® 2015 was chosen as the target adhesive due to its curing stability and possible validation with previously published literatures. The specimens were aged at 60 oC in deionised water and 5%wt NaCl solution, separately, with the water ingress evaluated by Fickian diffusion model. Nanoindentation was utilised to characterise the mesoscale modulus and hardness distribution along the water diffusion path. Then Fourier transform infrared spectroscopy (FTIR) and scanning electron microscopy (SEM) were conducted to investigate the variation of functional groups and microstructure, respectively. The results show that mechanical properties degrade as ageing duration increases, with higher degradation observed in the edge region where higher moisture concentration exists. Besides, higher ageing temperature leads to larger decrease in mechanical properties of saturated specimens. An empirical relation between local mechanical properties and moisture concentration was established. Chemical and morphology performance of adhesives also exhibited variations with hygrothermal ageing. The obtained local moisture-mechanical relationship can then be used to improve the accuracy of numerical simulation on the environmental durability of structural adhesive in future work.

Characterisation of aluminium matrix syntactic foams under high strain-rate loadings

abst. 2010
Room 1
Monday
June 14
12h40

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This paper investigates the potential of aluminium matrix syntactic foams as possible core materials for use in protection systems on military vehicles. Here, experimental work has been carried out to investigate the behaviour of the material subjected to a wide range of dynamic loading conditions. Numerical models have also been developed to simulate the dynamic behaviour of the foams. The effect of strain-rate on their compressive crush behaviour has been investigated, given that the rate-dependent characteristics of these materials are required for designing dynamically-loaded structures. Characterisation of the behaviour of the foam at high strain-rate loadings and identification of the underlying failure mechanisms were also undertaken to evaluate the effective mechanical performance. The results show that the aluminium syntactic foam is sensitive under high strain-rate loading. It was found that the 14 mm thick aluminium syntactic foam is capable of arresting a projectile travelling at 120 m/s and a 3 gram explosive charge detonated on its surface. Overall, the level of agreement between the numerical simulations and the experimental results is reasonably good.

Modelling of dynamic behaviour of brittle two phase composite platelets

abst. 2032
Room 2
Wednesday
June 16
15h20

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Ceramic composites have wide applications in almost all contemporary industries. The composites are often exposed to severe loading conditions like variable and impact dynamic loads [1-4]. In this presentation, a model of thin plates that are made of Al2O3/ZrO2 polycrystalline composites is proposed. A brittle damage model is used for both phases of the composite [5-7]. Interest is focused on modelling of interfaces between two phases of the composite. However, except for the interfaces Al2O3/ZrO2 particular attention is paid to the interfaces between the grains of Al2O3/Al2O3 and ZrO2/ZrO2, as well. It is observed damage initiation and its distribution in the analysed of the polycrystalline samples. In particular, degradation is concentrated along interfaces. During loading impulse one can observe damage growth and microdefects coalescence to create longer degradation areas within the polycrystal platelets. The numerical results were compared to experimental tests performed on Al2O3/ZrO2 cylinders using experimental stand SHPB and dynamic loading with velocity up to 30 m/s. The obtained results confirm the correctness of the proposed numerical model. Acknowledgement: This work was financially supported by National Science Centre (Poland) projects UMO-2019/33/B/ST8 and No 2016/21/B/ST8/01027. The calculations were done within PL-GRID national computational resources at the Academic Computer Centre Cyfronet at Krakow, Poland and Interdisciplinary Centre for Mathematical and Computational Modeling, University of Warsaw, Poland. MSC Patran program is provided by Academic Computer Centre in Gdańsk, Poland. Literature: 1. Postek E., Sadowski T., Thermomechanical effects during impact testing of WC/Co composite material, COMPOSITE STRUCTURES, Vol.241, pp.112054-1-25, 2020. 2. Postek E., Sadowski T., High-velocity impact of 2-phase WC-Co composite plate - beginning of the process, ARCHIVES OF METALLURGY AND MATERIALS, Vol.65, No.1, pp.265-274, 2020. 3. Postek E., Sadowski T., Impact model of WC/Co composite, COMPOSITE STRUCTURES, Vol.213, pp.231-242, 2019. 4. Postek E., Sadowski T., Distributed microcracking process of WC/Co cermet under dynamic impulse compressive loading, COMPOSITE STRUCTURES Vol.194, pp.494-508, 2018. 5. Sadowski T., Marsavina L., Craciun M., Cracking of two-phase ceramics under uniaxial compression deformation, ENGINEERING TRANSACTIONS, Vol. 65 (2017) 39-44.

6. Sadowski T., Craciun E., Marsavina L., Brittle behavior of ceramic matrix composites made of 2 different phases. AIP Conference Proceedings Vol. 1932, 030036 2018. 7. Sadowski T., Marsavina L., Multiscale modeling of two-phase ceramic matrix compostes, COMPUTATIONAL MATERIALS SCIENCE Vol. 50, 1336-1346, 2011.

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abst. 2126
Room 2
Wednesday
June 16
15h40

Rotordynamic response of Composite-Shaft-Disk-Bearing System Based on Finite Element Analysis

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This paper is concerned with the rotordynamic response of a rotor-disk-bearing system, shown in figure below, that consists of a driveshaft made of laminated composite material, a rigid steel disk, and rolling-element bearings. Utilizing Timoshenko beam theory and Classical Laminate Theory, the composite rotorshaft is modeled. The equations of motion are derived by using the finite element method and Lagrange's equations. The Lagrangian finite element formulation that yields accurate results and is efficient in modeling and analyzing the flexible rotor-disk system that is supported on linear-stiffness bearings is developed. The effects of rotary inertia and gyroscopic moments are included in modelling the rotor system. The formulation is validated by comparison with a case study that exists in the literature. The effects of the rotating speed and the lamination angle on the natural frequencies of the rotor system are studied. The resonant speed and instability speed are obtained as well that correspond to the states when the rotor system runs at one of the natural frequencies and when the value of the first natural frequency decreases to zero and the rotor becomes unstable. The effects of the bearing stiffness on the critical speeds and operational deflection shapes of the rotor are investigated. The Campbell diagram as well as the critical speed map of the rotor system are depicted. It is shown that the gyroscopic effect causes a coupling of orthogonal displacements to the axis of rotation, and consequently separates the frequencies into two branches, backward and forward precession modes. In addition, the bearing stiffness has significant influence on the first and second critical speeds but has only slight effect on the third critical speed. A comprehensive parametric study is conducted to determine the effects of various system parameters including the fiber orientation in the shaft, the rotating speed and the bearing stiffness on the rotordynamic response. Moreover, it is demonstrated that the bearing stiffness can effectively be used as one of the system design parameters to avoid undesired response.

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abst. 2142
Room 2
Wednesday
June 16
14h40

Buckling analysis of laminated composite panels using 2D spectral Chebyshev and lamination parameters

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In this study, the critical buckling load of laminated straight plates has been carried out using a meshless approach based on Chebyshev poylnomials and lamination parameters. The deflection of any point on the plate are modeled based on the first order shear deformation theory. The material invariants and lamination parameters are used to obtain the overall stiffness of laminated composite structure. The integral boundary value problem governing the dynamics of the laminated structure, is derived following extended Hamilton's method. The developed framework enables accurately and efficiently predicting the critical buckling force. To validate the precision of the presented solution method, critical buckling load of various case studies including square and rectangular plates having

symmetrical/asymmetrical stacking sequences are calculated and compared to those obtained through finite element method. The results are in excellent agreement, yet the presented method can solve the integral boundary value problem in a fraction of time compared to the FEM

A Study on the Vibration Damping Effect of Building Structures According to the Resin Ratio of Polymer Concrete

abst. 2156
Room 2
Wednesday
June 16
14h00

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Due to the recent increase in the number of apartment dwellings, the issue of inter-floor noise is emerging. In particular, influence to living spaces due to elevator noise is increasing. To minimize noise from elevators, the concrete was usually designed in the form of inserting a vibration-proof pad to enhance the ability to reduce vibration and noise. The thicker the anti-vibration pad, the better the performance can be, but the cost is high and the lifespan does not reach that of the building. Therefore, it is necessary to use polymer concrete in the form of a composite that has permanent performance and is not additionally inserted. In this study, in order to confirm the vibration reduction performance of polymer concrete, various ratios of polymer concrete were installed on the wall between the elevator and the living space, and the performance was compared. The damping performance of resin mortar concrete with 15%, 20%, and 25% ratios for concrete walls of 100mm and 150mm, respectively, was compared and analyzed using vibration response. As the resin ratio increased, the damping performance was increased. The effect of damping vibration in polymer concrete more than that of plain concrete was also observed. This research is expected to be of great help in improving the comfort of living spaces and research on effective vibration damping using polymer concrete.

Vibration analysis of porous metal aluminum foam truncated conical shells with general boundary conditions

abst. 2216
Room 2
Wednesday
June 16
14h20

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Present work attempts to investigate the natural vibration of truncated conical shells made of porous metal foam with closed-cell and the general boundary conditions. Three types of porosity distribution are taken into account, they are uniform distribution, nonuniform symmetric distribution and nonuniform asymmetric distribution through the thickness direction. Materials properties are dependent on the porosity distribution and location. The theoretical formulations are derived on the bases of the first order shear deformation and Hamilton principle. In case of clamped, free, simply supported, various combination of boundary conditions and general boundary conditions which have been reached by the method of virtual spring, the frequency of the system are calculated employing the generalized differential quadrature method (GDQM). The convergence and validation are carried out by the comparison researches of the present numerical results with those obtained from other literatures and the finite element analysis software ABAQUS respectively. The effects of the porosity ant its' distribution, geometry of the conical shell and general boundary conditions are studied comprehensively.

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abst. 2257
Room 2
Wednesday
June 16
15h00

FE analysis of PPF controller efficiency to suppression of composite beam large vibration

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In this paper a finite element model of a composite structure and its research are presented. The tested object consists of a glass-epoxy composite beam with embedded a Macro Fiber Composite (MFC) piezoelectric actuator controlled by means of the Positive Position Feedback (PPF). The numerical model taking into account the above components is developed in commercial Abaqus software. Properties of laminate beam layers are described using the layup-ply technique. However, the MFC element is modeled as piezoelectric material and its voltage supply is applied as electric boundary conditions. A special subroutine code of the PPF controller is developed, where the input is measured beam response and the output is desired voltage signal calculated from control algorithm. During solving the second order differential controller equation the fourth order Runge-Kutta method is engaged. The numerical simulations were performed using implicit procedure. Since, the beam large vibrations are analyzed, the nonlinear phenomenon so-called amplitude jump can be observed. The obtained system responses allow to compare beam dynamics with and without controller activation. Finally, the PPF controller effectiveness of composite beam large vibration suppression is determined. The research is financed in the framework of the project Lublin University of Technology-Regional Excellence Initiative, funded by the Polish Ministry of Science and Higher Education (contract no. 030/RID/2018/19).

Electro-thermal properties of composite materials

Non-isothermal crystallization kinetics of PEEK/CNT composites and analysis of the mechanical and electrical conductivity properties

abst. 2163
Repository

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The crystalline properties of Poly (ether ether ketone) (PEEK) have significant impact on the mechanical properties, temperature resistance and product performance. In this work, the PEEK composites with high carbon nanotube (CNT) content were prepared by melt mixing method to improve the mechanical and electrical conductivity properties. Thanks to the unique properties of CNT, the PEEK/CNT composites exhibit excellent electrical conductivity and tensile strength, reaching to 2.13 S/cm and more 90MPa. The crystalline properties of PEEK/CNT composites were also investigated before and after the annealing process by using non-isothermal crystallization kinetics. After the annealing process, the crystallinity of the composites is improved, but the conductivity is decreased by 17%, which is attributed to the formation of conductive paths hindered by the polymer chains rearrangement. Furthermore, the PEEK/CNT composites exhibit ultra-high electromagnetic interference, reaching to 35dB, which can be used in aerospace and communication filed.

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abst. 1016
Room 1
Monday
June 14
11h40

Non Destructive Evaluation Of Damage In Drilled Carbon Fibre Reinforced Plates – Correlation With Mechanical Tests

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The use of carbon fibre reinforced polymers (CFRP) has increased at a steady pace in a widespread range of industrial, transport or even sporting applications. Along the last decade the annual worldwide demand for fibre reinforced polymers has risen tenfold, approximately, demonstrating the interest for increased knowledge on this type of materials. The development of complex structures in CFRP's implies the need for their drilling for further assembly in sets or subsets. The application of this type of parts in structural components, as is observable in the aeronautical industry, highlights the quest for a high degree of certainty on the loss of mechanical characteristics in the machined areas. The combination of the laminar nature of carbon fibre reinforced plates with the abrasive nature of carbon fibers led to the onset of several damages during machining operations, like drilling. The most evident of these damages is the push-down delamination, recognizable by the existence of a damaged edge around the machined hole. For CFRP's this damage is not easily identifiable in a visual inspection, as plates are opaque. Other possible damages are fiber pull-out, thermal damages or worn out tools. Normally, these damages are more visible at the exit side of the drill. Another possible damage mode is the peel-up delamination that is likely to occur at the entry side of the drill, although its onset is easier to avoid. Delamination is defined as the separation of adjacent plies of the laminate and is usually considered as the most critical damage, as it can contribute to a substantial loss in the mechanical strength of the part. So, the control and reduction of this damage is of the utmost importance to the composites industry. In this work, a batch of CFRP plates is drilled under different machining conditions regarding drill geometry, cutting speed and feed rate. During drilling, the thrust force is monitored to help on the determination of the delamination onset. This thrust force is compared with results from the delamination onset test set suggested by Lachaud et al [2001, Composite Structures, 52, 3-4, 511-516]. After drilling, the hole surrounding area is inspected by enhanced radiographed, a non-destructive method that uses a contrasting agent, and a digital image of the hole plus the delaminated edge is attained with the help of a 60 kV, 300 kHz Kodak 2100 X-ray system associated with a Kodak RVG 5100 digital acquisition system. From these digital images it is possible to compute the damaged area, using appropriate MatLab® tools, like the Image Processing Toolbox. Besides the damaged area other features related with the delaminated region are also computed, like the major diameter or other functions. Finally, the test coupons were prepared for mechanical tests. In this work, results of the bearing test ASTM D5961 - 17 and the pin-bearing test [Wang et al, 1996, J Comp Materials, 30, 12, 1284-1313] are presented. The damage geometrical features are correlated with the data from the mechanical tests performed, using statistical tools. The most favorable relation of geometrical feature with the loss of mechanical strength is highlighted for a future damage quantification criterion. The results of this experimental sequence help to demonstrate that is possible to establish and model the relation between the damaged region caused by the drilling operation and the material's mechanical resistance, thus machined parts in sets or subsets. As expected, the bearing resistance decreases with the increase of the delaminated region. The results also display the importance of the selection of tools geometry and cutting parameters to enhance reliability on the use of these materials. Acknowledgement: this work was funded by the FCT–Portuguese Foundation for the Development of Science Technology, Ministry of Education and Science, under the Project UID/EMS/0615/2019.

Identification of a set of macroscopic elastic parameters for aerogel composite material with high porosity using inverse method with multi-region strategy

abst. 2023
Room 2
Monday
June 14
11h40

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Silica aerogel material has low thermal conductivity because of its ultra-fine skeleton particles and nano-porous microstructure, which is used as the critical insulation core for the integrated thermal protection system (ITPS). In order to strengthen the silica aerogel, through-thickness stitched foam core sandwich structure was fabricated by using vacuum infusion molding process (VIMP) process. Thus, it is always necessary to understand deformation mechanism of stitched foam core and develop an appropriate stress-strain response model with a set of macroscopic elastic parameters for structural design and analysis. The paper focuses on performing a single but complex mechanical test on the through-thickness stitched foam core sandwich structure rather than on small coupons to probe multiple strain states for identification of multiple macroscopic elastic parameters using full-field measurements. The performed bending test on the sandwich structure, which is analyzed using Digital Image Correlation (DIC), provides heterogeneous strain fields due to the complex loading condition. A set of macroscopic elastic parameters was extracted simultaneously using the FEMU technique firstly, and the strategy of a combination of multi-step and multi-region method in the inverse method was proposed to solve insensitivity of partial elastic parameters to the deformation for a single region of interest (ROI) and coupling between the stress-strain relations under a complex loadings. The extracted elastic parameters extracted from the proposed method was verified by the numerical virtual test and the axial compressive mechanical test further.

Experimental Study on the Out-of-Plane Deformation of Symmetrical Flat Laminate Composites Manufactured through Autoclave Process

abst. 2046
Room 2
Monday
June 14
15h40

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Out-of-plane deformation generally develops for laminate composites during autoclave processing due to unbalanced residual stress in the stacking. This can lead to undesired shape and poor dimensional control in part manufactured. This paper presents a study on out-of-plane deflection of symmetrical flat laminate composites. The effect of stacking sequences and tool surface conditions were taken into account. Firstly, the unidirectional prepreg M21EV/IMA was chosen as a raw material for composite manufacturing, aluminum was selected for a mold material in order to maximize the coefficient of thermal expansion of mold. Freekote release agent, PTFE release film and peel ply were used to modify tool surface condition. Afterward, the specimens with an overall size 250x250 mm2 and different layups cross-ply ([0/90]s) and angle-ply ([45/-45/45/-45]) were manufactured. Tool surface was classified into four conditions: 1) Freekote and one layer release film, 2) Freekote and one layer peel ply, 3) Freekote and two layers release film, 4) Freekote and three layers release film. In addition, four specimens were manufactured for each configuration of tool surface, thus, 16 specimens of cross-ply and angle-ply were done. Other process parameters such as mold material, curing temperature profile and autoclave pressure are identical. Digital image correlation (DIC) and laser displacement sensor were utilized to measure the out-of-plane deflection of all specimens in order to ensure the accuracy of measurement by comparison of both methods. Technically, the DIC can assist to examine the behavior of warpage

and to indicate maximum and minimum values for magnitude of deformation while laser displacement sensor is supportive to search for the maximum deformation by measuring 17 points on each specimen. The correlation for both measurement methods is in good agreement. It can be clearly seen that the effect of stacking layup plays an important role for the out of plane deflection in term of shape and magnitude. Angle-ply laminates show much higher deformation than cross-ply laminates, twist shape was observed for angle-ply while cylindrical and rotated cylindrical shape were observed for cross-ply. In term of tool surface effect, the difference of tool surface conditions has no significant effect for angle-ply laminates while the use of peel ply provides a little higher deflection for cross-ply laminates compared to the use of one, two and three layers release film; moreover, the difference in deformation behavior when using peel ply and release film can be clearly observed for cross-ply laminates.

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abst. 2102
Room 2
Monday
June 14
16h00

Cyclic Testing of Composites and Textile Cords – Design of Experiment Methods and Results for Practical Use

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The paper deals with specific testing of polymer composites and textiles cords, which are used as reinforcement for the composites. Textile cord-rubber composites were selected for the research. A low cyclic uniaxial tensile load was performed with simultaneous room temperature (20 °C +- 2°C) and high temperature (180 °C) exposure. As these are not standardized tests of polymer composites, part of the research is the design of experimental method for these composites and load parameters such as load rate, preload and other parameters - strain for start and stop of cycle steps. For textile materials – fibres, the DIN 53835-13 standard is defined and according to this standard the conditions are taken into consideration during the first five cycles. Moreover, stress relaxation is taken into account in testing of textile cords. Due to fact, video-extensometer is used to testing of the composites and the textile cords, it should be emphasized that the output is true stress values. For the testing, module Cycle at Trapezium X software is used at Autograph AG-X plus 5kN Shimadzu Japanese testing device with video-extensometer and WEISS TECHNIK EKE 60.180.70.C hybrid temperature-humidity chamber with range from -70 to 180 °C. This makes it possible to experimentally simulate the load that occurs during operation. The attention is paid to automobile tire casings which consist of polymer composites and rubber parts. The shape with geometric parameters of the composites were designed so that the measurement could be repeated on another test device. PA66 fibres have been selected for cyclic loading for their common use in tire casings as textile cords. Furthermore, the paper evaluated the effect of temperatures on material properties of textile cords, such as namely strength and ductility that are important for the assessment of practical applications. The angle of the cords to the resulting material parameters of the composites is also evaluated. The data results are dependences of true stress on elongation between points for the video-extensometer of fifth cycle of every cycle loop for selected cord angles in polymer composites. Next, the data results are dependences of true stress on elongation between points for the video-extensometer for the textile cords which can be used as input material data in calculations to simulate changes in the strength of the textile cords during vulcanization processes in the production of the tire casings. These results can be used in such conditions where the mentioned polymer composites are exposed to the cyclic loading at unsteady temperature such as conveyor belts and can also be used for computational modelling of the composites. The main result of this research is the experiment methods for low-cyclic testing of polymer composites and textile cords in relationship to practical use. Acknowledgments: This research work had been supported by the Cultural and Educational Grant Agency of the Slovak Republic (KEGA), project No. KEGA 002TnUAD-4/2019

"The influence of temperature and other parameters on the tensile properties of polymer composites and polymers under the uniaxial and biaxial cyclic loading" and the project "Advancement and support of RD for "Centre for diagnostics and quality testing of materials" in the domains of the RIS3 SK specialization", code NFP313011W442.

Monte Carlo strategy for SEM-EDS micro-nanoanalysis of geopolymer composites

abst. 2110
Repository

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Metakaolin-based geopolymers are inherently nanomaterials typically obtained by dissolving metakaolin micro-sized particles to generate a geopolymer resin which is eventually a nanostructured material. Particle and fibre reinforcements have been used to modify their physical properties, increasing the flexure strength and toughness of geopolymeric materials. In these regards, electron microscopy, thanks also to the micro-nanoanalytical capability when combined with energy dispersive X-ray spectrometry (EDS), is widely and effectively used both for the study of geopolymers architecture and chemistry, and to develop and optimize particle- and fiber-reinforced metakaolin-based geopolymer composites. However, when dealing with micro- and nano-sizes and complex architectures, several effects related to the generation and transport of electrons and X-rays, and to the SEM-EDS setup must be considered to avoid qualitative and quantitative errors. Here, a Monte Carlo simulation strategy for scanning electron microscopy – EDS microanalyses is proposed and applied to selected micro/nano-sized architectures of geopolymer composites. Monte Carlo simulations were recently proposed and effectively applied by the authors to the study of asbestos fibres and bundles [1]. In this work, the aim is to investigate the effects of micro-to-nanometric size (from 100 nm to 10 micrometre) and basic geometrical shapes of the reinforcing materials in SEM-EDS microanalysis of geopolymer composites. 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]. X-ray secondary fluorescence, a realistic SEM-EDS setup and EDS X-ray detector were also taken into account. The simulation results allowed to identify the optimal instrumental parameters and correct procedure for the analysis of the geopolymer composite, and showed a strong effect of the thickness and shape to the intensity of the X-rays measured by the EDS, possible sources of errors to be considered and avoided. Reference: [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. 2131
Room 2
Monday
June 14
12h00

Evaluation of a pressure resistance performance of composite cylinder using the mechanically structured ring burst test device

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When designing a pressure vessel used to store environmentally-friendly fuel gases or liquids, pressure resistance performances should be evaluated to prevent premature damage. Recently, composites having a high tank capacity in low weight have been widely used as an alternative material of previous metallic vessels Accordingly, the precise measurement of their fracture characteristics, particularly the burst pressure and fracture strain, are mandatory prior to the commercial release. A mechanically structured segment-type test method with a ring-shaped specimen is one of the efficient test methods to obtain the mechanical properties of the composite pressure vessel. However, due to structural limitations of the previous method, whether it is possible to transmit uniform pressure along the radial direction of the ring specimen is a crucial issue at the moment. Therefore, in this study, the modified segment-type ring burst test device was designed based on the load transfer ratio between the applied load and the transferred one. Moreover, to check the uniformity of pressure, the hoop strain distribution of ring specimens was compared with that of the hydraulic pressure test result by using the theoretical method and finite element analysis. As a result, the number of segments was divided into 24 pieces and a 2t PTFE layer was placed between segments and the ring specimen to reduce the hoop strain discrepancy. Furthermore, to verify the reliability of the test device, the strain distribution and the fracture behavior were assessed by utilizing the digital image correlation (DIC) method and a high-speed camera during the experiment.

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abst. 2178
Room 2
Monday
June 14
12h40

Experimental and numerical modal analysis of the glass composite plate damaged by cut

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The given paper is closely connected with the experimental and numerical modal analysis of the glass composite plate damaged by cut. In relation to the tested glass composite, modal analysis was performed by help of special measuring de-vice Pulse 12. The mentioned device was supplied by company Brüel Kjear and the experimental measurements were carried out using damaged and undamaged plate sample which were prepared from the mentioned material hereinbefore. The investigated and analyzed plates of glass composite were made of six layers of glass fibres and they were arranged under the angle 90º (it is like fabric materi-al made off glass fibres). The layers arranged in the given way were joined by epoxide resin MGS 285. The experimental measurement of natural frequencies of

glass composite plates was carried out using the undamaged and damaged sample with proportions 78 mm x 78 mm while ten measurements were performed for each one specified site of the sample. In relation to the damaged plate sample, there was cut length 20 mm in the centre border. The finite element method in the software system ADINA v.8.6.2 was used for numerical analysis of the natural frequencies.

Rotational molding composites containing mineral filler.

abst. 2251
Repository

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Rotational molding is one of the few processing technologies for thermoplastics, where it is not necessary to use complicated and expensive processing tools; additionally, this method allows for a relatively cheap manufacturing of products of large volume. Rotational molding is mainly used for the production of thin-walled products, hollow inside, usually of large sizes such as: tanks, containers, hulls or casings, in which the wall thickness can be adjusted by changing the mutual ratio of the rotational speed of the mold around the main and auxiliary axes. Thanks to rotational molding technology it is possible to obtain single-layer, multi-layer and foamed molds. Rotational molding of polymer materials has been constantly expanding its range and market areas. The use of unmodified polymers becomes insufficient to meet modern construction and economic requirements. The emphasis on reducing the manufacturing costs, associated to the size of the production, and the growing demand for materials with specific and unprecedented properties, makes the use of plastic modifications increasingly frequent. In recent years, a trend has emerged in publications pertaining to the processing of polymer materials to popularize the use of materials and natural waste of organic origin in the production of polymeric matrix composites. This is related, inter alia, to the pressure of global environmental protection organizations on environmental issues, such as waste storage and disposal, recycling and finally the use of natural waste in various industries. Differentiation of polymers39; properties can be achieved by their chemical or physical modification, reactive processing, filler or auxiliary additives. The main subject of the project is to obtain a mineral filler polymer composite through the rotational molding process (rotomolding). The prepared composites were subjected to mechanical properties assessment, as well as thermomechanical and structural analysis. The mineral filler was a quartz powder with a different mass fraction in relation to the matrix, which was a low density polyethylene. The appropriate dependence of the longitudinal elasticity coefficient, the highest tensile stress, breaking stress and corresponding deformations on the mass content of the mineral filler. The article was concluded with appropriate conclusions.

Effect of Physical Modification with Natural Fillers on Selected Mechanical Properties of Adhesive Compositions Based on Epidian 5 Epoxy Resin

abst. 2258
Repository

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The proper selection of adhesive composition components during the bonding process is a fundamental issue. As the requirements for constructions using assembly joints are increasing, the basic adhesives are often subject to extensive modifications. The most common way to modify structural adhesives is to physically modify them, which involves inserting fillers into the adhesive. The aim of the research was to determine the impact of physical modification of epoxy adhesive compositions. Epoxy compositions made on the basis of solvent-free Epidian 5 epoxy resin and three types of curing agents: TFF Mannich-type principle, Z-1 amine hardener and PAC polyamide hardener were tested. The compositions were modified using three fillers of natural origin: NanoBent ZR2 montmorillonite, CaCO3

calcium carbonate and CWZ-22 active carbon. Each filler was added in the amount of 5 wt. % of the composition. For comparison purposes samples made of unmodified composition were also tested. Adhesive samples in cured state were tested. The influence of modification on selected mechanical properties of the composition - tensile, compressive and bending strength was verified. The analysis of the obtained results showed that the addition of a filler to the matrix of the adhesive composition does not always improve the analyzed properties. The highest tensile strength was obtained for Epidian 5 epoxy resin composition, TFF curing agent and CaCO3 calcium carbonate. The distribution of results was similar in case of compression strength analysis. When considering the bending strength, the tests were carried out in a three-point bending test. In case of all the compositions, the modification resulted in deterioration of the results obtained, however, among the modified ones, the composition of Epidian 5 epoxy resin, TFF curing agent and CaCO3 calcium carbonate also obtained the highest bending strength. In order to precisely analyze the obtained results, a statistical analysis of the results was carried out using ANOVA statistics. Additionally, the cracking surface of epoxy compositions was analyzed using a scanning electron microscope in order to assess the distribution of fillers in the structure of cured adhesive.

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abst. 2280
Room 2
Monday
June 14
12h20

Experimental evidence of polymer and fiber type and fractional parameter influence on internal friction in fiber-reinforced rubber concrete

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The recent paper presents the extension of the previous research, where the internal friction and the fractional parameter for rubber concrete and fiber-reinforced rubber concrete have been investigated by means of Resonant Frequency and Damping Analyzer (RFDA Basic) implementing Impulse Excitation Technique (IET) [1]. Both of the materials contained SKDSN rubber as the main binder. In this paper, an attempt to study the influence of different factors, such as polymer and fiber type as well as the ageing effect, has been undertaken. Another type of binding material has been used for further investigation of internal friction phenomena in polymer concrete. Namely, low molecular weight polybutadiene rubber of mixed microstructure, PBN grade was applied to produce the samples for the experimental program. In order to evaluate the effect of fiber type on the desired values, two different types of fiber are used: metal and polymer fiber. All mix proportions are taken in their best-performance composition. The samples have been tested at the ages of 7, 14, 28, 56, 91 and 182 days. The obtained results are compared with those for the reference specimens made of Ordinary Portland Cement concrete and a certain influence of the selected parameters on internal friction of the above-mentioned materials is established. Acknowledgements. This research has been supported by the Russian Foundation for Basic Research, Project No. 20-38-70143-Stability. References 1. Popov I.I., Levchenko A.V., Shitikova M.V. Experimental identification of the fractional parameter for rubber concrete and fiber-reinforced rubber concrete, JOINT EVENT ICCS23 - 23rd International Conference on Composite Structures MECHCOMP6 - 6th International Conference on Mechanics of Composites. Book of Abstracts. Faculty of Engineering, University of Porto. 2020. P. 98-99.

Development of a Micro-Crack Toughening Mechanism for Unidirectional Composite Plates by using Peridynamics

abst. 2025
Room 2
Tuesday
June 15
14h20

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Composite structures serve as primary structural components in today's engineering applications because of their superior tensile stiffness and rigidity as well as low weight to stiffness ratios. However, the brittle nature of its matrix constituent makes composites structures prone to any damage occurrence, leading to rapid fracture propagation through the structure. The unexpected failure of such a critical component of a composite structure can cause the entire fiber-matrix system to become completely useless. Albeit traditionally being overdesigned to avoid any unexpected mechanical failure, these structures cannot be often responsive to the damage propagation after the initiation of a small failure/defect. To overcome these damage-propagation issues, in this study, a novel toughening enhancement model is proposed for unidirectional composites. The toughening mechanism is established by introducing the so-called micro defects/cracks for increasing the toughness of matrix constituent of the composite structure. Mechanical simulations are performed utilizing a non-local continuum formulation known as bond-based Peridynamics (PD). The PD formulation facilitates the modeling of material discontinuities such as complex crack/defects formations with an arbitrary size, orientation, and location features in composite structures. Here the toughening enhancement models are established by allocating various micro-crack formations in three different fiber orientations (0, 45, 90 degrees) of UD composite plates. The toughening effects of micro-crack clusters are thoroughly analyzed by making comprehensive comparisons on the propagation speed of an initially introduced macro-crack. As a result, unique micro-crack distributions are found for each fiber orientation of the UD composite, providing an augmented toughness to the brittle composite materials.

Failure simulation of four point bending CFRP laminate specimen including wrinkles

abst. 2055
Room 2
Tuesday
June 15
15h00

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The influence of manufacturing defects in laminated composites is an major field of research according to their detrimental effects on the residual strength of the structure [1]. Among the different types of defects, wrinkling and waviness are perhaps one of the most common and detrimental, especially under compression. Here the term "waviness" is used to describe in-plane misalignment of fibers and the term "wrinkling" refers to out-of-plane misalignment of fibers. In the literature, wrinkling in a planar part is massively studied [2-3] but to our knowledge, less interest was paid to the influence of wrinkling present in the radius of a curved part. In this paper, a numerical study the influence of wrinkles contained in the radius of L-shape specimen tested under four-point bending tests is done. The used model called 'Discrete Ply Model' (DPM) and developed at Institut Clement Ader [4–6] a decade ago [4–6], which has already demonstrated its capability to give a good agreement between experimental results and simulation of four points bending tests without wrinkles [7]. Several specimens with different severities of wrinkling were manufactured. Concave moulds were used with two strategies of stacking. The first one consists classically to lay in the concave mould the different plies

to obtain the stacking desired without defect. The second method permits to introduce wrinkling of plies and consists in realising the staking on a table and afterwards introducing the package in the mould. Depending on the number of plies previously stacked on the table, the wrinkles observed are more or less significant. By combining these two methods, the intensity of wrinkling created can be adjusted and regulated. This strategy produced good results when the number of plies initially stacked on a flat surface is low. When too much plies are used to insert wrinkling under the radius of curvature of the part, the defects created are too serious and many voids emerge caused by wrinkling of plies. Four points bending tests on the different specimens produced were carried out. Digital images correlation and infrared thermographic imaging were used simultaneously to follow the damage of specimens. This instrumentation has enabled to capture the scenario of failure of L-angle shapes with presence of wrinkling under the radius of curvature. Finally, the DPM was used to numerically simulate the tests previously mentioned taking into consideration the ply wrinkling experimentally observed. For that, a range of points corresponding to the interface of the different plies was measured and used to create a mesh, which perfectly corresponds to the specimen. [1] Potter KD. Understanding the origins of defects and variability in composites manufacture. In: 17th International conference on composite materials. Edinburgh International Convention Centre, Edinburgh, UK; 2009. p. 27–31 [2] Mukhopadhyay, S., M. I. Jones, and S. R. Hallett. 2015a. "Compressive Failure of Laminates Containing an Embedded Wrinkle; Experimental and Numerical Study." Composites Part A: Applied Science and Manufacturing 73:132–42. [3] Lemanski, S. L. and M. P. F. Sutcliffe. 2012. "Compressive Failure of Finite Size Unidirectional Composite Laminates with a Region of Fibre Waviness." Composites Part A: Applied Science and Manufacturing 43:435–44. [4] Bouvet C, Castanié B, Bizeul M, Barrau JJ. Low velocity impact modelling in laminate composite panels with discrete interface elements. Int J Solids Struct 2009;46:2809–21. [5] Hongkarnjanakul N, Bouvet C, Rivallant S. Validation of low velocity impact modelling on different stacking sequences of CFRP laminates and influence of fibre failure. Compos Struct 2013;106:549–59. [6] Dubary N, Bouvet C, Rivallant S, Ratsifandrihana L. Damage tolerance of an impacted composite laminate. Compos Struct 2018;206:261–71 [7] Journoud P, Bouvet C, Castanié B, Laurin F, Ratsifandrihana L. Experimental and numerical analysis of unfolding failure of L-shaped CFRP specimens. Compos Struct 2020;232:111563.

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abst. 2080
Room 2
Tuesday
June 15
15h20

Analytical modeling of fatigue crack growth in hybrid 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 the glass, carbon, and hybrid glass/carbon fibers, while a good convergence of results was obtained

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abst. 2104
Room 2
Tuesday
June 15
14h00

Methods of repairing mechanically damaged GFRP laminates and its verification in uniaxial tensile tests with the use of DIC

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In addition to the loads provided at the design stage, PMC composites may also be exposed to unforeseen point loads, both static and dynamic, e.g. hail impacts (aircraft fuselages), contact with hard ground (bicycle frames), collisions with birds (wind turbine blades) , contact with rocks, coastal elements (yachts, catamarans). In order not to recycling the entire structure, it must be repaired. Access to the damage is often possible only from one side, which makes repair difficult and limits its scope. In the study, samples from the GFRP laminate with dimensions of 250mmx30mmx1mm were tested, in which point damage was made with a steel ball indenter. Three indenters diameters were used: 10mm, 15mm and 20mm. The force with which the indenters were pressed was the same in each case and amounted to 2 kN. While pressing the indenter, the sample was placed on a pine wood substrate. Three levels of damage were obtained, characterized by cross cracks, laminate deformation and delamination. Before performing the repair, numerical simulations were carried out in the Abaqus program to select the appropriate dimensions of the reinforcing material. The numerical model took into account the phenomenon of reinforcement delamination through the use of cohesive elements and the level of effort of the GFRP substrate was analyzed using the Tsai-Hill criterion. The repair was carried out on one side with the use of epoxy resin and reinforcement in the form of: unidirectional glass fibers, glass fiber fabric and a patch made of the same laminate as the substrate. Samples without reinforcement were kept as reference. Uniaxial tensile tests were carried out, which allowed to determine the effectiveness of the repair and to select the best method of strengthening. The deformation fields obtained in the FEM simulation were compared with the results obtained using the digital image correlation (DIC) technique.

Discrete Element approach to simulate debonding process in 3D short glass fibre composite materials

abst. 2160
Repository

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The present contribution aims to investigate the efficiency of a 3D Discrete Element Method to deal with, one of the crucial aspects which controls interlaminar cracking failure, debonding process at the fibre/matrix interface. Here we develop a numerical approach to model the fibre/matrix debonding. The study is carried out on a short glass fibre composite known as Polyamide 6 reinforced with 30% of short glass fibre (PA6/GF30). First of all, mechanical properties as well as damage mechanisms of PA6/GF30 are evaluated using experimental campaign. Then, 3D DEM-model based on original methodology is developed to estimate effective elastics properties of PA6/GF30. Results are discussed based on some comparisons with micromechanical approaches and experimental data. Furthermore, delamination process on morde I, mode II and mixed mode are studied using an interfacial 3D DEM model based on a bilinear traction-separation law. Our results are in good agreement with analytical solutions which validated the capability of our developed approach to deal with delamination problems. Moreover, the case of single fibre composite as well as the multi-fibre composite are modeled using the proposed approach. Results in terms of onset and propagation of the debond on fibre/matrix interface confirm the potential of the present approach to simulate interfacial debonding process in short glass fibre composite material PA6/GF30. Finally, we integrate hygrothermal parameters into the developed interfacial model to simulate the behaviour and the damage of the PA6/GF30 material under a wide range of environmental conditions. The purpose of this study is to establish a powerful numerical 3D DEM tool to simulate thermo-hydro-mechanical behaviour of short glass fibre composite material.

Experimental and Analytical Study of the Mohr-Coulomb Envelope of Strain Hardening Fiber Reinforced Cementitious Composites

abst. 2170
Room 2
Tuesday
June 15
14h40

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This paper evaluates shear strength of the novel types of fiber reinforced cementitious composites and especially those with short discontinuous PVA fibers with strain hardening ability in tension. The strain hardening property is achieved by a multiple cracking phenomenon, that macroscopically changes the fracture behavior and ultimate capacities of the material. Multiple cracking is affected by a multitude of fibers bridging the cracks thereby delaying the onset of crack localization. The sustained tensile strength is also manifested by an increase of the shear capacity. A requirement for achieving tensile strain resilience (i.e. sustained tensile strength up to large strains) is in the use of fine aggregates in the mix. The maximum grain size must be significantly smaller than the fiber length in order to engage the fibers effectively; mixes with maximum grain size in the range of 300 to 1000 μm are the norm in the field of Strain Hardening Fiber Reinforced Cementitious Composites (SHFRCC). In the absence of coarse aggregates, the interlocking action - which is one of the shear strength components of concrete contribution to shear strength is eliminated. This aspect renders the behavior of SHFRCC in shear rather different from that of normal concrete. These mechanisms are explored by a series of push-off specimens designed with various geometries and varying angles of the shear plane, to evaluate not only the shear strength under pure shear but also the behavior of the failure plane under combined stress states (i.e., normal compression and shear and normal tension-shear). The effect of scale is also explored by considering two different sizes of specimens. Complementary tension, compression, split and flexural tests on beams were used to support the analytical investigation of the mechanical behavior. The push-off test results were used to derive the experimental Mohr-Coulomb envelope, while the results from the compression and tension tests were used to calibrate the needed parameters for the finite element simulation of the material, achieving a very good approximation to the push-off experimental results. The study concluded that PVA fibers can be used in cementitious composites as partial replacement of conventional transverse reinforcement, effectively increasing the shear strength of the material to levels that are up to ten times that of normal concrete. A new design criterion is provided for the determination of the shear strength of SHFRCC composites, that takes into consideration the contribution of the tensile and confining properties of the fibers, since available shear transfer equations provided in current Codes and Standards have been calibrated on experimental data obtained from normal concrete.

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abst. 2189
Repository

Determining dynamic stiffness degradation and damping properties of paperboard by random vibration fatigue

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Paperboard (corrugated paper board) is a lightweight, excellent compression resistance, and eco-friendly material, so it is widely used in transporting and packaging of home appliances to protect the product from external random vibration loads and to prevent separation of important internal parts. For this reason, it is necessary to study changes in dynamic stiffness and damping characteristics of paperboard when a continuous random vibration load is applied. In this paper, using the change of the flexural wave propagation characteristics of the beam according to the boundary condition, the forced flexural wave propagation characteristics of cantilever beams midpoint-supported by paperboard were analyzed. The paperboard was modeled as a viscoelastic supported boundary condition, and the transfer function was measured using acceleration at two points of a cantilever beam that is midpoint-supported by the paperboard and is randomly excited. Using this transfer function, frequency dependent viscoelastic characteristics of paperboard were measured. Also, the viscoelastic properties of paperboard were measured over time with controlled initial compression strain and the magnitude of random vibration.

The stiffness degradation and damping characteristics of paperboard under random vibration fatigue were obtained.

Preparation of interpenetrating metal matrix composite based on 3D-printed metallic glass foams produced by gas pressure infiltration

abst. 2208
Room 2
Tuesday
June 15
16h20

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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 laser-based additive manufacturing 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. Resulting microstructure was investigated using X-ray diffraction (XRD) measurements, scanning electron microscope (SEM) and X-ray computed tomography (CT). In addition, the mechanical properties and damage behavior were determined by compression tests.

Clustering of breaks and avalanches in impregnated fiber bundles as precursors of failure

abst. 2221
Room 1
Monday
June 14
15h40

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In the 80s of the last century, an analogy between the process of damage and phase transitions has been discovered, leading to many studies applying the concepts of statistical physics, like susceptibility, clustering, correlations, fluctuation-dissipation theorem, metastability, nucleation, critical nucleus, renormalization group, to damage prediction (a review can be found in [1]). As always, the pioneering studies targeted one-dimensional or mean-field systems with global load redistribution keeping three-dimensional or locally-interacting systems to be approached in later years. The fiber-bundle model (FBM) was and is one of the most popular systems to simulate damage development and analogy with thermal systems of statistical physics. However, in the FBM the load from a broken fiber is redistributed, locally or globally, by model rules instead of a matrix transferring load among fibrous reinforcement. This limits FBM's applicability to composites where load redistribution by matrix is significant for the correct description of system's behavior. One of FBM's modifications, impregnated fiber-bundle model (IFBM), simulates matrix either numerically or analytically, causing three-dimensional stress-strain state of load redistribution from a broken fiber, which makes the IFBM applicable for modelling unidirectional impregnated plies or tows. In our study, we utilize the IFBM to verify predictions of statistical physics

for damage evolution. Numerical simulations are performed with the model developed by Swolfs et al. [2]. A carbon/epoxy tow of 2000 fibers with the fiber volume fraction of 60% and their strength varying along them is loaded by a tensile load along the fibers. We observe that in contrast to the expectations from statistical physics, the behavior of break clustering and avalanches does not diverge at the point of failure leaving correlations short-range. Until the point of the final avalanche leading to a catastrophic failure, avalanches are space-distributed and clustering of breaks is three-dimensional. Planar, two-dimensional morphology is forming only in the course of the final avalanche. Susceptibility of damage clearly exhibits a finite-size effect, which was found by us to be the best precursor of failure. In the result, we conclude that damage in composites differs significantly from phase nucleation in homogeneous media. Instead of a critical cluster as a relative of a compact nucleus of critical size from statistical physics, we observe three-dimensionally, spatially distributed nucleus of a different nature. We attribute this difference to the heterogeneity of the composite (to a quenched disorder) in contrast to homogeneous systems of classical phase transition theory, like liquid-gas systems. Acknowledgements The work in KU Leuven was performed within the framework of the FiBreMoD project and has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 722626. SVL holds the Toray Chair at KU Leuven, the support of which is gratefully acknowledged. References [1] S. G. Abaimov, "Statistical physics of non-thermal phase transitions: From foundations to applications", Springer, 2015. [2] Y. Swolfs, R.M. McMeeking, V.P. Rajan, F.W. Zok, I. Verpoest, and L. Gorbatikh "Global load-sharing model for unidirectional hybrid fibre-reinforced composites." Journal of the Mechanics and Physics of Solids 84: 380-394, 2015.

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abst. 2252
Room 2
Tuesday
June 15
16h00

On the interlaminar shear deformations in the thick GLARE laminates

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In this presentation we discuss the phenomenon of the interlaminar shear deformations that arise in the thick GLARE laminates under bending loading. Based on the experimental results and simulations we show that it is important to take into account the plastic strain that arise in the GFRP layers during the short beam tests with GLARE (see also Solyaev et al., Composites Part B, 2020, 108302). These effects allow to explain the significant size effect for the apparent interlaminar shear strength of GLARE and the reduction of the load bearing capacity of such materials under bending. Intensive localization of the interlaminar shear in GFRP layers is observed directly by using digital image correlation analysis of the samples surface under loading. The change of the failure mechanisms for the samples with different span-to-thickness ratio in the three-point bending test is also discussed and explained theoretically. Experimental data is presented for the GLARE structures with 17 layers (GLARE1-9/8 A, B), that can be used for the manufacturing of the aircraft wings.

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abst. 2288
Room 2
Tuesday
June 15
15h40

Effect of binder weave structures on the tensile properties of 3D woven composites and their failure mechanisms.

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The mechanical properties and failure modes of 3D woven composites are different from the traditional 2D and UD composites due to the complex geometrical structures of the reinforced material i.e. 3D woven preforms [1]. In 3D woven preforms, the load-bearing warp and weft tow layers are held by the Z directional binders. The Z binder in the 3D woven structures makes the preforms coherent yielding excellent delamination resistance and higher damage tolerance. At the same time, this Z binder

creates fibre waviness and crimps in the load-bearing tows resulting in disturbance in resin flow and a reduction in in-plane mechanical properties [2]. The structure of the 3D woven preforms and the ultimate composite properties can be varied by changing the Z binder parameters [3-4]. This research aims to investigate the effect of the binder weave structures on the tensile properties of the 3D woven composites. The considered weave structures are 1X1 plain, 2X1 twill, 2X2 twill with orthogonal binding pattern and one angle interlock (AI) preform. The weave structures are chosen considering the sequential increase of the fibre floating in the final preforms. The preforms are woven using an automated jacquard loom with controlled parameters. All the preforms are manufactured with 12K T700SC 50C untwisted carbon tows as warp weft and for binder 6K carbon tows are used of the identical group. In all the structures the fibre density is kept the same. Both warp and weft way bound preforms are made to comprehensively investigate the influence of binder weaves on tensile failure modes of 3D woven composites. The composite panels are made by using the vacuum infusion method with two plates to get uniform thickness. The composites are subjected to in-plane tensile loading to explore the effect of binder weave structures on the tensile properties of the composites and their failure modes. Online video imaging with digital image correlation (DIC) is used to track the nature of the tensile failure. Investigating the tensile behaviour using both warp bound and weft bound structures is expected to give a comprehensive understanding of the effect of binder weave architectures on the failure mechanisms in tension for 3D woven composites and thus it gives novelty to this research. References 1. L. Tong, A. P. Mouritz, M. K. Bannister, L. Tong, A. P. Mouritz, and M. K. Bannister, "3D Woven Composites," in 3D Fibre Reinforced Polymer Composites, 2002. 2. R. Umer, H. Alhussein, J. Zhou, and W. Cantwell, "The mechanical properties of 3D woven composites," J. Compos. Mater., vol. 51, no. 12, pp. 1703-1716, Jan. 2002. 3. S. Dhiman, P. Potluri, and C. Silva, "Influence of binder configuration on 3D woven composites," Compos. Struct., vol. 134, pp. 862–868, Dec. 2015. 4. P. Potluri, P. Hogg, M. Arshad, D. Jetavat, and P. Jamshidi, "Influence of Fibre Architecture on Impact Damage Tolerance in 3D Woven Composites," Appl. Compos. Mater., vol. 19, no. 5, pp. 799–812, Oct. 2012.

abst. 2286
Repository

Stress-Strain Behavior and Design-Oriented Model for FRP Spiral Strip-Confined Concrete

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Partial fiber-reinforced polymer (FRP) wrapping has become an attractive strengthening techque for reinforced concrete (RC) columns. Apart from FRP full wrapping strengthening techque, FRP partial wrapping using FRP spiral strips leads to some advantages such as automatic wrapping and better fire resistance. However, existing study on FRP spiral strip is limited and the confinement mechanism of concrete in FRP spiral strip wrapped columns remains unclear. To this end, axial compression tests on 28 concrete columns wrapped by FRP spiral strips are conducted and the test results are presented in this paper. Results show that the ultimate axial stress and the slope of the post-peak linear segment of the axial stress-strain curve are significantly affected by the proposed actual confinement effectiveness factor. The desired actual confinement effectiveness factors for specimens are achieved by varying the confinement parameters (i.e., spiral angle, width and layers of FRP strips). It is found that an increase in FRP strip width and thickness leads to enhancements in both axial stress and strain of the FRP spiral strip-confined concrete, whereas a decrease in the spiral angle has a more pronounced effect on the axial stress enhacement than the axial strain enhacement. A new design-orientated stress-strain model is proposed for FRP spiral strip-confined concrete based on a new test database. The predictions corrobarate reasonably well with the test results, demonstrating the accuracy and robustness of the proposed model.

Effect of load distribution on debonding failure of RC beams strengthened in flexure with NSM CFRP strips

abst. 2024
Repository

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Premature debonding failures of FRP were frequently observed in reinforced concrete (RC) beams strengthened in flexure with near-surface mounted (NSM) fiber-reinforced polymer (FRP) in laboratory tests. Numerical and theoretical studies aimed to predict the loads of such debonding failures in NSM-strengthened beams have been carried out, and relevant strength models have also been proposed. However, these studies are usually based on the simply-supported RC beams tested under one or two loading points without considering the practical condition of a distributed load. This paper presents the first experimental study into the effect of load distribution on the debonding failure of NSM-strengthened RC beams. A series of full-scale RC beams strengthened in flexure with NSM carbon fiber-reinforced polymer (CFRP) strips were tested, under two-point loading, four-point loading and eight-point loading. The test results show that these NSM-strengthened beams all failed by FRP end concrete cover separation, and an increase in the load uniformity led to the increases in both the load and deformation capacities of beam.

Temperature effects on the flexural response of NSM CFRP-strengthened RC beams under sustained load

abst. 2097
Room 1
Monday
June 14
16h20

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In the last decades, fiber-reinforced polymer (FRP) materials have been widely used to strengthen damaged reinforced concrete (RC) structures, by using either the externally bonded reinforcement (EBR) or the near-surface mounted (NSM) strengthening techniques. The instantaneous flexural performance of NSM FRP strengthened RC beams has been widely studied in the literature, but fewer studies have been performed to investigate its performance under sustained load. Furthermore, epoxy resins are usually used as a bonding material. Exposure of these resins to relatively high temperatures (i.e. around or beyond the glass transition temperature, Tg) may lead to changes in their mechanical properties that may affect the FRP-concrete joint performance and, therefore, the effectiveness of the strengthening system. Because of this, the study of the effect of temperature on the performance of NSM FRP strengthened elements has attracted attention during the last years. However, the scarce available studies under long-term loading are focused on the flexural performance of FRP-strengthened RC beams at room temperature, and further studies are needed to understand their time-dependent behavior in the presence of temperature. The main objective of the current study is to investigate the effect of temperature on long-term flexural performance of NSM carbon fiber-reinforced polymer (CFRP)-strengthened RC beams. Different parameters have been considered, namely two different steel reinforcement ratios (i.e. 1.14 % and 0.79 %), two different NSM CFRP ratios (i.e. one strip and three strips), and two different temperatures (i.e. room temperature and 50 [U+1D52]C). The beams have rectangular cross section of 140 × 180 mm and a total length of 2400 mm. The clear span is 2200 mm and the shear span is 750 mm, thus leading to a flexural span of 700 mm. Furthermore, CFRP strips have a thickness of 1.4 mm and a width of 10 mm. The test matrix is composed of a total of 20 beams; 10 of them were tested to know their instantaneous flexural behavior and other 10 were tested under long-term loading. Prior to applying the sustained load, the beams were loaded up to service conditions so as to be in the usual cracked state. Results of preliminary tests in terms of time-dependent deflection, evolution of strains in concrete and strain in FRP and influence of temperature

are presented and discussed. Acknowledgment The authors acknowledge the support provided by the Spanish Government (MINECO), Project Ref. BIA2017-84975-C2-2-P. The first author acknowledges the Generalitat de Catalunya for FI grant (grant number 2019FI$_B$00054).

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abst. 2129
Repository

Efficient Flexural Strengthening of PSC Beams using Prestressed NSM CFRP Bars

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Recently, strengthened reinforced concrete (RC) structures with prestressed near surface mounted (NSM) carbon fiber reinforced polymer (CFRP) bar system has been studied. Research on strengthened prestressed concrete (PSC) structure with prestressed NSM CFRP bar system. PSC beams with a length of 6.5 m were fabricated for the four-point loading tests. The experimental parameters were concrete compressive strength (20 MPa, 40 MPa), prestressing load of PSC beam (140 kN, 280 kN), number of prestressed CFRP bar (0, 1), and number of non-prestressed CFRP bar (0, 1). One PSC beam was reinforced with the non-prestressed NSM CFRP bar system. Four strengthened PSC beams with prestressed NSM CFRP bar systems were fabricated. Four PSC control beams were fabricated as reference. As the experiment results, the ultimate flexural strength of strengthened PSC beam with prestressed NSM CFRP bar system increased by up to 30.9% compared to the un-strengthened PSC control beam. In this study, the ultimate flexural strength of prestressed NSM CFRP bar system changed due to the influence of experimental parameters. The prestressed NSM CFRP bar system was evaluated to be more efficient than non-prestressed NSM CFRP bar system. The experimental results were compared with the finite element analysis (FEA) results. The parametric study was performed using design conditions of PSC beam. Keyword: Flexural strength, Near surface mounted, CFRP, PSC beam, Finite element analysis

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abst. 2195
Repository

On the evaluation of the bond capacity of concrete-FRP joints under environmental actions

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FRP composites have been widely used in the last decades as external reinforcement of concrete structures. In particular, both FRP strips and FRP sheets have been used to improve the performance of RC columns, beams, and slabs. In the literature, a large number of studies on the mechanical properties of the FRP composites and on their bond properties are available. On the other hand, the long-term behaviour of externally bonded FRP systems is strongly affected both by the strength degradation of the constituent materials and by the bond characteristics at the interface between FRP and concrete. Several standards and guidelines suggest the use of the so-called environmental conversion factors in order to evaluate the bond capacity, for different exposure conditions, of FRP system with respect to the bond capacity of unconditioned systems. Unfortunately, in some cases, these conversion factors are calibrated on a limited amount of experimental data and their reliability is then an issue. In this work, different kinds of environmental actions are taken in account (freeze-thaw cycles, exposure to chemical solutions, effect of temperature cycles and continuous immersion in water). Outcomes from experimental campaigns performed by some of the authors and data from the literature are collected together to create an extended database. A detailed analysis of the failure modes is presented. The most frequently observed ones were the cohesive failure within the concrete substrate and the adhesive one at the interface between adhesive layer and the concrete substrate. In some cases, mixed cohesive-adhesive failure modes or mixed adhesive failure modes, with partial crisis in the adhesive layer were found as

well. First, the experimental database is statistically analyzed in order to provide a better estimation of the bond capacity of unconditioned specimens. In particular, the effects of the reinforcement width and the reinforcement type (pultruded strips or in-situ cured sheets) are examined. Then, for conditioned specimens, the environmental conversion factors are estimated and compared to the predictions of standard and guidelines. It is noticed that in some cases, if the environmental conditioning causes the hydration process and thus the concrete hardening, the debonding failure loads may slightly increase. In other cases, the adhesive failure mode leads to a significant decrease of the debonding failure loads, thus reducing the environmental conversion factors. For all these different scenarios, proper models of the bond capacity of concrete-FRP joints are presented and discussed. In particular, when failure of the adhesive interface is observed, an innovative model from the literature is used to the separate the effect of mechanical interlocking from the chemical bond.

PARAMETRIC STUDY ON MOMENT REDISTRIBUTION OF FIBER REINFORCED CONCRETE CONTINUOUS BEAMS WITH BASALT FRP BARS

abst. 2203
Room 3
Monday
June 14
15h20

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This study addressed the effect of using basalt fiber reinforced polymers (BFRP) bars and basalt macro-fibers (BMF) on the serviceability and moment redistribution of reinforced concrete (RC) continuous beams. For this purpose, 10 RC continuous beams were experimentally tested under five-point loading until failure. The tested beams were continuous over two-equal effective spans of 1800 mm. The investigated parameters included the reinforcement type, reinforcement ratio, stirrups spacing, and volume fraction (Vf) of BMF. The test results suggested that BFRP-basalt fiber reinforced concrete (BFRC) beams exhibited higher crack widths, tensile strains, and deflections than steel-BFRC beams. However, increasing Vf of BMF and reinforcement ratio, or decreasing the stirrups spacing significantly improved the aforementioned properties. In addition, test results revealed that BFRP-BFRC beams had higher moment redistribution compared to steel-RC beams. The moment redistribution of the tested beams significantly increased by an increase in the sagging reinforcement-to-hogging reinforcement ratio and Vf of BMF. However, decreasing the stirrups spacing resulted in a slight increase in the moment redistribution. This study also sought to create a two-dimensional nonlinear finite element (FE) model using ABAQUS 6.14 software. The FE model was verified and calibrated through the experimental load-deflection responses. The verified model was then used to perform a parametric study on the moment redistribution of BFRP-BFRC continuous beams by extending the levels of aforesaid parameters. Furthermore, a statistical regression analysis was performed to generate a linear model that predict the moment redistribution of BFRP-BFRC continuous beams.

Shear Behavior of Green Concrete Beams Reinforced with Basalt FRP Bars and Stirrups: An Experimental and Analytical Investigations

abst. 2205
Room 3
Monday
June 14
15h40

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Recently, researchers have shown an increased interest in the application of Fiber reinforced polymers (FRPs) in concrete structures. Meanwhile, debate continues about the best strategies for mitigating CO2 emissions during concrete production. This study is therefore will investigate the shear performance of large-scale green concrete (GC) beams reinforced with basalt (B) FRP bars and stirrups. The GC concept will be implemented in this study by partially substituting the cement content with 35% by weight of industrial by-products such as fly ash and silica fume. The main test variables are the reinforcement ratio, the shear span to depth ratio (a/d), the spacing between stirrups. Three beams were transversely reinforced with steel stirrups to serve as a control. The results in this study indicated that the ultimate shear capacity was significantly increased at higher reinforcement ratio, but their effect

was reduced at lower spacing between stirrups. In addition, the BFRP stirrups were effective in reducing the diagonal shear crack width and increasing the beam's ultimate shear capacity. Furthermore, beams with higher a/d ratio have shown higher deflection and reduced ultimate shear capacity. Comparing the experimental results of the current study with the major design code provisions, the CSA-S806-12 has shown the best predictions with a mean experimental to predicted shear (Vexp/Vpre) ratio of 1.2 $\pm$ 0.21.

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abst. 2229
Room 3
Monday
June 14
16h20

Use of CFRP U-Wrap Anchors in Flexural Strengthening of RC T-Beams with CFRP Sheets

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Externally bonded CFRP sheets are proven to be one of the effective techniques to strengthen concrete structures because of many synergistic characteristics. One of the major shortcomings of this technique is premature debonding between the FRP sheets and the concrete substrate prior to attaining the full capacity of the CFRP sheets. This study investigates the effectiveness of CFRP U-wrap anchors when used to secure CFRP sheets for flexure strength enhancement of full scale reinforced concrete T-beams. The U-wrap anchors are used as an anchorage system to prevent premature failure due to debonding and allow the CFRP sheet to reach its full capacity with an anticipated rupture failure. Six full scale T-beams are designed, built, and tested under four-point bending until failure. The test beam specimens have section dimensions of 6 in. (152 mm) web width, 16 in (406 mm) flange width, 4 in (102 mm) flange thickness and 12 in. (305 mm) total depth. They are simply supported with 186 in. (4724 mm) clear span. One of the T-beams is tested with no strengthening as a control beam. Double layers of unidirectional CFRP sheet is applied to the beam soffit for each of the remaining beams. Moreover, CFRP U-wrap anchors are installed to anchor the CFRP sheet and to transfer stresses from the sheet to the concrete core when the CFRP sheet tends to debond at a later stage of loading. Different modes of failure and a significant increase in the flexural strength have been observed, depending on the number and spacing of the CFRP U-wrap anchors along the shear span of the T-beams. Comparison between the test results and nonlinear numerical analysis are also made. A simplified design model is proposed to account for sizing the CFRP U-wrap anchors to achieve a certain design criterion.

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abst. 2266
Room 3
Monday
June 14
16h00

Assessment of RC beam strengthened with NSM C-GFRP rods by experimental tests

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Inserting fiber reinforced polymer (FRP) rods into grooves using the near surface mounted (NSM) technique has been demonstrated to be a suitable method for repairing reinforced concrete (RC) elements. In this work the effect of different type of FRP in the structural response of RC beam models has been analysed. The static and dynamic behaviour of RC beams damaged and strengthened by FRP rods utilizing the near surface method (NSM) has been evaluated. Glass and carbon fiber reinforced polymers (G-CFRP) rods have been used as strengthening and their different behaviour has been evaluated. The RC beam models have been subjected by bending tests in order to obtain the concrete's cracking. Experimental vibration monitoring through dynamic tests have been adopted as nondestructive method of control during the experiments to assess the response of RC beams at different damage steps of concrete or due to decrease of bond of C-GFRP rod. The analysis of frequency changes due to damage for bending cracks and loss of adhesion allow discussing and comparing the behavior of RC beams strengthend with NSM C-GFRP rods.

Functionally graded materials and structures

Influence of spatial variability of material properties on warping torsion of FGM beams with open cross-section.

abst. 2028
Repository

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The paper contains an original numerical solution of the influence of spatial variability of material properties on the deformation and stress state of functionally graded (FGM) beams with an open cross section. A new benefit will be the consideration of the influence of longitudinal and transverse and lateral variability of material properties on the calculation of bimoment normal and shear stresses as well as individual stiffnesses and warping of the open cross section of the FGM beams. Results of the author's original solution will be compared by the ones obtained by 3D solid finite elements. The accuracy and effectiveness of the new approaches will be discussed and evaluated.

Nonlinear vibration of functionally graded nanobeams with diverse porosity distributions carrying several buckyballs

abst. 2057
Repository

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In this presentation, an attempt is made to investigate the large-amplitude nonlinear vibration response of functionally graded (FG) porous nanobeams carrying several buckyballs. The influence of various porosity distributions as well as position and mass of buckyballs on the nonlinear vibrational behaviour is particularly studied. To model size effects on the vibrational response, a higher-order nonlocal elasticity and strain gradient theory in conjunction with Euler-Bernoulli theory is used to model the nanobeams. Using Hamilton's variational principles, the strain energy, external work and kinetic energy of the ultrasmall system is formulated. The governing partial differential equations and the corresponding boundary conditions are derived incorporating von Kármán geometrical nonlinearity. According to the power-law mixture of constituent materials with cosine function, inhomogeneity in the material parameters of the FG porous nanobeam is modelled. A discretization technique based on Galerkin's approach and a perturbation solution method are employed to estimate the shift in the nonlinear frequencies of the nanobeams due to the attached buckyball. The nonlinear frequency shift of the complex coupled nanosystem is calculated for various boundary conditions. The validity of the estimated results is evaluated by performing several comparison studies with available data in the literature. Several system parameters such as porosity distribution, material index, the number, position and mass of attached buckyballs, as well as size parameters including the length scale and nonlocal coefficients are taken into consideration in the nonlinear vibration analysis. Acknowledgement: 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"

On static and free vibration analysis of FGM plates using an efficient quadrilateral finite element based on DSPM

abst. 2069
Repository

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In the present paper, a shear-locking free quadrilateral element called Q4Ys with 5 D.O.F.s per node, is developed using a discrete shear projection method (DSPM). Transverse shear strains are formulated using a tangential coordinate system, and discrete shear strains are assumed along the element edges to get the constant shear strains. These constant shear strains are projected on each corner node, and the cartesian shear strain components are interpolated over the element domain with standard bilinear shape functions. The implementation of Q4gs in a finite element program is quite simple, and the resulting element is an alternative to MITC4. The applications in static and free vibration analysis of functionally graded material plates show good convergence behaviour, high reliability and accuracy.

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abst. 2124
Repository

Peridynamic Analysis of One Dimensional Functionally Graded Plates

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Composite structural components are used extensively in many diverse fields including military, aerospace, and nuclear due to their ability of adapting to different working conditions and desirable properties lightweight, strong, and high-temperature resistance. The geometrical or material discontinuities along the interfaces between two distinct materials may lead to local interlaminar stress concentrations. These may cause catastrophic failures although the stress levels are not unduly high. The functionally graded materials (FGMs) enable to minimize the aforementioned stress concentrations by tailoring the material properties continuously in one or more coordinate directions in structures. In order to design FG structures safely, it is very crucial to understand and investigate possible damages under different loads. Since structural testing and analysis techniques may be costly, there is a necessity to use improved and accurate computational tools to predict the deformation and stress fields of the FG structures. Numerical simulation of the dynamic crack propagation mechanism in FGMs remains a formidable challenge in computational mechanics because the material properties of FGMs are not symmetric. PeriDynamic (PD) theory is based on integro-differential equations involving time and spatial coordinates. Hence, the equilibrium equations of PD theory are still valid even if the material includes a discontinuity. This feature allows damage initiation and propagation at multiple sites with arbitrary paths inside the material without resorting to special crack growth criteria. This study aims to investigate the material variation in FG structures and boundary/loading conditions on the failure behavior of one-dimensional FGMs by using the PD theory. The robustness of the present approach is demonstrated by considering FG plates under various boundary and loading conditions as well as material variations.

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abst. 2161
Room 1
Monday
June 14
14h00

Multi-scale topology optimisation design of porous femur implant with graded-density anisotropic microstructures using latent variable Gaussian process

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Porous femur implant with lattice microstructure design has attracted increasing attention in the treatment of total hip arthroplasty (THA) for its satisfactory performance in ossature biomimic. Nevertheless, conventional implant porous design adopts isotropic lattice microstructure, which does not accord with femur bone's ascertained structural anisotropy. In this research, a topology optimisation framework is established for design of porous femur implant based on multi-scale anisotropic finite element analysis. The framework enables the adjustment of both relative density and lattice pattern of microstructures to further decrease the total stiffness of the implant, thereby moderating stress shielding phenomenon and preventing post-operative adverse events such as osteoporosis. The implant geometry refers to Ti6Al4V Tri-lock Femoral Stem to guarantee minimum invasion space. The majority of the implant optimisation domain is meshed by anisotropic hexahedral elements. Remaining areas are meshed with isotropic tetrahedral elements. One library containing anisotropic face-diagonal cubic lattice unit cells with different beam weight combinations and another library containing isotropic

unit cells with different relative densities are prepared. The stiffness matrices of the unit cells are computed from numerical homogenisation method. The anisotropic unit cells are then positioned in a multi-dimensional latent space via latent variable Gaussian process (LVGP), by which a continuous mutual-mapping relationship between microstructure lattice pattern and anisotropy stiffness properties is established. The variance of the isotropic microstructure stiffness properties against relative density is formulated by single-variable polynomial regression analysis. The framework entity is summarised as a maximum compliance optimisation problem. Constraints include fatigue failure criteria, fracture failure criteria, bone growth requirement and manufacture requirement. The optimisation process adopts modified proportional topology optimisation (PTO) algorithm for isotropic elements and modified moving asymptotes (MA) algorithm for anisotropic elements. Optimisation results are evaluated by comparison of resorbed bone mass fraction and stress shielding intensity between solid implant / uniform-isotropic implant and porous implant designed by the proposed framework. Anisotropic porous implant samples are manufactured via selective laser melting (SLM) method. Digital image correlation results obtained from sawbones compression test are analysed to verify the simulation results.

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abst. 2066
Repository

Damage characterisation of scaled laminated composites under indentation by Acoustic Emission

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In this paper Acoustic Emission (AE) technique was used to characterize indentation-induced Damage Mechanisms (DMs) in scaled Quasi-Isotropic (QI) S-glass/8552 epoxy composite laminates. A comprehensive series of scaled Quasi-Static Indentation (QSI) tests with in-plane and intra-plane scaling were performed. A detailed assessment of the damage evolution is carried out through clustering of the monitored AE signals. The AE results were validated by Ultrasonic C-scan and visual observations. It was observed that delamination, ¬matrix cracking and fibre breakage are observed in all the investigated samples. However, both in-plane and intra-plane scaling alter the induced DMs, and the AE analysis was able to accurately identify and quantify the DMs in each case. It was observed that frequency is the best AE feature to differentiate different DMs, yet different variables such as size, geometry and stacking sequence affect the AE frequency distribution range. This highlights the potential and challenges to develop AE as a reliable structural health monitoring system for scaled laminates.

Impact Problems

Finite Element Modeling of Low Velocity Impacts on Coated Composite Structures

abst. 1006
Room 3
Tuesday
June 15
11h40

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Composite structures are always in danger from out of plane low-velocity impacts, as common failures include delamination, matrix crushing and fiber kinking. Such failures can significantly reduce the compressive strength of laminated structures. The objective of this work is to investigate the effect of coating materials, metallic and polymeric, on composite laminates when subjected to low velocity impacts at a one-joule impact energy. Placing thick coating layers is not ideal as they may cause in the loss of the major advantage of composite materials being of high strength and low weight. A validated finite element model on ABAQUS was used. Two different materials were tested as coatings, aluminum and polyurea. Additionally, a study on the effect of the thickness of the coating was investigated for laminate failure. The results showed that aluminum had limited protection to the laminate, as the coating was excessively damaged, due to its absorption of the impact energy. On the other hand, polyurea provided an almost elastic impact with the energy absorbed less than 0.2% of the impact energy at a 1-Joule impact.

Use of Artificial Neural Networks to optimize UHMWPE personal protections

abst. 2118
Room 3
Tuesday
June 15
12h40

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Olmedo, Álvaro (aolmedo@fecsa.net), FECSA Company Calle de Acacias 3, 28703, San Sebastián de los Reyes, Madrid, Spain
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Ultra High Molecular Weight Polyethylene (UHMWPE) personal protections have shown excellent properties 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 these 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 front, middle and back plies is not clear. The study of the best configuration is usually conducted by means of experimental or numerical approaches. However, these techniques are not suitable to analyse the wide range of possibilities in the design of personal protections; therefore, more efficient methods would be required. This work proposes a combined methodology including experimental tests, numerical models based on FEM, and Artificial Neural Networks (ANN) to predict accurately the ballistic limit of different configurations of UHMWPE protections. 361 configurations are analysed to study the optimal stacking sequence. Conclusions obtained can be used by design engineers to set the proper weight ratio of each material and to select their best position. [1] Aktaş, A., Aktaş, M., Turan, F. (2013). The effect of stacking sequence on the impact and post-impact behavior of woven/knit fabric glass/epoxy hybrid composites. Composite Structures, 103, 119-135. [2] Zhang, T. G., Satapathy, S. S., Vargas-Gonzalez, L. R., Walsh, S. M. (2015). Ballistic impact response of ultra-high-molecular-weight polyethylene (UHMWPE). Composite structures, 133, 191-201. [3] Bandaru, A. K., Vetiyatil, L., Ahmad, S. (2015). The effect of hybridization on the ballistic impact behavior of hybrid composite armors. Composites Part B: Engineering, 76, 300-319. [4] Artero-Guerrero, J. A., Pernas-Sánchez, J., Martín-Montal, J., Varas, D., López-Puente, J. (2018). The influence of laminate stacking sequence on ballistic limit using a combined Experimental/FEM/Artificial Neural Networks (ANN) methodology. Composite Structures, 183, 299-308.

abst. 2147
Room 3
Tuesday
June 15
12h00

Compression After Impact of Fibre Metal Laminates – evaluation possibilities

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Fibre Metal Laminates are one of the most advanced hybrid structures used in large scale aerospace constructions. Because of applications on fuselages, one of the most critical types of the mechanical load is fatigue and impact. Fibre metal laminates are known as materials with high damage tolerance, including delamination and cracks. However, complex loads can be dangerous for FMLs structural integrity. Among others, the compression after impact (CAI) is one of the main points of interests. The CAI tests are normalized for the conventional fibre-epoxy composites. In the case of thin composites plates, some unusual practices for CAI assessment were also described in the literature. However, in the case of FML structures, currently known methods are not appropriate, due to the plastic response of metal part of FML. Above feature do not lead to local buckling mode as an effect of delamination inside the composite. Rather than that, the global buckling, outside the impact damaged region occurs. The goal of the work was to assess the possibilities of effective research methods concerning thin FML resistance to compression after the low-velocity impact. Three sets of boundary conditions of CAI test were proposed and compared. It was (1) the normalized test based on standard, (2) fully closed compression area and (3) centralized compression area. The analysis was conducted with the 3D digital image correlation of plates deformations. Moreover, the NDE techniques were used for internal damage control. The response of FMLs based on aluminum/carbon and titanium/carbon impacted with various impact energies to axial compression was examined. It was noted, that the global buckling is a standard FML behaviour to the axial compression. The first negative factor is initially flatness failed of FML plates after impact. The second one is an elastoplastic nature of a metal component of FML which protect local buckling of rigid composite layers. It was demonstrated, that the centralization of compression stress, in the damaged area of FML is perspective for the analysis of impact damage progress due to a further compressive force. The stress concentration was observed in the impacted point with simultaneously local deformation of external FML layers. Finally, the residual strength of FML after impact was determined.

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abst. 2172
Repository

Impact resistance of composites with carbon fiber reinforcement subjected to weather conditions

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Recently fiber-reinforced composites have been used in many different applications, especially in the field such civilian and military aerospace applications, automotive industry, etc. Many different researches has been conducted to understand behaviors of fiber reinforced composites, especially their response after impact. Their response to such conditions should be clearly understood, because during

maintenance for example aircraft, it happens that a tool can be dropped onto a composite or a flying fragment with low velocity that can impact the composite structure. The form of delamination, fiber breakage and matrix failure can be observed If the impact energy is high enough. For aircraft aplication, carbon fibers has become the dominant fiber due to their the highest modulus or stiffness (the stiffness-to-weight ratio).Therefore, it was decided to investigate the behavior of a composite with fiber reinforcement subjected to impact loads with four energies: 2, 3, 5 and 10 J. The test was performed on instrumented drop-weight impact tester INSTRON CEAST 9340. Two types of carbon fiber fabrics were used as reinforcement material: fabric with a plain weave of 160 g/m2 basis weight (GG 280T) and modular fabric with a plain weave of 220 g/m2 basis weight (DYF 160/25). As matrix, was used L 285epoxide resin manufactured by Havel, cured in room temperature by H 285 hardener, manufactured by Havel, as well. Four composites were manufactured, differing in terms of the reinforcement arrangement. As a result of the conducted research, measurements were made and the damage surface area was compared on the side of the impact and opposite to it. The obtained results were also analyzed: maximum displacement, maximum impact force and absorber energy. In addition, a bending strength test for composites was performed as an evaluation test to determine the influence of impact energy on the change in bending strength and bending modulus. In the next stage, the samples made of all composites were subjected to the influence of three weather conditions: UV radiation with temperature 50 °C and irradiance 076 W/m2, steam with temperature 50 °C and water, according to the sequence specified in the standard ISO 4982-3. The samples were divided into 4 groups and then each group was placed in the climate chamber respectively on: group no 1 – 168 hours, group no 2 – 336 hours, group no31 – 501 hours, group no 4 – 672 hours. Then the samples were subjected to impact loads with Energy 10 J. Measurements were made and the surface area of the damage from the impact side and the opposite side was compared, and a test was performed to estimate the bending strength and bending modulus. The obtained results were analyzed in relation to the samples not exposed to the weather conditions. Based on the analysis of the results, a number of practical conclusions have been formulated that can be used in the design and use of structures made of composites with carbon fiber reinforcement.

Impact and multiple impact of titanium based FML – experimental and numerical approach

abst. 2209
Room 3
Tuesday
June 15
12h20

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During exploitation of fibre reinforced polymer (FRP) composites in aviation, the issue of out-of-plane dynamic loads has been spotted. Tools dropped on FRP structure while maintenance, debris and small rocks hitting aeroplane's surface by taking off and landing, collisions with birds, hail etc. came in the reason of barely visible impact damage (BVID) or non-visible impact damage (NVID). FRPs could absorb energy deriving from dynamic load through elastic deformation and damage only. While research of fibre metal laminates (FML), it has been stated, that such hybrids during impact can dissipate the energy in over 90% for plastic deformation of the metal sheet. This brings up the reduction of damage in fibrous parts of the material and protects against damage progress in further loads, such as compression. Currently, besides GLARE or CARALL, the second generation of FML is under development. Among others, the titanium-based FMLs are one of the most perspective materials. The use of titanium is dictated by its relatively higher stiffness than aluminium, what is crucial for proper exploitation of thin-walled structures. Besides, titanium offers higher energy absorption capacity. Moreover, the titanium can be connected with carbon fibres without risk of the galvanic corrosion. Due to the above advantages, the titanium-composite hybrid laminates (TCHL) can be future trends in the aerospace industry. Simultaneously, the deep investigation of the mechanical behaviour of these materials should be made, including impact behaviour. Except performing the experiments, the numerical approach is an issue either. Although the modelling strategy of fibrous composites damage behaviour is well

known, there is still the inconsistence in modelling the damage behaviour of metal in FML. For now, few papers describing mechanical behaviour of titanium-based laminates are present, but to the authors best knowledge nobody described the response on multiple impact so far. The intention of authors is to assessed the experimental single-impact behaviour and multiple-impact behaviour of TCHL's. The results of experiment was validated by series of FEA. The impact tests were based on drop weight tower. The energies range of 5 – 20 J were used. The multiple testing was conducted in the range of 1 to 9 impacts. Each impact was recorded in term of force and displacement changes. The numerical analysis of the impact behaviour of TCHL was made with Abaqus software. According to the analysis, was noted, that the titanium-based laminates characterized by high impact resistance in comparison to more common aluminium-based laminates. The multiple impacts progress the damage range, but the progress slowing down with each next impact. This is due to the high participation of the metal part of FML in the energy absorption process. The fixed area of the stress concentration due to the same impact point caused increasing of friction and the metal share in energy absorption rather than delamination growth. Damaged, after first (and second) impact interface and composite part is not effective in energy absorption during further impacts.

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abst. 2223
Repository

Energy absorption behaviors of non-uniform hexagonal tubes under compression

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Hexagonal thin-walled structures are widely used in protective and energy absorption applications. In the present study, by changing the distribution of tube wall thickness, several newly designed non-uniform hexagonal tubes are proposed. A large plastic deformation model is constructed for guiding the design of hexagonal tubes with superior energy absorption performance. The crushing and energy absorption behaviors of non-uniform hexagonal tubes under lateral compression by two rigid plates are presented. The deformation modes of compressed hexagonal tubes are verified by finite element simulations.

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abst. 2224
Repository

Effect of hybridization on low velocity impact of GLARE laminates

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Low velocity impacts are critical to laminated structures which can cause major breach in safety of aerospace structures if left unattended. In the present study the impact properties of GLARE 4-3/2 laminates are compared to that of a hybrid GLARE 3/2 configuration laminate having the middle aluminium layer replaced with KEVLAR-49/epoxy laminates. The present study investigates the effect of laminate configuration on the dynamic response and impact strength on account of low velocity impact. A 3D FE code is developed for the analysis of low velocity impact using Hertzian contact law and Newmark- integration scheme for impact by a spherical impactor. The interfacial stresses are evaluated and delamination at the interfaces are also assessed using the developed FE code in order to investigate the effect of hybridization of GLARE laminates. The present investigation shows that replacing the inner aluminium layer with KEVLAR-49/epoxy laminate helped in arresting delamination at the inner interfaces thereby providing improved impact behaviour.

Joints

Net tension failure analysis for composite laminate bolted joints using complex potential method

abst. 2043
Room 3
Wednesday
June 16
12h20

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Bolted joints are a common means to connect safety-critical composite laminate structures in the aeronautical industry and precise assessment tools are crucial to ensure a safe and lightweight-optimal design. These tools can be based on analytical methods beneficial in terms of computational effort, which shall be scope of this contribution. For the stress field determination, use is made of complex potential method. Finite dimensions effects as well as material orthotropy raising the stress concentrations are extensively discussed. Then, based on the present stress solution, tension failure stresses are predicted using Finite Fracture Mechanics and Theory of Critical Distances. The different failure prediction concepts are compared against each other. Further, the hole size effect and failure load mitigation influenced by finite dimensions is analysed.

Performance of monolithic and precast dry beam-column joints using GFRP bolts and GFRP reinforcements under impact loading

abst. 2050
Room 3
Wednesday
June 16
11h40

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Natural catastrophes and terrorist attacks have been the most serious hazards faced by human beings. Impact and blast loads related to these hazards could cause sudden failures of structural elements. Beam-column joints are critical structural components. Failure of a beam-column joint in a building frame may lead to complete collapses of the building structure. Understanding of the performance of beam-column joints under impact or blast loads is still very limited. Some research has been conducted to investigate the behaviours of the beam-column joints of steel structures under impact load while there is very limited study on the joints of reinforced-concrete (RC) structures under impact or blast loads. Prefabrication construction has attracted more and more interests in recent decades. Significant research efforts have been devoted to study the performance of wet and dry beam-column joints of prefabricated structures under static and seismic loads, but no study of such joints under impact or blast loads can be found in open literature yet. This study investigates the performances of a new type of dry exterior beam-column joint using glass fibre reinforced polymer (GFRP) bolts, GFRP reinforcements, and concrete-end-plates recently proposed by the authors under impact loading. Two monolithic and two precast dry joints were cast and tested under impact loading and cyclic loading to investigate their performance. The test results are presented and analysed in this paper. The application of this dry joint type could effectively resolve a very costly issue of corrosion in the common dry/steel joints and also paves way to a significant reduction of construction cost due to no requirement of formwork.

Anchor bolts for load introduction into cross-sectional faces of thick fiber-reinforced polymer composites: Stress analysis of the adhesive layer

abst. 2062
Room 1
Tuesday
June 15
09h10

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Load introductions are a key challenge designing fiber-reinforced polymer composite (FRPC) structures. This is mainly caused by the anisotropic material properties. Without adequate technological concepts for load introductions, the potential lightweight advantage of the material cannot be exploited to its full extent. Therefore, basic research - i.e. the detailed analysis combined with experimental validation of new concepts - is essential and needs to be provided to design engineers. Industries yet untypical to the use of FRPC structures, e.g. machine tool manufacturing, show an increasing interest in fiber-reinforced polymer composites. In these industries structures generally exhibit greater wall thicknesses and therefore demand the development of new load introduction concepts exactly suited to the material properties and the present boundary settings. In addition to mechanical demands, concepts need to be economically viable. Concerning these economic requirements, for many cases screw joints are desirable for easy mounting and demounting of structural components. Subsequently bonded, threaded bolts are a favorable and thus commonly used concept to implement local loads into concrete or timber structures. Tests demonstrate that an adaption of this concept into cross-sectional faces of thick FRPC results in high maximum loads for the joint due to the strength of the substrate. Beside this primary advantage the concept offers a standard screw joint between the FRPC and the surrounding structures. A subsequent integration can be easily performed by drilled or milled bores and adhesive bonding of the anchor bolt. It can therefore facilitate and standardize load introductions into FRPC structures and enable their economic use. The adhesive layer between the bolt and the surrounding laminate is crucial for the load transfer of this load introduction concept. However, because of specific geometry conditions and material properties it differs from typical bonded joints - e.g. single-lap joints. Hence, it is the objective of this study to analyze numerically the influence of geometry parameters – e.g. the laminate thickness or the anchorage length – and of the material properties on the stress distribution within the adhesive layer. The results will be discussed and complemented by an experimental study determining the influence on the load-bearing capacity and the failure behavior.

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abst. 2083
Repository

Meshless analysis of the stress singularity in composite adhesive joints

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Adhesives are an exceptionally well-suited method for joining composites. Unlike other methods, such as bolting or riveting, adhesives do not introduce holes in the material that they are joining. This is a major advantage in the case of composites because the holes required by bolting or riveting induce stress concentrations and can also lead to tears, burrs or delamination. A point of concern in adhesive joints is the adhesive/adherend interface corner where a stress singularity occurs and where failure usually initiates. So, it is important to study this stress singularity to better understand the mechanical behaviour of adhesive joints. The goal of this work is to calculate the exponents and the intensity of this interface corner singularity for composite adhesive joints with eight different overlaps. In addition to that, a method to predict joint strength using this stress singularity is also proposed. The numerical work was done using a meshless method, the Radial Point Interpolation Method (RPIM).

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abst. 2139
Room 1
Tuesday
June 15
10h10

TENSION-TENSION FATIGUE BEHAVIOR OF DUCTILE HYBRID FRP JOINTS

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An experimental investigation on the tension-tension fatigue behavior of ductile hybrid bonded/bolted double-lap joints was conducted at EPFL-CCLab. The hybrid joints were composed of a ductile acrylic adhesive, steel bolts and multi-directional BFRP laminates; the static joint resistance corresponded to almost the full summation of the resistances of the bonded and bolted connection parts due to almost equal and large deformation capacities. The fatigue behavior of the hybrid joints was characterized by the cyclic energy dissipation, cyclic stiffness, cyclic creep displacement and self-generated temperature, and was also compared to that of only bonded and only bolted joints of similar dimensions. The results showed that the fatigue life of the hybrid joints was much improved and more energy was dissipated by adding bolts to the ductile bonded joints. The fatigue life of the hybrid and bonded joints was always reached at almost the same failure displacement, i.e. when the adhesive molecular chains in the adhesive layer were fully stretched and failure occurred through rupture of the primary bonds. The corresponding shift of the hysteresis loops proved that the behavior was dominated by creep. The cyclic creep displacements of the bonded joints were accelerated by damage caused by fatigue (mainly at high load levels), damage caused by creep (in the tertiary stage, mainly at low load levels), and temperature (mainly at low load levels at the end of the fatigue life). However, by adding bolts in the hybrid joints, the adhesive creep displacements were delayed due to the smaller crushing deformations caused by the bolts in the middle laminate. This delay extended the fatigue life of the hybrid joints compared to that of the only bonded joints, since more cycles could be sustained to attain the same failure displacement, at which both, bonded and hybrid joints failed.

CRACK ROWTH IN ADHESIVELY BONDED STRUCTURES AND THE IMPORTANCE OF SIMILITUDE

abst. 2151
Room 3
Wednesday
June 16
12h00

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Although not explicitly stated in the certification standard MIL-STD-1530D [1] or in the Composite Materials Handbook CMH-17-3G [2] the USAF Damage Tolerant Design Handbook explains that the existence of a similitude parameter () is an important, possibly essential, feature of any durability and damage tolerance (DADT) assessment. Indeed, a valid similitude parameter is needed both for DADT analysis, and to ensure that laboratory test data obtained using simplified geometries tested under representative flight loads can be directly related to crack growth in the fleet. In the context of fatigue crack growth we have adopted the definition of similitude given by the USAF in [2], albeit slightly reworded, viz: Similitude: If two cracks in two different geometries subjected to different load conditions have the same (crack tip) similitude parameter then both cracks will grow at the same rate. For the results of laboratory tests on simplified geometries to have any bearing on cracking in the fleet the (crack tip) similitude parameter in the laboratory test specimen must have the same value as in the aircraft. For metallic components it is accepted that, to a first approximation, cracks grow perpendicular to the maximum principal stress field and that the other principal stresses play a secondary role. The enables the effect of cracking in the fleet to be estimated by uni-axial laboratory tests. Unfortunately, this simplification is often not true for composite and bonded airframes. For example, consider the adhesive disbonding and subsequent delamination growth found in US Navy [4] F/A-18 inner-wing lap-splice joints (IWSLJ). In this instance in order to relate the results of laboratory tests performed on (idealized) specimens to the delamination/disbond growth rate seen in the fleet it is essential that the similitude parameter in the test specimens be the same as seen by the damage in the aircraft. It is now known [5-7] that the Hartman-Schijve crack growth equation resolves many of the problems associated with expressing crack growth in adhesively bonded structures as a function of G, Gmax, or $\sqrt{G}$. This formulation is built around the similitude parameter first proposed by Schwalbe [8]. This paper illustrates that for adhesively bonded structures the Schwalbe similitude parameter is able to reconcile the difference in the da/dN versus G (and/or Gmax, or $\sqrt{G}$) crack growth curves seen in specimens with different adhesive thicknesses and different adherends. It is also shown to be able to account for the effect of the temperature range seen in operational aircraft on crack growth in an adhesive bonds. REFERENCES 1. MIL-STD-1530D, (2016) Department of Defense Standard Practice; Washington, DC, USA, 2016. 2. CMH-17-3G, (2012) Composite Materials Handbook, Volume 3: Polymer Matrix

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abst. 2162
Room 3
Wednesday
June 16
11h00

Influence of heat input on the laser welded steel/CFRP lapped joints

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DP590 (Dual phase 590 steel) and CFRP (Carbon fibre reinforced plastics) were successfully connected by laser welding. Experiments and numerical simulations were adopted to clarify the influence of heat input on the welding characteristic, mechanical properties and bonding mechanism. Melted width and depth of CFRP would increase with the enhancement of laser powers due to larger interfacial heat input. Under relative low laser power, un-bonded steel/CFRP interface would be generated due to the relative low interfacial peak temperature (lower than the melting point of CFRP). Compact-bonded interface would be produced during the laser power range of 400W-600W. Decomposition of CFRP at the middle interface would be appeared with the further increase of laser powers to 700W and 800W as a results of higher peak temperature than the decomposed temperature of CFRP. The highest bonding strength of 3855N was produced when the laser power of 600W was adopted. Three different joint fractured modes were found in interface: entirely fractured along the interface (interface failure) at the laser powers of 300W and 400W, fractured along interface at outer region and CFRP matrix at inner region (cohesion failure) at the laser powers of 500W and 600W, fractured along CFRP matrix at outer region and interface at inner region (adhesion failure). XPS (X-ray photoelectron spectroscopy) results showed that C-M and O-M chemical bonds were formed at the interface due to the reaction between resin matrix and DP590. Stronger C-M and O-M chemical bonds produced under higher laser power were beneficial for the improvement of interfacial bonding strength.

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abst. 2194
Room 3
Wednesday
June 16
11h20

Interfacial Strength Analysis of Shape Memory Fibers Reinforced Epoxy Adhesive

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In this industrial world recycling is an important issue in the environment. The necessity of recycling metals and plastics is increasing day by day and composite material is one of them. Due to its lightweight and high strength, usage of the composite is becoming very popular in electronics, automotive, and aerospace industries all over the world. Metal-composites hybrid structures have become the topic of interest for automotive and aerospace applications providing lightweight and high performance. Joining between dissimilar materials is necessary for hybrid material systems. Mechanical joints are easy for recycling, but increase the overall weight of the structures and reduce the structural strength. In other words, adhesive joints can improve structural strength but are very difficult to be recycled. Recently, our research team proposed advanced debondable adhesives for making the adhesive joints separation process easy. Proposed debondable adhesives consist of epoxy adhesives and shape memory fibers. If SMFs are embedded in the epoxy adhesives, we can increase the adhesion strength at the operating condition like composite materials. When specific conditions, which accelerate the phase transformation of the SMFs, are implemented to the adhesive joints, the separation of adhesive joints can be easy since internal stresses by the phase transformation can minimize the adhesion strength. The feasibility of this concept largely depends on the interfacial shear strength (IFSS) between SMFs and epoxy adhesives. So, the IFSS of SMFs reinforced epoxy adhesive (SMFREAs) were analyzed. Nickel-Titanium alloys (25mm diameter) and DP460 off-white were used as the SMFs and structural epoxy adhesives respectively. IFSS of SMFREAs was investigated by the single wire pull-out test method. Surface morphologies of SMFs were characterized by FESEM and AFM. Commercial simulation software Ansys was used to characterize the most affecting factors for IFSS. The results show that if the pre-strain of SMFs increases, IFSS increases because of surface roughness and phase transformation of SMFs. The results also indicate that before and after the phase transformation temperature of SMFs, material degradation of epoxy adhesives, and phase transformation of SMFs are the most affecting parameters on IFSS respectively.
Keywords: Shape memory fibers, pull-out test, surface analysis, FEA

Effect of stacking sequence of CFRP composite laminates on the single lap hybrid joint strength under tensile loading

abst. 2211
Room 3
Wednesday
June 16
12h40

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Joints in the composite structure is always an area of interest for many researchers. Any significant increase in joint efficiency is appreciable either by improving the existing conventional joints methods or by developing some new joint techniques. The hybrid joint can be used to join the composite structures when the two laminates placed partially overlapped are bonded using adhesive material and then fastened by the bolt. Composite laminates joined using the hybrid joint method could take a higher static load and exhibits better fatigue life than conventional bonded and bolted joints. Hybrid joint is more damage-tolerant, exhibit improved joint performance and also a fail-safe joint. Hence, it can be used to better meet the current requirements for joint application in primary aircraft composite structures. The effectiveness of the joining technique is the function of the various design parameters involved with the particular joint. For bonded joint it depends upon the overlap length, adhesive thickness, adhesive material type (High modulus/ Low modulus) adherend thickness, surface preparation, and temperature and for bolted joints, it depends upon the geometric parameters (W/D, E/D), bolt-torque, stacking sequence, bolt-hole clearance, bolt geometry (countersunk bolt or bolt with hexagonal head), etc. All aforementioned parameters that affect the bonded and bolted joint performance exclusively are a considerable design parameter for the hybrid joint. The initial studies performed on the hybrid joint in the late 1980s mostly focused on the significance of the hybrid joints and researchers found that hybrid joint can be used as a damage tolerance design feature for the joints. Later, in further studies, it has been observed that like the other conventional joint it's performance depends upon more on the design feature, but its dependency is different from the conventional joint. For illustration, adhesive layers more than 0.5 mm exhibits higher strength in case of hybrid joint unlike for the bonded joint where the thickness lesser than 0.5 mm is more advantageous. Likewise, the low modulus adhesive exhibits higher load-carrying capacity with the hybrid joint whereas intermediate modulus adhesive is more favorable for the bonded joint. An ample amount of work has been reported on the effect of various parameters

on the hybrid joint static strength but the effect of the stacking sequence on the hybrid joint is not carried out yet as per the author's knowledge. As stress concentration factor around the hole in the composites depends upon the anisotropic nature of the concerned composite laminate. Hence, the percentage of anisotropic nature can play an important role when it comes to the effectiveness of the hybrid joint over other conventional joints. In this study, the adherends made of the CFRP composites with three different stacking sequence including unidirectional [0]4s, cross-ply [0/90]2s, and quasi-isotropic [45/90/-45/0]s are considered for the strength prediction of the hybrid joint and its compared with bonded and bolted joint to evaluate the effectiveness of the hybrid joint. A numerical analysis has been performed using a three-dimensional finite element model. The progressive damage model able to capture intralaminar damages including fiber and matrix failure under tension and compression is based on the three-dimensional Hashin criteria's and Chang's fiber-matrix shear failure for fiber-shear matrix failure and Ye-delamination criteria to model delamination and set of material degradations rule proposed by Camanho and Tserpes is used for the damage progression in the laminate. An experimental study is performed to validate the model and a further numerical model is used for strength prediction and damage assessment of the joints with other stacking sequences. As stated in the literature, the bonded joint has shown a negligible effect of stacking sequence on the joint strength. The bolted joint is found to be more vulnerable with uni-directional (UD) stacking sequence and showed least strength as stress concentration factor around the hole is maximum when (Exx » Eyy) of the laminate and bolted joint strength with cross-ply and quasi-isotropic stacking sequence are found approximately equal. The hybrid joint has shown equal strength with UD and cross-ply stacking sequence and exhibits the highest strength with quasi-isotropic stacking sequence laminate.

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abst. 2222
Room 1
Tuesday
June 15
09h50

Bond strength of aluminum die castings and thermoplastics by overmolding

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The combination of thermoplastics and aluminum die castings to form hybrid components is one way to implement lightweight design to reduce vehicle weight and thus reduce carbon dioxide-emissions of combustions engine driven vehicles and to extend the range of battery-electric vehicles. For the production of suchlike components, the In-Mold Assembly (IMA) using injection molding, is one promising approach. In addition to the reduction of process steps by combining molding and joining, the IMA can also meet the requirements of large batch production with regard to short production times. The joining process is based on an overmolding process in which the bond is achieved by injecting a molten fiber reinforced thermoplastic (FRTP) onto the die castings surface taking advantage of the adhesive character of the thermoplastic matrix. The adhesion between die casted aluminum and FRTP is one important challenge, due to the high complexity of the process which is subject to various disturbance variables such as preheating temperature and surface conditions of the aluminum die casting parts. Comparable to the pretreatment of die casting surfaces for adhesive bonding applications, a pretreatment of die cast aluminum components is necessary to guarantee bonding using IMA. In this paper a fiber laser is used to locally remelt the die casting surface, resulting in surface structures in various sizes and a change in surface chemistry. Based on this, the investigations focus on the interdependence of structure size and surface temperature on bonding strength in order to generate a basic understanding of the need to preheat die casting inserts for using them in the IMA process. Therefore, various combinations of preheating temperature and structure size are considered. Another focus of the investigations is the durability of the bonds under different temperatures which can occur when the hybrid components are used in different climatic regions. The test setup including the heating technology for the production of lap-shear specimens is presented. Scanning electron microscopy and energy dispersive X-ray spectroscopy are used to evaluate the surface changes of the laser pretreatment used. Furthermore, reflected light microscopy is used to examine micrographs of the pretreatment and joining zone and mechanical tests are carried out to determine the joint strength.

The effect of fiber orientation mismatch on scarf joint damage mechanisms under fatigue load

abst. 2226
Room 1
Tuesday
June 15
09h30

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Wind turbine rotor blades commonly 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 to restoring the mechanical properties of such lightweight fiber reinforced polymer (FRP) structures is to locally patch these areas with scarf joints. This type of repair allows for a smoother load distribution across the joint, and is favored especially on structures where minor aerodynamic contour changes are key [2 – 5]. The effects of such repairs on the structural integrity, however, are still largely unknown. Building upon an understanding of the static load failure mechanism of GFRP scarf joints presented at the ICCS23 in 2020, the influence of the fiber orientation mismatch between parent and repair materials of 1:50 scarf joints on the failure mechanism of monolithic glass FRP specimens under cyclic fatigue load were examined in this study. Specimens with various layups were produced with the vacuum-assisted resin infusion (VARI) process using biaxial E-glass non-crimp fabric (NCF). The patch layers were then joined directly to the parent structure with the VARI using biaxial E-glass NCF with half the areal weight of the parent side to allow for better drapability. This mimics the soft-to-hard patch style utilized in wind turbine blade shell field repairs. The specimens were tested under uniaxial fatigue load, during which they were periodically monitored for damage onset. A comparison of the +45/-45° and 0/90° layups allowed 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. In addition to the tensile strength and stiffness property recovery assessment, a grayscale analysis using in-situ camera images determined the damage state leading to failure in each region across the scarf joint, which varied in the parent material versus scarf joint region, providing insight to the critical regions in this composite structure under cyclic loading. 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. [3] Siener, M P. "Stress Field Sensitivity of a Composite Patch Repair as a Result of Varying Patch Thickness." Composite Materials Testing and Design (Tenth Volume), ASTM STP 1120, Glenn C Grimes, Ed. American Society for Testing and Materials, Philadelphia, 1992, pp 444-464, doi:10.1520/STP20176S. [4] Jen, Y.-M., and Ko, C.-W. "Evaluation of Fatigue Life of Adhesively Bonded Aluminum Single-Lap Joints Using Interfacial Parameters," International Journal of Fatigue, vol. 32, no. 2, 2009, pp. 330-340, doi.org/10.1016/j.ijfatigue.2009.07.001. [5] Caminero, M.A., et al. "Analysis of adhesively bonded repairs in composites: damage detection and prognosis." Composite Structures, vol. 95, 2013, pp. 500-517, doi:10.1016/j.compstruct.2012.07.028.

Keynote Lectures

abst. 1001
Room 2
Monday
June 14
11h00

Nonlinear solid-shell elements for 3D stress analysis of composite and smart structures

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The effective nonlinear exact geometry or geometrically exact (GeX) four-node laminated composite and piezoelectric solid-shell elements using the method of sampling surfaces (SaS) are presented. The term GeX reflects the fact that the parametrization of the middle surface is known and, therefore, the coefficients of the first and second fundamental forms and Christoffel symbols are taken exactly at element nodes. The SaS formulation is based on the choice inside the layers of an arbitrarily number of SaS parallel to the middle surface and located at Chebyshev polynomial nodes to introduce the displacements and electric potentials of these surfaces as basic shell unknowns. The outer surfaces and interfaces are also included into a set of SaS. The SaS shell formulation uses the objective Green-Lagrange strain tensor that exactly represents large rigid-body motions of the shell in a curvilinear coordinate system. The developed solid-shell elements are based on the hybrid-mixed method through the Hu-Washizu variational formulation. The tangent stiffness matrices are evaluated by efficient 3D analytical integration proposed by the author. As a result, both GeX solid-shell elements exhibit a superior performance in the case of course meshes and allow the use of load increments, which are much larger than possible with existing displacement-based finite elements. They can be utilized for the analysis of the second Piola-Kirchhoff stresses and electric displacements in thick and thin laminated composite and piezoelectric doubly-curved shells because the SaS solutions asymptotically approach the exact solutions of elasticity and piezoelectricity as a number of SaS tends to infinity. This work was supported by the Russian Science Foundation under Grant No. 18-19-00092.

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abst. 1003
Room 3
Monday
June 14
11h00

Sublaminate variable kinematics approach for the numerical analysis of composite structures

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The complexity of composite structures (laminates, sandwich panels) calls for structural models that go beyond the limitations of classical theories such as CLT, based on Kirchhoff-Love's hypotheses, and FSDT, based on Reissner-Mindlin's hypotheses. A huge number of models have been thus developed in the past decades to include refined descriptions of the kinematics as well as the stress response, as well as towards meeting the so-called C0z-Requirements that should be met for taking into account the mesoscale heterogeneity of a composite stack. The large variety of models that have been proposed, ranging from Equivalent Single Layer (ESL) to Layer-Wise (LW) and Zig-Zag models, can be explained by the fact that their accuracy is strongly application-dependent. Variable kinematics approaches offer a generic framework for the mechanics of structures, which can be exploited for assessing the accuracy of such axiomatically formulated models and, eventually, for identifying the "best" model in terms of the ratio between accuracy and computational cost. The Sublaminate Generalized Unified Formulation (SGUF) is the formal extension of the well established Carrera's Unified Formulation (CUF) to formulate arbitrary models for groups of plies (the sublaminates): in SGUF, different axiomatic models (ESL, ZigZag, LW) are introduced in each sublaminate by referring to Demasi's Generalized Unified Formulation (GUF), and the model of the whole composite stack is obtained as a LW assembly of sublaminates. Displacement based plate models expressed in SGUF have been implemented within a highly efficient Ritz-type solution as well as within a dedicated, locking-free FEM. The talk provides an overview of this approach along with numerical applications highlighting its current capabilities. Linear elastic problems are addressed to highlight the robust FEM implementation, which is also available as Abaqus User Element. The Ritz-type solution is used to discuss the extension of the SGUF approach to geometrically nonlinear bending problems. Applications to heterogeneous composites are also considered, in particular by addressing the modal and harmonic response of composite panels hosting piezoelectric plies and frequency-dependent viscoelastic materials.

Machine learning based modeling in composite materials

abst. 1065
Room 2
Monday
June 14
16h40

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Developing of conventional continuum-based numerical models in composite materials has been grown continuously over the past decades. Diversity of these models, however, prevents them from the practical applications. Machine Learning (ML) based methods, in contrast, have a great potential to construct generalized surrogate models to realize the behavior of composite materials from the available data under various conditions and loading terms. This yields particularly to reliable results for any nonlinearity between input and outputs. Assuming the availability of limited data on the response of composite materials, ML methods employ the deep learning algorithms constructed based on the multi-layer artificial neural networks (ANN) to build the input-output relationships. The data can be extracted from the numerical simulations or experimental data. In this contribution, various aspects of the ML based modeling for composite materials including training and testing methods are investigated. Particularly, the proper orthogonal decomposition (POD) and the dynamic mode decomposition (DMD) in combination with the ANN is introduced to simulate the dynamical behavior of composite materials under material uncertainties in load terms and modeling parameters. The method leads to a drastically reduction in the rank of system matrices to improve the computational time. Application of the method is presented for the dynamic analysis of fiber reinforced composite plates under material uncertainties.

Layered Structures – Advantages and Disadvantages of Various Modeling Approaches

abst. 1066
Room 1
Monday
June 14
11h00

Altenbach, Holm (holm.altenbach@ovgu.de), Otto-von-Guericke-Universität Magdeburg, Germany

Layered Structures are used in many applications because of the possibility to design materials with prescribed properties. At the same time, they are often thin and one gets a lightweight structure. During the last 100 years, many suggestions were made to improve the Euler-Bernoulli beam theory or the Kirchhoff plate theory. The idea was to have simple one- or two-dimensional theories, but better predictions of the mechanical behavior of such structures which is necessary for high inhomogeneous in the thickness direction structures. The mechanical behavior is influenced by both the mechanical properties' ratios and the thickness size of the different layers. There are four main directions in development beam or plate theories: - Assuming hypotheses with respect to the stress, strain, etc. states one can deduce the full set of governing equations including the constitutive relations. - Introducing a deformable surface a set of two-dimensional continuum mechanics equations can be established. The problem is the identification of the constitutive parameters from the three-dimensional images. - Assuming a small parameter, mathematical techniques can be used to formulate the two-dimensional equations. Such techniques are series expansions or asymptotic integration. - Consistent formulation are based on power series expansions and on consistent truncation of the series the strains, etc. It is obvious that each approach has advantages and disadvantages. Anyway, on gets only an approximation of the structures, which are three-dimensional even if the thickness is small. The last one is also the reason for inaccuracies of Finite Element based simulations. On different aspects will be reported in the lecture.

Steered Fiber Paths and Effects of Manufacturing Constraints on Future Advanced Aerospace Structures

abst. 1067
Room 1
Tuesday
June 15
16h40

Waas, Antony (awaas@umich.edu), University of Michigan, USA

Automated Fiber Placement (AFP) technology has revolutionized composites manufacturing and is quickly replacing traditional manual production. Among others, the notable advantage of AFP is that the designer is no more restricted to the use straight fibers, which means it is possible to have steered fiber paths designed for optimizing structural performance. The scope of this work is to identify the manufacturing parameters and associated constraints imposed by these parameters on the mathematical

design space and introduce this in an optimization framework to design future aerospace structures (wings, fuselages etc.) for superior mechanical performance. In this talk, the design of a structural panel with a cutout to minizime stress concentration and the design of a skin to maximize buckling loads will be addressed. Furthermore, the effects of manufacturing induced unintended defects on the strength (tensile and compressive) of these strucures will also be addressed through experimentally validated computational models that account for the material microstructure.

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abst. 1069
Room 1
Wednesday
June 16
16h40

Impact response of glass fibre reinforced PEKK laminates and GF/PEKK based titanium fibre metal laminates

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We have developed glass fibre-reinforced PEKK composites. Firstly, woven S-glass fibre (GF) reinforced poly-ether-ketone-ketone (PEKK) thermoplastic prepreg materials were manufactured using a dry powder prepregging method. Quasi-static tensile and perforation tests have shown that the optimum weight fraction of PEKK, wf, is approximately 0.4, which give the peak tensile strength and perforation resistance. Tests at elevated temperatures highlighted the excellent stability of these materials under extreme conditions. As expected, the energy required to perforate the targets increased with projectile diameter. Subsequent tests highlighted the severity of conically-shaped projectiles with the perforation resistance dropping under sharp object impact loading. Then, GF/PEKK based titanium fibre metal laminates (FMLs) have been manufactured. Here, the effect of applying a laser surface treatment to the metal plies in the FML has been evaluated and the response compared to that measured on a comparable untreated laminate. It has been shown that applying a laser fluence of 4.54 J/cm2 to the titanium layers in the FML results in a good bond strength between the titanium foil and the glass fibre/PEKK composite. The response of the FMLs under dynamic loading was then studied and compared with that measured at quasi-static rates. It has been shown that FMLs based on a titanium alloy exhibit a rate-sensitivity, both in terms of energy absorption and the maximum impact force. A series of finite element models were then developed to predict the response of the glass fibre/PEKK composites to impact by projectiles based on different diameters and shapes and to simulate the response of the FMLs under impact loading. The results of the FE analysis were validated against the corresponding experimental data by comparing both the load-displacement traces as well as the resulting failure modes and good agreement was observed in most cases.

Laminated composites with material uncertainties

Reliability design optimisation of classic composite plates using a CUF-based layerwise approach

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abst. 2038
Room 3
Monday
June 14
15h00

Uncertainties in the manufacturing process of structures may arise at any moment of the fabrication chain. In the case of composite structures, such uncertainties may appear in the material elastic properties as a result of the microscale features of such material or even from manufacturing flaws, such as misalignments, fibre waviness, etc. [1] when assembling the final product. As a result of these defects, the structural response of the final structure might be compromised. Therefore, a reliability analysis is needed. In this work, a reliability-based design optimization (RBDO) [2] regarding the linearized buckling behavior of a straight-fibre composite laminate is carried out concerning homogeneous material elastic properties variation. In order to perform such analyses, Carrera Unified Formulation (CUF) [3] is used, according to which structural theories with low-order accuracy to layerwise models can be implemented in a hierarchical and unified manner. These analyses are then used to build a surrogate model based on Polynomial Chaos Kriging (PCK) [4], which substitutes the finite element model and thus accelerates the optimization process. The final scope of the work is to show that layerwise models can help to broaden the design space that other structural approaches may have shrunk, while subjected to the manufacturing constraints that the industry has imposed through the years [5].

Micromechanics

abst. 2022
Room 2
Wednesday
June 16
08h50

Investigation of constitutive response and failure prediction for aerogel matrix composites based on a combination of meso-scale finite element model and tensor decomposition method

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Fiber reinforced silica aerogel matrix composites have a very promising application as face-sheet panel of integrated thermal protection system (ITPS) for hypersonic vehicles due to its good mechanical properties at high temperature. 2.5D fiber-woven aerogel matrix composite panel shows complex deformation mechanism under a multiaxial in-plane loadings, and the coupling of the tensile and shear stresses can accelerate the damage evolution and reduce the strength significantly. Thus understanding of the mechanical response and failure prediction for the aerogel matrix composite panel are desired as the panel is used as a critical load-bearing component of ITPS. The focus of this paper is to examine the effect of the coupling between the tensile and shear stress components on the deformation and failure response of the aerogel matrix composite subjected to off-axis tensile loading. The mechanical response of composite panel in the principal material coordinate was studied experimentally and the results obtained are used to motivate the development of a phenomenological-based 2.5D representative volume element (RVE) model a framework of continuum damage mechanics. Modified criterions of fiber bundles and aerogel matrix considering the shearing effect for accelerated damage evolution are developed to describe variation of the nonlinear stress-strain behavior under 0o on-axis, 15o, 30o, and 45o off-axis tension in the principal material coordinate. The predicted stress-strain response principal material coordinate compare well with the experimental results captured by digital image correlation. The effects of the mesoscale parameters on the macroscale deformation and failure mechanism of the composite under a complex in-plane stress state have been analyzed further. A combination of the fully validated RVE model and tensor decomposition method was used to develop a mapping between the mesoscale parameters and macroscale mechanical properties of the 2.5D fiber-woven aerogel matrix composite panel with an explicit polynomial expression. The dominant mesoscale parameters on the mechanical properties are identified clearly, and the strategy of strengthening material with multiset of optimum parameters is proposed in the work.

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abst. 2093
Room 2
Wednesday
June 16
08h30

Oxidation behavior of SiC fiber reinforced SiC-Ti3SiC2 matrix composite at high temperature

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Three different SiCf/SiC-Ti3SiC2 composites were prepared by slurry impregnation pyrolysis and reactive melt infiltration. The oxidation behavior of the composites at 1300[U+2103] from 2h to100h was studied. These samples were examined by using scanning electron microscopy, energy dispersive X-ray spectrometry and X-ray diffraction analysis. Then, three-point bending and nano indentation test were carried out to investigate the mechanical performance of the composites with and without oxidization. The results revealed that the Max phase Ti3SiC2 can improve the strength and toughness of the composites. After oxidation at 1300[U+2103], Max phase still existed in the matrix, and the strength retention rate of the material was 83%. Furthermore, the possible oxidation mechanism was proposed on the basis of the results.

Multiscale simulation based constitutive modeling of chopped glass fiber reinforced plastics considering damage evolution and failure strength under complex loading condition

abst. 2134
Repository

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Great potential of chopped glass fiber reinforced plastics (CGFP) from injection molding process is shown for its competitive lightweight effect, fabricability and low cost, which is being widely used in automobile, energy, architecture and many other industries. However, complex fluid motion of injection molding process results in spatially random fiber location and orientation distribution in microscale. This heterogeneous micro structure with anisotropy property and sophisticated failure mechanism makes it great difficult to predict damage evolution and strength property. In this research, damage evolution and failure strength of CGFP are studied based on computational micromechanics and multiscale approach. In micro scale, representative volume element (RVE) models under complex loading condition are established to understand the relationship between the microstructure characteristics and failure mechanism of the material. In macro scale, a three-layer laminate model, also called as skin-core-skin model, is built to consider variation of fiber volume fraction and orientation distribution in thickness direction, of which homogeneous properties of micro RVE are applied in each single layer. A modified Tsai-Wu strength criterion is proposed based on multiscale simulation under complex loading condition and constitutive model of CGFP is finally established to predict initial damage, damage evolution and failure strength of the material. The accuracy of proposed constitutive model is validated by uniaxial tensile, compressive and in-plane shear experiments.

Cross-scale characterization of thermoelastic properties of attractive-dominated DNA films and its concave-packaged design based on microbeam frequency drift

abst. 2198
Room 2
Wednesday
June 16
09h10

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Biochip technology, as a multidisciplinary hot area, has many breakthroughs in genome research, cancer detection, drug monitoring and other fields in recent years. While microbeam-based DNA-sensors, with typical laminated structure characteristic, have attracted much attention due to their advantages such as no-label, small size and high sensitivity. Relevant studies have shown that different microstructures in DNA films with different packing patterns have significant influence on mechanical properties of DNA films and detection signals of microbeam sensors. In addition, the emerging DNA nano-grafting technology provides a possibility for the regulation of DNA film at the nanoscale. However, up to now there are few systematic researches about the influence of new DNA packing patterns on

detection signals of microbeam sensors. In this paper, we investigate the diversity of thermoelastic properties of concave-packaged DNA films with attractive-dominated interaction and its influence on dynamic frequency drift of DNA-microbeam. First, considering the competition between attraction and repulsion interactions between DNA chains in buffer solutions, the mesoscopic interaction potential of DNA liquid crystal by Pasergian et al. is updated; then, a thought experiment method of continuum DNA films and force balance relation of nonlinear elastic network nodes of coarse-grained DNA cylinder are combined to multiscalely predict the elastic modulus, prestress and thermal expansion coefficient of DNA films with different microstructures; finally, based on an effective macroscopic continuum model of DNA microbeam deformation, we study the microcantilever dynamic frequency shifts caused by DNA adsorptions in the case of attraction or repulsion dominated interstrand interaction. Results show that, for classical regular hexagon packaging patterns with repulsive-dominated interaction, the analytical predictions for static and dynamic responses of DNA-microbeams agree well with the previous experimental detections and theoretical predictions; while for re-entrant honeycomb packaging pattern, compared with the repulsive-dominated DNA films, the attractive-dominated one has a smaller thermal expansion coefficient, and a larger adjustable range of elastic modulus and prestress within specific microstructural parameter spaces, which greatly enhances dynamic frequency drift of DNA-microbeam. These results provide new ideas for ultra-high sensitivity detection of DNA-microbeam sensors.

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abst. 2247
Room 2
Wednesday
June 16
09h30

Stochastic multiscale failure analysis of textile composite structures using a dehomogenisation approach

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Textile architectures of carbon fibre reinforced polymer (CFRP) composites are increasingly being preferred for structural applications in the aerospace industry due to their improved manufacturability and damage resistance but the significant conservatism in design practices undermines their maximum potential for weight reductions. This provides a strong motivation to develop integrated material characterisation and simulation framework for accelerating their design cycle while potentially reducing the extensive testing requirements for certification. This paper presents a stochastic dehomogenisation based multi-scale modelling approach for predicting damage initiation at the constituent materials (resin and fibre) level incorporating realistic textile weave architecture and fibre arrangements. The work involves textile weave geometry generation and demonstrates the application of periodic boundary conditions which are required to realistically capture the deformation of textile weaves in a representative volume of the bulk material. The approach further considers a discrete random field variation in local fibre volume fraction of yarns. Parametric studies have indicated that the critical locations will be regions around weft-warp crossover locations and inter-ply/inter-yarn contact regions in textile weaves and is strongly influenced by the variation of volume fraction of the yarns. The findings from this work will help achieve more accurate virtual testing capabilities of CFRP textile composite specimens in the testing pyramid for designing and certifying aerospace structures.

Incremental Transformation Field Analysis for Heterogenous Composite Materials using Numerically Determined Interaction Tensors

abst. 1023
Room 1
Monday
June 14
14h40

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Two-scale simulations for multiscale modeling purposes require the solution of boundary value problems for each macroscopic material point. Each macroscopic point contains a representative volume element (RVE) that exhibits the micro-structure of the material, constituted by microscopic points. When dealing with complex heterogeneous micro-structures, the computational effort to solve the boundary problems for all macroscopic points is immense. In order to make multiscale simulations utilizable for a wider range of purposes, a reduction of the computational complexity is indispensable. A reduction of the systems internal variables can be achieved by a decomposition of the full RVE into several subdomains, constituted by clusters of microscopic material points. Constitutive equations need to be solved for all subdomains instead of for all microscopic points in the so-called "online" stage, using quantitites pre-computed in the "offline" stage. In this work, the Transformation Field Analysis (TFA) strategy is implemented, assuming uniform stress and strain fields within the subdomains (Dvorak, 1992). The division of all microscopic points into the clusters depends on their mechanical behavior, represented by the strain concentration tensors at all microscopic locations. The subdivision based on the mechanical behavior is expected to improve results in the elasto-plastic range due to the enhanced ability to account for strain concentrations, a known shortcoming of the original TFA method. The constitutive equations for the TFA model are coupling relations between the macroscopic internal variables and the internal variables in the single subdomains. The coupling equations rely on the "offline" and once for all computed strain concentration tensors of the subdomains, representing the distribution of the applied macroscopic strain in the single subdomains. After the onset of plasticity in one or more subdomains, interactions between the occurring plastic strain, treated as present eigenstrains in the corresponding subdomains, and the strain in the other clusters need to be taken into account to compute the overall RVE response. These influences rely on eigenstrain – strain interaction tensors, which are also determined once for all and numerically. The numerical instead of analytical determination of the interaction tensors allows to account for eigenstrain influences in highly heterogeneous and anisotropic geometries.For the solution of the TFA equations in the "online" stage, an increasing number of clusters provides more accurate results due to a better capability to represent plastic strain effects. The incremental tangent stiffness is commonly utilized to account for the inelastic deformation in the single subdomains. However, this approach can lead to over-stiff results according to various numerical findings. In order to recuperate this shortcoming, a different approach was tested: the use of the incremental secant stiffness instead of the incremental tangent stiffness for the subdomains. The incremental secant stiffness is determined by a virtual elastic unloading step to a vanishing stress of the homogenized material and computation of the new internal variables of the subdomains from the total unloaded state. The use of the incremental secant stiffness instead of the incremental tangent stiffness is expected to provide more accurate results and an improved way for the modeling of the material behavior under non-proportional loading conditions. The research has been funded by the Walloon Region under the agreement no.7911-VISCOS in the context of the 21st SKYWIN call

abst. 2071
Repository

Analysis of the influence of damage in composite sandwich structures

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The reduction of fossil fuel need requires the expansion of the renewable energy industry. In this context, the Europe Union strategy includes a target of reaching 32% of gross final energy consumption from renewable sources by 2030; thus, to reach this goal the wind energy capacity should be expanded by two orders of magnitude. Currently, one of the challenges facing the wind energy sector is to manufacture larger structures, from which the evident increase in size of wind turbines in recent years is derived. From a structural point of view, one of the most relevant elements of present and future wind turbines are blades. Any improvement in its design, manufacture and operation conditions will have a direct impact on the entire energy production system. A wind turbine blade consists basically of two faces joined and stiffened either by one or several webs linking the upper and lower parts of the blade shell or by a box beam. The largest parts of the blades are usually manufactured with sandwich structures, due to their high specific strength and stiffness. Composites sandwich structures consists of two composite face-sheets and lightweight core. The traditional sandwich structures used in wind turbine blades are usually made of GFRP face-sheets and polymeric foam cores. However, longer blades are usually associated with large deflections, so it is important to improve their bending stiffness, ensuring low weight. In this context, the use of CFRP for both face-sheets and honeycomb core (i.e, Nomex) is being analysed as an alternative for large-size wind turbine blades. As structural components, wind turbine blades are susceptible to be damaged during their service life, and the possibility to present damage increases with their increasing size. During the first two years of operation, the failure of a wind turbine blade is usually associated with manufacturing defects or damage caused during transport or assembly operations, the latter being represented by low-velocity impacts. Additionally, because of the operation of rotating blades, existing defects or damages may spread. Consequently, it is necessary to develop reliable methods that allow the detection of damage, in order to establish adequate maintenance plans and possible repairs before complete failure occurs. The most common damages in composite sandwich structures are divided into three main groups: composite face-sheet damage (i.e., delamination, fibre breakage), core damage (i.e., core crush, butt-joints, cracks) and face-sheet-to-core damage (i.e., debonding). All of them have an influence on the behaviour of composite sandwich structures, thus it is needed to get knowledge about their effect on the response of composite sandwich structures when subjected to different loads. To carry out a detailed experimental analysis of all these types of damages and under different conditions can be expensive and time-consuming; therefore, the aim of this work is to investigate the effect of pre-existing damage on the static and vibrational behaviour of composite sandwich structures made of CFRP face-sheets and honeycomb core using a 3D finite-element model. The results will be compared with those of intact structures (structures with no defects).

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abst. 2249
Room 3
Wednesday
June 16
10h10

Low velocity Impact behaviour of a sandwich panels based on flax fibres reinforced epoxy bio-composites

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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 impact behavior 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 VUSER fortran Routin for explicit computation. Validation of the model is realized on simple samples. Second part of the work present failure prediction of a new sandwich panel design. 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, different impact tests are realized and analyzed. Velocity and energy of impact changed and damages occurs from upper skin to the lower one. 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 and local damages observed during the experimental campaign. Numerical and experimental Damage and failure are compared. 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 Antigoni K. Barouni, Hom N.Dhakal Damage investigation and assessment due to low-velocity impact on flax/glass hybrid composite plates , Composite Structures, Volume 226, 15 October 2019, 111224 GilsuPark, HyunbumPark Structural design and test of automobile bonnet with natural flax composite through impact damage analysis, Composite Structures, Volume 184, 15 January 2018, Pages 800-806 Amélie Cuynet, Daniel Scida, Émile Roux, Franck Toussaint, Rezak Ayad,Manuel Lagache Damage characterisation of flax fibre fabric reinforced epoxy composites during low velocity impacts using high-speed imaging and Stereo Image Correlation, Composite Structures Volume 202, 15 October 2018, Pages 1186-1194 Fabrizio Sarasini, Jacopo Tirillò, Teodoro Valente, Carlo Santulli, Fabienne Touchard, Laurence Chocinski-Arnault, David Mellier, Luca Lampani, PaoloGaudenzi Damage tolerance of carbon/flax hybrid composites subjected to low velocity impact, Composites Part B: Engineering,Volume 91, 15 April 2016, Pages 144-153

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abst. 2090
Repository

Evaluation of the Equivalent Mechanical Properties in a Novel Composite Cruciform Honeycomb using Analytical and Numerical Methods

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Abstract In the present study, a novel theoretical model is developed, based on the energy method, to predict the equivalent mechanical properties of the morphing structures with zero Poisson's ratio. These structures are composed of continuous fiber reinforced composite struts and have a higher strength than isotropic honeycombs. Furthermore, the unit cells with zero Poisson's ratio increases the flexural strength of the honeycomb. Therefore, in this paper, a parametric study is conducted on the structural properties of the orthotropic unit cells with zero Poisson's ratio. The geometrical effects and mechanical properties of the unit cell is extracted for various unit cell angles and the strut thickness. Then, using the appropriate failure criterion, tensile and compressive strength for this structure is studied. The evaluated mechanical properties of the morphing structure can be implemented for different loading conditions. It should be noted that, in order to validate the developed formulation, experimental tests and finite element methods will be used. Keywords: morphing structures, composite, equivalent properties, energy method.

Multi-scale Modeling of Graphene- and Carbon Nanotube-Reinforced Composites

Graphene Origami/Metal Nanocomposites with Tunable Negative Thermal Expansion Coefficient

abst. 2100
Room 1
Wednesday
June 16
11h00

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Materials with tunable coefficient of thermal expansion (CTE), even from positive to negative, are capable of achieving desired surface area or volume changes with the variations of temperature. Such materials are of great significance in a wide range of applications in aerospace, mechanical, construction, energy, photonic and electronic engineering. Although extensive studies have been conducted in this area, no research work on metal based metamaterials with negative thermal expansion has been reported yet. This paper makes the first attempt to fill this research gap by developing graphene origami structures to engineer and tune the CTE of graphene reinforced copper (Cu) composites. Extensive molecular dynamics (MD) simulations are carried out to investigate the mechanism of tuning the CET of graphene origami/Cu composites. AIREBO potential, EAM potential and Lennard-Jones (LJ) potential are used to describe the C-C interaction in graphene, the interactions of Cu atoms in matrix, and the van der Waal (vdW) interactions between graphene and Cu matrix, respectively. The surface functionalization in predefined areas of the graphene sheet is designed to generate graphene origami, characterized by fold width and density of adatoms. Then the graphene origami with various sheet size, fold width, and density of adatoms is embedded into a Cu matrix to control its CTE. Our results manifest that graphene origami (200 Å) with a wider fold width, higher density of adatoms and a larger folding angle can lead to a larger negative CTE whereas the use of graphene origami with a smaller size (100 Å) can achieve tunable positive CTE of Cu composites.

Nano-Composites

abst. 2130
Repository

Experimental Study on the Thermal Performance of Concrete with Multi-walled Carbon Nano Tube

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This research is to study the thermal performance by mixing Multi-walled Carbon Nano Tube (MWCNT) with concrete. The thermal performance experiment was conducted to measure the thermal performance of the MWCNT cementitious composites. The surface temperature measurement and internal structural analysis of the specimen were performed by Thermal image analysis and Field Emissions Scanning Electron Microscope (FE-SEM), respectively. The size of specimen was 100×100×60 mm3. The experimental parameters are concentration of MWCNT, ratio of the coarse aggregate, water-cement ratio, and the addition of superplasticizer. The concentration of MWCNT was selected as 0.0wt%, 0.25wt%, 0.5wt% and 1.0wt% per weight of cement. The ratio of coarse aggregate was selected at 40% to 60% and 80% per total aggregate weight. The water-cement ratio was selected at 50%, 55% and 60%. As a result of the thermal performance experiment, the thermal performance of MWCNT cementitious composite was improved up to 218 times at 60V as the concentration of MWCNT increased. When the superplasticizer was added to the specimen, the thermal performance was improved by 4.1 times. The internal structure of the specimen was confirmed through FE-SEM that the higher the thermal performance, the greater the number of CNT-network formed inside.

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abst. 2244
Repository

Effect of heat treatment and MWCNTs on Selected Mechanical Properties of the Epoxy Resin doped with TiO2

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Titanium dioxide nanoparticles (TiO2) are a commercially available filler used to modify mechanical, electrical and optical properties of epoxy resin. In our previous research, we have investigated a composite composed of TiO2 concentrations corresponding to mass fractions form 0.0 wt.% to 25.0 wt.% and the MGS L285 epoxy resin specially designed for aerospace applications. In addition, we have conducted a study of the effect of heat treatment on the crosslinking of the neat resin and the effect of carbon nanotubes concentration on selected properties of MWCNTs/EP nanocomposite. The aim of this paper is to investigate the effect of heat treatment as well as MWCNTs on the mechanical properties of the epoxy resin doped with selected concentrations of TiO2. In this study, two different concentrations of TiO2 were applied (5.0 and 20.0 wt.%). TiO2/epoxy composite samples were samples were either heat treated at 50, 60 and 80 ° C for 15 hours or stored at ambient temperature. MWCNTs/TiO2/EP nanocomposite samples with four different mass fractions of carbon nanotubes (0.0, 0.5, 1.0 and 2.0 wt.%) were tested. A number of tests were carried out, namely Dynamic Mechanical Analysis (DMA), tensile testing, compression testing, three-point bending flexural testing, Charpy impact testing, Shore D hardness, density measurements. Moreover, the tensile toughness UTT, the brittleness B and the linear isobaric thermal expansivity L were calculated. The obtained results made it possible to trace changes in the glass transition temperature, tensile strength, compressive strength, bending strength, impact strength, hardness, density as well as toughness and brittleness as a function of heating temperature or MWCNT concentration. The study showed the difference between the effect of heat treatment and MWCNT on the TiO2/epoxy composite with high and low concentration of titanium dioxide.

Nano Magnetic Composite Materials based on magnetic nanoparticles with Polymer Matrix

abst. 2256
Room 2
Wednesday
June 16
10h10

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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. [1]. Polymer-embedded nanostructures are potentially useful for a number of technological applications, especially as advanced functional materials. Governing and directing the assembly of matter on the nanometer 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]. As part of this work, we will focus on understanding the mechanisms of mechanical reinforcement of polymeric materials by the inclusion of fillers. This reduction in size made it possible to obtain important modifications of the mechanical properties of the material, demonstrating the very important role of the contact surface between the particles and the polymer. [3] Polymer-embedded nanostructures are potentially useful for a number of technological applications, especially as advanced functional materials. Governing and directing the assembly of matter on the nanometer scale has the potential to provide new classes of novel materials and enable the unprecedented capability of tuning material properties by altering their microstructure. [4 – 7] The target of this research is to obtain new materials having magnetic and mechanical controllable properties. NMF, also known as ferrofluids, are ultra stable colloidal suspensions of ferri/or ferromagnetic particles – e.g. magnetite (Fe3O4) – in various carrier liquids. Bibliography: 1. N. Crainic, A. Torres Marques, Nano - Composites – a state of the art review – Mareriais'2001 – 1 ISBN 0-87849-905-9; 2. Francesco Delogu a, Giuliana Gorrasi b,⇑, Andrea Sorrentino, Fabrication of polymer nanocomposites via ball milling: Present status and future perspectives, Progress in Materials Science, 86 (2017); 3. Anne-Sophie Robbes, Nanocomposites based on magnetic particles: synthesis and contribution of the dispersion of charges and of the conformation of the chains on the properties of enhancement, 2011, https://tel.archives-ouvertes.fr/tel-00648214; 4. Francesco Delogu a, Giuliana Gorrasi b,⇑, Andrea Sorrentino, Fabrication of polymer nanocomposites via ball milling: Present status and future perspectives, Progress in Materials Science, 86 (2017); 5. Chawla KK. Composite materials. New York, NY: Springer, New York; 2012; 6. A.T. Marques, N. Crainic, D. Bica, L. Vekas, P. J. Novoa, Control of nanomagnetic fluids during the production of composite parts components in EC-SF, workshop on Nanotechnology (2002), Grenoble, France; 7. N. Crainic, A.T. Marques, D. Bica, L. Vekas, Nuno Correia, N.C. Popa, and colaborators, Magnetic nanocomposite materials obtained using magnetic fluids and resins, International Journal of Nanomanufacturing, Vol 6, Nr. 1-4, 2010, ISSN 1746 – 9392).

New analytical solutions for free vibration of rectangular Mindlin nanoplate with arbitrary boundary conditions

abst. 2278
Repository

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Nanoscale structures have superior performances and great application potential, thus comprehensive study of their mechanical properties is necessary. This paper presents the analytical solutions for the free vibration of rectangular nanoplates with arbitrary homogenous boundary conditions. The nonlocal elasticity theory, combined with Mindlin plate theory, is employed to take the small scale effect into

account. The energy functional of the nonlocal Mindlin plate is derived using the weighted residual approach. Then an extended separation-of-variable method for solving this problem is developed, in which the mode functions are in a separation-of-variable form and natural frequencies corresponding to two-direction mode functions are assumed independent in the mathematical meaning. The characteristic governing equations and eigenvalue equations in two directions are obtained by employing the Rayleigh principle. Finally, the closed-form analytical solutions for arbitrary boundary conditions are achieved by solving two eigenvalue equations simultaneously, in which two independent natural frequencies are unknowns. In physical sense, the natural frequencies in two directions should be the same, which has been validated numerically. The correctness of the present solutions is validated through numerical comparisons. Especially, for nanoplates with at least two opposite sides simply supported, the present solutions are identical to the exact Navier and Levy solutions. Moreover, comprehensive parametric study is conducted to discuss the effect of nonlocal parameter, boundary conditions and plate size on the free vibration.

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abst. 2293
Room 2
Wednesday
June 16
09h50

FRACTURE BEHAVIOUR OF NANOBEAMS THROUGH TWO-PHASE LOCAL/NONLOCAL STRESS-DRIVEN MODEL

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It is well recognised that material properties change if the specimen sizes or deformed volume are reduced to micrometer regime. As a matter of fact, materials (both natural and human made) show behaviours significantly different from those exhibited at macroscale level, manifesting the so-called size effect [1]. Such a statement had been experimentally proved by highlighting that macroscale materials behaviour may not be directly applicable to micro- and nano-scale materials, due to the different deformation mechanisms [2]. Several attempts to capture these small scale effects in nanostructures, by accounting for the nonlocal nature of the phenomenon, have been done and various non-classical continuum theories have been developed [1]. Among them, the so-called Stress-Driven non-local integral Model (SDM) is available in the literature [3,4]. In order to better represent the behaviour of nanobeams subjected to various loading conditions, the SDM has been employed in conjunction with a local/nonlocal formulation by introducing a mixture parameter capable of properly weighting the local/nonlocal response of the nanostructure [5-6]. Therefore, the aim of the present work is to employ the above two-phase local/nonlocal SDM to analyse the size-dependent Mode I fracture behaviour of the Bernoulli-Euler cracked nanobeams, in terms of energy release rate, stress intensity factor and non-local stress field near the crack tip. Both edge- and centrally-cracked nanobeams, subjected to concentrated forces, are examined. The edge-cracked nanobeam is modelled as a pair of cantilever nanobeams subjected to concentrated forces at the free ends, whereas the centrally-cracked nanobeam is modelled according to the recent formulation proposed in Refs.[7-8]. It is observed that the energy release rate decreases by increasing the nonlocality, showing the superior fracture performance of nanobeams with respect to large-scale beams.

Natural Fibre Composites

Study of different flax/PLA biocomposite bumper configurations

abst. 2119
Room 1
Wednesday
June 16
12h00

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This work presents a study of the behaviour of bumper beams made of PLA/flax composites subjected to low velocity impacts. The relevance of this material resides in the biodegradability of both fibres and matrix. Impact tests have been performed using a drop weight tower within the range of impact energies 5 J [U+2A7D] Eimp [U+2A7D] 80 J. The experimental setup enabled the measuring of impact velocity, residual velocity, load-time history and failure mode. Moreover, the after-impact behaviour of the bumpers was analysed by means of three-point bending tests. Results show that damage generated during impact produces a significant reduction of residual stiffness but the residual strength is not affected by damage generated in the range of the applied impact energies considered. Different geometries are compared to analyse the influence of cross section on impact behaviour and residual properties. [1] Tanlak, N., Sonmez, F. O., Senaltun, M. (2015). Shape optimization of bumper beams under high-velocity impact loads. Engineering Structures, 95, 49-60. [2] Rubio-López, A., Artero-Guerrero, J., Pernas-Sánchez, J., Santiuste, C. (2017). Compression after impact of flax/PLA biodegradable composites. Polymer Testing, 59, 127-135. [3] Huber, T., Bickerton, S., Müssig, J., Pang, S., Staiger, M. P. (2013). Flexural and impact properties of all-cellulose composite laminates. Composites science and technology, 88, 92-98. [4] Díaz-Álvarez, A., Wang, L. J., Feng, C., Santiuste, C. (2020). Energy Absorption and Residual Bending Behaviour of Biocomposites Bumper Beams. Composite Structures, 112343.

Preparation of cellulose filled elastomer blends and study their properties

abst. 2122
Repository

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An effective way to improve the properties of polymers and thus reduce the negative impact on the environment is the use of organic fillers. Cellulose is economically advantageous and is a renewable source of raw materials. In this work the physicochemical, mechanical, rheological properties and morphology of the prepared blends was focused. Natural rubber (NR) was blended with surface silanized cellulose (CELsil) and pure cellulose (CEL) as a filler in amounts of 0; 30; 35; 40; 45; 50 and 55 phr. Mentioned properties were studied on prepared blends, before and after thermo-oxidation aging. Amount of filler in the NR blends mainly affected hardness, tensile strength, and elongation at break. Modified cellulose (CELsil) has significant effect on interfacial adhesion between filler and rubber, what can be observed from SEM. The importance of the work lies in finding the optimal amount of filler to obtain the desired properties of the blends and to prevent the addition of excessive amounts of filler, which would lead to increased costs of preparation and degradation of blends. This research work had been supported by the project " Advancement and support of RD for "Centre for diagnostics and quality testing of materials „in the domains of the RIS3 SK specialization, ITMS2014: 313011W442, supported by the Operational Program Integrated Infrastructure financed through European Regional

Development Fund and the Cultural and Educational Grant Agency of the Slovak Republic, project No. KEGA 002TnUAD-4/2019 " .

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abst. 2148
Repository

Study of properties of elastomer blends based on natural rubber and chitosan

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Elastomers are generally reinforced with various fillers, in order to make the final product cheaper, but especially to optimize its properties for the selected application. The most commonly used industrial filler is carbon black, mainly because of its prices and effects on elastomers. Nowadays, more emphasis is placed on alternative fillers, or new types of filler based on renewable materials. The most common biopolymers with interesting properties as filler include cellulose, chitin, starch, xylans and galactomannans. Chitosan is a derivative of chitin, which is commonly found in nature. The work examined the properties of natural rubber blends with bio-filler chitosan, as well as the interaction of the bio-filler with commonly used filler (carbon black N660). In conclusion, chitosan have an antioxidant effect on elastomeric blends, and thus to affect degradation due to the thermo-oxidative ageing. With the correct ratio of fillers (N660:chitosan), both fillers react together during the vulcanization process, the mentioned effect it is possible to see also in the case of determining the hardness and tensile properties. The adhesion of the bio-filler with the matrix, which affects the properties of the prepared elastomer blends, was also investigated by SEM analyse. This work was realized within the frame of the project Advancement and support of RD for "Centre for diagnostics and quality testing of materials"in the domains of the RIS3 SK specialization, ITMS2014: 313011W442, supported by the Operational Program Integrated Infrastructure financed through European Regional Development Fund.

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abst. 2184
Room 1
Wednesday
June 16
11h40

Elaboration of hybrid bio-composites with thermoplastic matrix: optimal material formulation and modelling of the quasi-static behaviour for an automotive structural application parts

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BINETRUY Christophe (christophe.binetruy@ec-nantes.fr), Centrale Nantes Institute of Civil Engineering and Mechanics (GeM), UMR CNRS 6183 Modelling Simulation and Processes Mechanics of Materials Groups, France

The evolution of environmental constraints guides the automotive industry. In fact, the new European regulations require the minimization of CO2 emissions by developing clean engines or lightening cars. Composite materials provide an excellent alternative to standard steels through their high mechanical resistance and considerable potential of mass reduction. This study is part of a two-phases project:

the first step is dedicated to the development of a new hybrid composite material that can satisfy the mechanical, thermal and economic specifications. The combination of two fibres with complementary properties allows optimising the overall performance of the resulting composite material with the conservation of its homogeneous behaviour [1]. The second phase of this project focuses on the development of a numerical tool for the pre-dimensioning of composite parts made with this new material. This tool will allow meeting automotive needs through a fast and economical way compared to the costly trial-and-error experimental approach. The results presented here concern firstly the experimental part of this project; they will be supplemented by some results on the multi-scale homogenisation approach [2]. Through a comparative study of natural fibres (vegetal and mineral) and thermoplastic matrices, it was decided to choose the combination of flax, basalt and PA11 matrix [3]. These different components are compatible and have complementary mechanical properties. The flax fibre has an adequate damping capacity and low density, while basalt fibre offers rigidity and high moisture resistance. Thermoplastic matrix and natural fibres provide better recyclability for this bio-composite. Three different composites reinforced by a flax twill, a unidirectional basalt and a hybrid flax-basalt/PA11 twill have been manufactured by thermo-compression and were subjected to (simple and cyclic) tensile tests in quasi-static loading. The principal purpose of the experimental phase is to identify the mechanical characteristics of these materials (Young's modulus, Poisson's ratio, damages, irreversible strains, failure stresses/strains...) and to understand the impact of the environmental conditions on the evolution of the composite mechanical behaviour. To reach the earlier objectives, we have applied various environmental conditions (temperature and Relative Humidity) for several orientations (0°/45°/90°). Five samples were tested for each experiment to guarantee the reproducibility. The experimental results highlight the benefit of the fibre hybridisation to improve the composite mechanical performances and to mitigate the impact of environmental conditions (temperature and hygrometry) on bio-composite behaviour. The fracture surfaces were examined by Scanning Electron Microscopy to identify the damage mechanism of the composite material. These experimental results will be used to identify the adequate material behaviour laws that will be implemented in the numerical homogenisation tool. We remind that the objective of this numerical tool is to allow the best design for the fibres hybridisation easily. In a first step, we only focus on the numerical determination of the elastic characteristics of the composite. The multi-scale numerical homogenisation method is divided into two phases. The first step concerns the homogenisation of the constituents (fibre and matrix) at the microscopic scale to predict the behaviour of the yarns, the second step represents the homogenisation at the mesoscopic scale (yarns and matrix) which gives the behaviour of the composite. The final objective of this study will be the correlation between the numerical results and the experiment. The conclusion of the experiment and the use of the double-scale numerical homogenisation will allow to develop a methodology in order to study the influence of three levels of hybridisation (ply scale, fibre bundle scale and fibre scale) and, therefore, to define the best fibre distribution that optimises the properties of this hybrid composite. References [1] C. Fragassa., C Santulli., A Pavlović., M Šljivić " Improving performance and applicability of green composite materials by hybridisation". Contemporary Materials Vol. 1 n° 6, pp. 35-43, [2] G ALLAIRE," Introduction to homogenisation theory". CEA-EDF-INRIA school on homogenisation, Ecole Polytechnique, 2010. [3] F. Destaing, " Contribution à l'étude du comportement mécanique de matériaux composites biosourcés Lin/PA11 élaborés par thermocompression ". Ph.D.thesis,Université de CAEN Basse-Normandie, 2012

Investigation into the fatigue properties of flax fibre vinyl-ester composites and hybrid composites based on flax and glass fibres

abst. 2233
Room 1
Wednesday
June 16
11h20

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Natural fibre reinforced composites (NFRC) offer a sustainable and environmentally friendly alternative to composites made from synthetic polymers. However, industry remains reluctant on the

adoption of NFRC in load-bearing components due various issues related to variability, moisture absorption, weak interfacial bonding and inferior mechanical performance compared to their synthetic fibre reinforced composites. However, recent developments in NFRC are making them more attractive for use in applications subjected to dynamic loading. As many engineering components functioning under dynamic loading tend to fail in a more catastrophic manner under fatigue-related mechanisms, determining the fatigue life and performance of natural fibre composites is of crucial importance, provided that research on the fatigue behaviour of these materials is still limited. The current work aims to study the fatigue response of flax fibre composites and their hybrid alternatives with glass fibres and produce robust results that can motivate the adoption of NFRC in load bearing applications. Three different batches of specimens based on flax fibre, and glass fibre composites along with flax-glass hybrid composites will be investigated. The composite materials will be fully characterized by conducting all the necessary mechanical testing to extract their mechanical and physical properties. Then, the fatigue resistance behaviour will be studied by correlating various parameters and it will be compared for each batch of specimens. Various NDT methods, such as thermography, X-ray computed tomography and DIC will be employed at different stages of the testing to monitor and assess the damage mechanisms developed in the material.

Terahertz radiation in non-destructive testing of composite pyrotechnic materials

abst. 2248
Room 1
Wednesday
June 16
12h20

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In the past years, terahertz (THz) technology has received more interest and attention because of its unique properties and capabilities that make it very attractive as a non-destructive evaluation (NDE) tool. Most items consisting of dielectrics, such as plastic, glass fibre reinforced plastics (GFRP), ceramics, and certain composites (e.g. GFC), are transparent to THz waves, whereas metals and other conducting materials, such as carbon fibre reinforced plastics (CFRP), are opaque to them. Solid pyrotechnics (e.g. rocket fuels) are among those materials that transmit terahertz radiation. The paper presents preliminary results of the possible application of terahertz radiation in the detection of defects in composite pyrotechnic materials.

abst. 1008
Room 1
Wednesday
June 16
12h40

Automated modeling of damages in large-scale composite structures based on NDT images

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Semeno, Sergey (), ,

In this study, we develop an efficient approach to model typical macroscale damages in composite structures using digital image processing and finite element simulations. The damages under concern include surface cracks and interfacial damages such as skin/core debonding, adhesive joint debonding and composite delamination. Digital cameras and/or nondestructive testing (NDT) such as infrared thermography, ultrasonic testing and shearography acquire the images of these macroscale damages. The images are further processed to detect and digitalize the complex geometries of the damaged regions. A tool, AUDI, i.e., AUtomated Damage from Images, is developed using Python to automate this process as a preprocessor for the subsequent finite element modeling. In a three-dimensional solid element model, the surface cracks are modeled by an extended finite element (XFEM) method using discrete level set functions when a linear elastic fracture mechanics assumption applies. Cracks with arbitrary geometries are explicitly represented in the model without remeshing the damaged region. The interfacial damages, e.g., skin/core debonding, adhesive joint debonding and composite delamination, are defined as the initial debond contact conditions and are modeled by separating nodes of the damaged interfacial region. The resolution of the geometric representation of the damages depends on the mesh density of the finite element model. A virtual crack closure technique (VCCT) or a cohesive zone model is used to perform progressive failure analysis and estimate the criticality of the damages. The proposed modeling approach uses the simulation functionalities readily available in most commercial finite element software. In addition, the modular design of the approach also allows user-defined material damage models to be used for specific damage assessment. Using the proposed modeling approach, composite structures with damages that have realistic and complex geometries can be analyzed efficiently, helping bridge the gap between damage inspections and damage assessments of composite structures.

Optimization techniques and methods

A Study on the Optimal Curing Process of Filament Wound Tow-preg Laminated Composites through Multi-scale Modeling

abst. 2095
Room 1
Wednesday
June 16
08h30

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Filament winding technology is an automated composite manufacturing process which uses dry tow or tow-preg as manufacturing medium. This technology has been widely used for manufacturing convex-shaped composite part including pressure vessels, one of the most important applications of composite material. Performance of the filament wound composite products mainly depends on the curing process. One of the main defects that reduces composite performance is entrapped void left in the product. To minimize the void content, achieving good resin impregnation to the fiber net by controlling resin viscosity and flow time during the curing process is important. However, there is lack of detailed study on the resin flow in wounded tow-preg and previous researches have focused on overall resin behavior throughout the composite laminate. In this work, multi-scale modeling scheme from the detailed tow scale behavior to laminate scale behavior of resin was adopted to analyze the resin flow. Cure kinetics model and viscosity model for the resin system were constructed based on the experimental data obtained from rheometer and Differential Scanning Calorimetry (DSC), thereafter these models were applied to the multi-scale simulations. In micro-scale, cross section of the tow-preg was observed with the aid of Scanning Electron Microscope (SEM). Hydraulic permeabilities of the tow-preg in the direction parallel and perpendicular to fiber were calculated by flow simulation with Representative Volume Element (RVE) generated by using fiber volume fraction and fiber distribution data obtained from image processing with the SEM images. In meso-scale, consolidation of tow-preg including resin bleeding characteristics and tow thickness reduction were analyzed with the hydraulic permeability data obtained from the micro-scale simulation. In macro-scale analysis, the resin bleeding characteristics from the meso-scale simulation were applied to the laminate model and resin flow and impregnation characteristics through the laminate were simulated with respect to cure cycle. Filament wound composite cylinders were manufactured according to various cure cycles and impregnation state of the composite specimen taken from the cylinder was tested. In addition, burst pressure of the composite cylinder were measured by using segment-type ring burst tests. With these procedures, a relation between cure cycle parameters and composite performance was obtained. Since there are multiple parameters affecting the performance, artificial intelligence was introduced to generate cost function for optimizing cure cycle parameters.

Analysis of the Possibilities of Forecasting Selected Properties of Aviation Polymer Composites

abst. 2185
Room 1
Wednesday
June 16
08h50

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Experimental determination of the properties of polymer composites can be a valuable source of information about the behavior of a given material, and the use of modern information technologies, such as artificial neural networks, gives the possibility of forecasting its properties while reducing the number of observations carried, bringing both economic and environmental benefits. The aim of the publication is to consider the possibility of using artificial neural networks as a model describing the impact of the percentage mass friction modifier on selected mechanical properties and the formation of abrasive wear of polymer composites used in aviation. Using of models of ANN will allow obtaining

good generalizing (generalizing) properties resistant to the input of incorrect input data. The authors chosed ANNs for accurate recognizing the relationship between any sets of inputs and outputs (from tribological experiments) without formulating a physical model of a phenomenon under consideration. The research was carried out for aviation polymer composite are investigated with the matrix of L285-cured hardener H286 and six reinforcement layers of carbon fabric GG 280T and a physical modifier of friction in the form of alundum with changed mass share and grain size. The experiment data were used to build artificial neural network (ANN). The different various percentage mass shares parameters and grain sizes of alundum were used as inputs and the weight loss between the cycles and selected mechanical properties as output of the model. The predicted values of the ANN model were verified with the actual values. The proposed solution is an attempt to describe a complex nonlinear system which is tribological system. The authors see the potential of this method in planning research experiments. The model can help to reduce the number of samples produced. This is a time, economic and environmental advantage. However, it should be noted that the effectiveness of the ANN model crucially depends on the amount and generality of the training data.

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abst. 2253
Repository

DEPLOYMENT OPTIMIZATION METHOD FOR DESIGNING PRE-FORM OF CFRP SHELL STRUCTURES WITH FREE MATERIAL-ORIENTATION

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Free fiber orientation of CFRP on free-form surfaces has been a challenge in actual manufacturing. In this paper, we present a novel optimization method for designing deployment shape with cutlines (often called pre-form) to support the manufacturing of free fiber orientation shell structure. The proposed method consists of two processes. One is to generate the optimal cutlines besed on the concept of crack growth, in which the optimal cutlines are generated by separating the boundaries of the neighbor elements according to the magnitude of weighted strain energy density. The other is to determine the optimal deployment shape with the cutlines. We formulate a shape optimization problem with large deformation that minimizes the work mapping from the planer deployment shape to the original free-form surface under the area constraint, and derive a shape gradient function. Then, the optimal planer deployment shape is obtained using the H1 gradient method. The effectiveness of the proposed method involving the cutlines generation process and the shape optimization process is demonstrated through numerical examples.

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abst. 2285
Repository

Inverse Convolution Method for Periodic Media under stochastic Condition

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Wavenumber extraction has been used in periodic structures field to reveal many unique properties, such as complex band structure which has been applied to many applications, such as damage identification, vibration isolation, unable filters, wave guides and more. With the development of contactless measurement devices, such as scanning doppler laser vibrometers, displacement can be obtained on fine meshes. Comparing to traditional model-based analysis methods, such as Transfer Matrix Method (TMM) and Wave Finite Element method (WFEM), inverse method involving Fourier-based wavenumber estimation methods and improved signal processing methods can be used in the medium and high frequency region and it just regards the experimental displacement as input parameters. These advantages make operation simple and practical. Fourier-based inverse method contains two-dimensional spatial Discrete Fourier Transform (2D-DFT), McDaniel's method, Inhomogeneous Wave Correlation

(IWC) method and so on. For signal processing methods, Matrix Pencial, ESPRIT, Prony method, MUSIC and HRWA are created. But until now, most of papers mainly focus on optimizing robustness of inverse method to noise by using SVD, LU numerical solution while few papers consider the influence of small perturbation on wavenumber extraction when using inverse method. Small perturbation problem is a common but tough problem caused by sampling error. The fine samples are crucial for inverse method. However, the samples usually lose accuracy because of machine or manipulation fault in practice, resulting in ill-posed problem. Boukadia recently proposed a novel improved signal processing method referred to INCOME as an extension of Prony method. This method can be applied to extract wavenumbers in 1D and process K-space analysis in 2D based on linear algebra. But the periodic measurement is still a strong constraint. In order to solve this problem, this paper optimizes INCOME in S transform combing a Prony-like method and LS polynomial fitting method.

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abst. 2099
Repository

Fabrication of Porous Aluminum Composites Containing Hollow Ceramics

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Porous aluminum (Al) is a porous metallic material that has many pores inside the aluminum. Because of its porous nature, it is very lightweight and has excellent multifunctional properties such as shock absorption and thermal insulation. One of the methods to fabricate porous Al is the melt foaming process. In the melt foaming process, a thickening agent such as calcium is added to the molten metal to maintain pore structures, and the viscosity of the molten metal is increased by stirring in air. By adding TiH2 powder to the thickened molten metal and stirring it, H2 gas generates by thermal decomposition and it dispersed in the molten metal and foams. In this study, we investigated the use of hollow ceramics called microballoons as a substitute for the thickening agent. In this study, hollow ceramics were used as a substitute for the thickening agent. By using hollow ceramics as a thickening agent, we can expect to fabrication porous Al that is lighter than conventional ones. It is also expected to fabricate porous Al with a bimodal structure that has both hollow ceramics and pores generate by the foaming agent. By using a hand mixer, we attempted to mix the hollow ceramics with poor wettability into the molten metal and to uniformly mix the foaming agent into the molten metal. As a result of the experiment, it was shown that the foaming condition was better when hollow ceramics were added, than that without hollow ceramics. It was also found that the higher the amount of hollow ceramics added, the better the pore foam. The addition of hollow ceramics was superior to no addition in terms of lightweight properties. This suggests that the hollow ceramics have a thickening effect on the molten metal and can maintain the pore structures. SEM observation of the cross section also confirmed that the hollow ceramics were mixed in the cell walls without being collapsed. From these investigations, it was found that the hollow ceramics were effective as a thickener and could maintain the pore morphology of the porous Al. It was also suggested that bimodal porous Al could be fabricated by mixing hollow ceramics into the cell walls of porous Al.

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abst. 2137
Repository

Friction welding of aluminum foam and resin plate

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Kamakoshi, Yuichiroh (), Gunma Industrial Technology Center, Japan

Composite materials consisting of aluminum foam and resin are expected to meet the current demand for weight reduction of parts. In this study, friction welding of aluminum foam and a resin plate was conducted. We showed that joining between aluminum foam and a resin plate can be achieved by friction welding via the anchor effect without the collapse of pores. The observed joining strength was similar to the strength of the aluminum foam itself.

Probabilistic modeling and reliability of composites

Comparative reliability analyses of pressure vessel made of steel, aluminum alloy and composite material.

abst. 2201
Repository

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Reliability design is a calculation methodology that is increasingly important both in the design phase and in the verification phase of a component. This approach, born and applied essentially in the nuclear energy sector, has found increasing interest in the scientific community in recent years. This is because, compared to classical deterministic methods, the probabilistic approach allows to evaluate the reliability of a component or a machine in general, in relation to the variability of the parameters that define the machine itself. In particular, in the present work the objective is the study of a pressure vessel made of composite material with two different types of fibers (60% carbon fibers and epoxy resin and 60% glass fibers and epoxy resin) by adopting both a reliable approach and both the classical deterministic one. The pressure vessel has an internal diameter of 1 m and an axial length of 2.5 m; the internal volume is approximately 2 m3. The dimensioning of the component was carried out using the theory of axial symmetrical components considering thin thicknesses and this both for the shell and for the bottoms (hemispherical and ellipsoidal). The mistake made by adopting the theory of thick thicknesses, which is more complex, is of a few percentage values in the values of the maximum stress. The results of the analytical analyzes were confirmed by the results of the numerical analyzes performed through the finite element analysis, carried out after the creation of the solid model of the component. The finite element method has made it possible to estimate the real stresses present in the junction between the shell and the bottom of the pressure vessel; whose analytical solution was determined by considering the displacement method by adopting the elastic coefficients determined for the shell and for the bottoms of the pressure vessel. The finite element analyses s also made it possible to verify the geometric solutions developed especially in the area of the openings on the two bottoms which are the most critical. The project of the pressure vessels has been expanded considering also different materials such as high-strength structural steel (S460 UNI EN 10025) and aluminum alloy (3000-H18 UNI EN 485). This phase made it possible to compare the overall weight of the component (with the same internal volume) and the reliability of the component designed with different materials. In particular, the thickness of the shell for the solution with carbon fiber is equal to 34.92 mm, while for the solution with glass fiber the thickness is equal to 47.63 mm. For the component made of steel, the thickness of the shell is equal to 30.41 mm while for the one made of aluminum, the thickness is equal to 60.81 mm. The reliability aspect was addressed by determining the curves that allow to correlate the reliability of the component to the deterministic safety coefficient adopted. Especially, this study was dealt on the shell in the different schematizations of the materials employed. In particular, it is emphasized that these curves have a markedly non-linear trend and that they are significantly different between the diverse materials adopted. In other word if the safety coefficient increases for a specific value, the reliability increases with another rate that depends both the magnitude of the safety factor and the material used to design the component. The final whole weight of the pressure vessel designed is equal to 1283.7 kg for the one made with carbon fibers, 2305.1 kg for the one with glass fibers while it is equal to 3204.2 kg for the steel one and 2767.8 kg for the aluminum one.

Effective material properties of hyper-elastic particulate composites with random interface

abst. 2225
Room 1
Monday
June 14
15h20

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Efficient algorithm for determination of basic probabilistic characteristics for the effective material properties of hyper-elastic composites with stochastic interface defects is developed in this work. This

approach could be applied for various hyper-elastic potentials, and resulting uncertainty in material properties is aimed for direct usage in macro-scale computations of reliability in composite structures. Numerical analysis is delivered for High-Density Polyurethane Laripur LPR5020 filled with 5% of fullerenes F60. Laboratory tests include uniaxial tension of pure matrix and a filled composite, which serves for a verification of efficiency of the proposed numerical approach in practical case study. Hyper-elastic potentials under consideration include Arruda-Boyce, Mooney-Rivlin, and also Neo-Hookean models. Numerical experiments are completed using homogenization method implemented for a cubic single-particle Representative Volume Element (RVE) of this composite using the FEM system ABAQUS. This homogenization scheme is based on numerical investigation of the strain energy density accumulated in the RVE under uniaxial stretches. The particle is spherical, remains in linear elastic regime, is centrally located in this RVE and perfectly surrounded by hyper-elastic matrix. The interphase is a thin layer around particle that has elastic properties weaker than the matrix, because of the defects located on the particle-matrix transition; these defects are considered as the semi-spherical voids. A constitutive relation of the matrix is recovered experimentally in the uniaxial stretch test and approximated computationally by the best fitting hyper-elastic material model. Uncertainty of the voids volume fraction is modelled using Gaussian distribution with the given mean value and coefficient of variation not larger than 0.15. A relation of the effective properties to this uncertain parameter is recovered via the Response Function Method (RFM) and by the Least Squares Method (LSM). The RFM polynomial order is optimized by simultaneous maximization of correlation and minimization of the LSM error and variance. Probabilistic calculus is carried out using three independent approaches, the generalized iterative stochastic perturbation, the crude Monte-Carlo simulation and the semi-analytical method. Probabilistic characteristics include expected values, coefficients of variation, skewness and kurtosis of the effective material properties. It is investigated numerically how the proposed algorithm works for a chosen composite and how a fluctuation of the voids volume fraction affects effective composite properties in the context of probabilistic analysis. Further SFEM computational studies will concern numerical simulation of the RVE in hyper-elastic composite with spherical reinforcing particles and stochastic hysteresis. [1] D. Sokołowski, M. Kamiński, Probabilistic homogenization of hyper-elastic particulate composites with random interface, Compos. Struct. 241: 112118, 2020, [2] D. Sokołowski, M. Kamiński, Homogenization of carbon/polymer composites with anisotropic distribution of particles and stochastic interface defects, Acta Mech. 229: 3727–3765, 2018. [3] H. Shin, J. Choi, M. Cho, An efficient multiscale homogenization modeling approach to describe hyperelastic behavior of polymer nanocomposites, Compos. Sci. Technol. 175: 128-134, 2019.

Smart Composites

Tuning topological state in a composite piezoelectric rod via electric means

abst. 1005
Room 3
Wednesday
June 16
08h30

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Topological mechanics is a new area of mechanics, mostly concerning topological states of wave propagation that can be realized in metamateirals through a particular design of the units involved. We consider a homogeneous piezoelectric rod, but with mechanically negligible electrodes double-periodically inserted to tune the wave propagation behavior. It is a piezoelectric phononic system, with each unit cell consisting of three sub-rods forming an A-B-A structure. It is discovered that the switch of electrical boundary conditions from A-closed and B-open to A-open and B-closed will yield topological phase inversion, based on which topologically protected interface mode is realized. When different capacitors are connected to the electrodes of sub-rods A and B, a lot of physical phenomena will be observed. The study illustrates that the eigenfrequency of the topologically protected interface mode be manipulated by appropriately varying the capacitance. The tunable topologically protected interface mode may have wide engineering applications.

Investigation of a Composite Single-lap Joint (SLJ) Reinforced by Multifunctional Thermoplastic Composite Fastener (MTCF)

abst. 1036
Room 3
Wednesday
June 16
09h50

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Carbon fibre reinforced composites are progressively replacing metal structures in modern civil aircraft. This is because composite materials have large potential of weight saving comparing with metal. However the achievement to date of weight saving in composite structure is far less than the theoretical potential due to many uncertainties in structural integrity and safety concern. Unlike the conventional metallic structure, composite components are bonded together along the joints where structural integrity is a major concern. To ensure the safety, metal fasteners are used to reinforce the composite bonded joints. One of the solutions for a significant weight saving of composite structure is to develop an effective technology of on-board Structural Health Monitoring (SHM) System. By monitoring the real-life stress status of composite structures during service, the safety margin set in the structure design can be reduced with confidence. It provides a means of safeguard to minimize the need for programmed inspections and allow for maintenance to be need-driven, rather than usage-driven. The aim of this paper is to develop smart composite joint. The key technology is a multifunctional thermoplastic composite fastener (MTCF). The MTCF will replace some of the existing metallic fasteners in the most concerned locations distributed over the aircraft composite structures to reinforce the joints and form an on-board SHM network system. Each of the MTCFs will work as a unit of the AU and AE technology. The proposed MTCF technology has been patented and developed by Prof. Guo in Cranfield University, UK in the past a few years. The manufactured MTCF has been successfully employed in the composite SLJ. In terms of the structure integrity, the hybrid SLJ reinforced by MTCF achieves 19.1% improvement in the ultimate failure strength in comparison to the bonded SLJ. By increasing the diameter or rearranging the lay-up sequence of MTCF, the hybrid SLJ reinforced by MTCF is able to achieve the equivalent ultimate strength as that reinforced by titanium fastener. The predicted ultimate strength in simulation are in good agreement with the test results. In terms of the structural health monitoring, a signal from the MTCF was measured well before the load of mechanical failure. This signal provides a warning of initial crack in the joint which could not be detected by the strain gauge until the final failure.

An Integrated electrode with the bipolar plate / current collector to reduce contact resistance in vanadium redox flow batteries

abst. 2072
Room 3
Wednesday
June 16
09h10

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Owing to the international environmental regulation, renewable energy sources such as solar and wind powers have been considered as strong candidates to replace fossil fuels. However, irregular and discontinuous energy production is a critical problem of the renewable energy. In order to solve this problem, available energy storage technologies such as the batteries, electrochemical capacitors, hydrogen storage, and others were introduced. Li-ion batteries have the advantages of high efficiency and energy density, but the risk of explosion remains an important issue, which attracted great attention for the development of non-hazardous battery systems. In particular, a vanadium redox flow battery (VRFB) is in the spotlight as the next generation energy storage system owing to its low explosive property. Also, its independent capacitance and power enable a largescale installation of energy storage system effectively. Despite their advantages low energy density and efficiency still remain the major obstacles for the application of the VRFBs in energy storage systems. In addition, high contact resistance between the various components in the VRFBs can degrade its performance at high current density. In this study, a novel fabrication method to reduce the contact resistance by integrating current collector, bipolar plate, and electrode of the VRFB system is proposed. To reduce contact resistance significantly, we fabricated an internally connected structure in which the bipolar plate and the electrode consist of double layers on a single sheet of carbon felt. In order to prevent changes in porosity of the electrode, the carbon felt was filled with a glucose solution prior to the pressing process to make the integrated structure. Before immersing the carbon felt into the glucose solution, selective hydrophilicity was offered by applying plasma treatment in the thickness direction of the carbon felt. The plasma treated thickness of the carbon felt was controlled by adjusting the treatment time. When the carbon felt was immersed into the glucose solution, the plasma treated part was selectively filled with the solution due to surface hydrophilization. To fabricate the bipolar plate layer in the integrated structure, the epoxy was impregnated into the part that was not filled with the glucose, and then the copper plate as a current collector was attached to the bipolar plate layer of the carbon felt by co-cure method using a hot press. The electrode layer was made by removing the glucose coating from the carbon felt by immersing it into distilled water. The integrated structure had 46% lower electrical resistance than a conventional stack of VRFBs. In addition, we confirmed that interface between carbon felt and copper plate showed high chemical stability and liquid tightness in electrolyte of the VRFB. Finally, the electrochemical performance was evaluated using a VRFB single cell test and compared with the conventional cell stacks.

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abst. 2096
Room 3
Wednesday
June 16
09h30

Sandwich type shape memory polymer composite to increase the recovery force for space deployable structures

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Due to the limitation of a spacecraft size, deployable structures have become one of the key technologies for large space applications such as space solar power systems (SSPS), satellite panels, and solar sails. The requirements of the space deployable structures are lightweight, high shape deformability, and ease of operation. One of the good candidates satisfying these requirements is shape memory polymers (SMPs) owing to its low density, high elastic deformation, and convenience of production. Besides, SMPs recover to its original shape reacting to external stimuli like heat and water without additional devices. For these reasons, a lot of research has tried to make actuator which can unfold the deployable structures using SMPs. The structures are supposed to be deployed by the recovery force of the SMPs, but this recovery force is not enough to substitute the commercial actuators of the space structure. To overcome this problem, shape memory polymer composites (SMPCs) based actuators reinforced with fibers or fillers have been investigated. But, increasing the recovery force by

only reinforcing the materials has limitations such as fiber strain limit and micro-buckling problems. In this study, a sandwich structure with the re-entrant core was applied to the bending actuator to increase the recovery force. The programming process of the sandwich type SMPC actuator was progressed in the two steps: compression followed by bending at the temperature above glass transition temperature (Tg). Adding the compression step enables the high global elastic deformation with small local strain. In addition, re-entrant core helped the compression without failure so that the optimum shape of the re-entrant core was selected through the simulation and the experiment. Finally, the recovery force was measured to evaluate the performance of the sandwich type SMPC actuator.

Evaluation of piezoelectric energy harvesting for aeroelastic wind tunnel test model

abst. 2187
Room 3
Wednesday
June 16
08h50

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In the present work, an aeroelastic wind tunnel test model with piezoelectric-based energy harvesting capability is evaluated by means of an Iterative Finite Element Method (FEM). For the first time, a numerical method for investigating piezoelectric energy harvesting from aeroelastic vibration is used to verify a wind tunnel test model. The FEM model represents a typical wing section attached to piezoelectric composite structures, functioned as springs and energy harvesters. The results of the Iterative FEM investigation are compared with experimental data.

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abst. 2035
Repository

On the bifurcation buckling analysis of symmetric FGM porous nanobeams with electro-elastic coupling effect

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The piezoelectric effect on bifurcation buckling of sandwich FGM porous nanobeam is investigated based on a higher-order nonlocal elasticity and strain gradient theory in conjunction with the third-order shear deformation beam theory. We used properties of the strain energy density function and electric enthalpy density function to derive constitutive relations for porous functionally graded, as well as piezoelectric materials. Equations of motion for elastically supported layered FGM nanobeam with diverse distribution of porosity and electro-elastic coupling are derived based on the modified Hamilton's variational principle. The formulated boundary value problem is analytically solved. Effects of porosity distribution, volume of voids, distance between porosity and FGM core surfaces as well as material gradation, layers size, aspect ratio, stiffness of Kerr foundation, and external electric voltage on critical in-plane force, critical porosity and critical voltage are comprehensively discussed. A new insights to stability of symmetric FGM porous nanobeams with piezoelectric layers is presented. Acknowledgement: 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. 2075
Room 2
Monday
June 14
16h20

Closed-form solution for buckling of shear-deformable laminated plates with rotational restraints

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This study considers the buckling of orthotropic plates where transverse shear is a factor. That is the case when the ratio of the in-plane dimension and the plate thickness becomes small or when the transverse shear modulus is relatively small. The considered orthotropic plates are under uniaxial pressure and simply supported at all edges where the unloaded edges additionally are subjected to rotational restraints. These plates are known by the abbreviation SRSR (simple supports (S), rotational restraints (R)). In the framework of Reddy's Third Order Shear Deformation Theory (TSDT) an analytical closed-form solution is developed, which is formulated based on energy-based methods in the form of the Rayleigh quotient. Therefore, shape functions are made for the out-of-plane buckling deflections as well as for the two rotational deformations. This method leads to an explicit representation of the critical buckling load which can be applied straightforwardly in engineering work. The method can be used for compressively loaded plates where elastic restraints become relevant, e.g. in the context of local beam buckling or skin fields of stiffened composite panels. Furthermore, the Lévy-type solution is considered for the mentioned plate type. The comparison of the analytical approach shows satisfactory agreement with the Lévy-type solution. This makes the approach applicable in practice, especially when computational efficiency is a major factor e.g. in optimizations.

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abst. 2138
Repository

Analytical approach to buckling analysis of multi-layered and FG sandwich cylindrical shells under combined loads based on the third-order shear deformation theory

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In this study, based on the third-order shear deformation (TSD) and Donnell's shell theory as well as von Karman strain-displacement relations, the buckling analysis of functionally graded (FG) sandwich and multi-layered cylindrical shells with transversely isotropic layers, subjected to different types of loadings, was carried out. To this end, by employing the principle of minimum total potential energy, the five nonlinear coupled equilibrium equations with total order of twelve are obtained and reformulated into two nonlinear partial differential equations; one in terms of the transverse deflection with order of six and the other in terms of a force function with order of four, as well as one linear differential equation with order of two in terms of a boundary layer function. Then, using adjacent equilibrium method, the two nonlinear governing equations are reduced to one tenth-order decoupled linear stability equation in terms of transverse deflection. Such a reduction of equations makes it possible to conveniently present closed form expressions for critical loads of non-homogenous cylindrical shells under different types of loading within the third-order shear deformation theory which are reported for the first time. The loadings include external pressure, axial, torsional and thermal loadings as well as different combinations of them. Four different categories of cylindrical shells including multi-layered cylindrical shells with transversely isotropic layers, FG cylindrical shells and two types of FG sandwich cylindrical shells with FG core and homogenous layers as well as FG layers and homogenous cores are considered. The numerical results are verified with the existing ones in the literature. Finally, the effects of shear deformation, geometric parameters, type of the cylindrical shell, material constant, and initial stresses on the buckling loads and mode shapes for various cases of loadings are studied in details. Numerical results show that the effect of shear deformation on buckling loads (difference between critical loads obtained from TSD and first-order shear deformation theory) increases for shells with smaller aspect ratio and larger wall slenderness ratio. This effect is more pronounced in multi-layered and FG sandwich cylindrical shells rather than in FG shells. Furthermore, it is observed that initial stresses have significant effect on buckling behavior of shells.

On Dynamic Stability of Thin Cylindrical Shells with Two-Directional Micro-Periodic Structure

abst. 2168
Repository

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The objects of considerations are thin linearly elastic Kirchhoff-Love-type circular cylindrical shells with a periodically micro-heterogeneous structure in circumferential and axial directions (biperiodic 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 reinforced by periodically spaced families of stiffeners or composed of different materials periodically and densely distributed in circumferential and axial directions. The aim of this paper is to investigate the effect of a periodicity cell size on the dynamic stability of such shells (the length-scale effect). In order to take into account this effect, an averaged mathematical non-asymptotic model for the analysis of stability problems for the biperiodic cylindrical shells under consideration is applied. This model, proposed in [Tomczyk B. Length-scale effect in dynamics and stability of thin periodic cylindrical shells. Scientific Bulletin of the Lodz University of Technology, No. 1166, series: Scientific Dissertations, Lodz University of Technology Press; 2013], was derived employing the tolerance modelling procedure. Contrary to the starting exact shell equations with highly oscillating, non-continuous and periodic coefficients, governing equations of the tolerance model have constant coefficients depending also on a microstructure size. The obtained fourth-order ordinary differential frequency equation for unknown function of time coordinate, being a starting point in the analysis of dynamical shell stability, can be treated as a certain generalization of the known Mathieu equation. It reduces to the classical Mathieu equation provided that the length-scale effect is neglected. The generalized Mathieu equation comprises

the new additional higher-order free vibration frequencies and the new additional higher-order critical forces dependent on a cell size. Comparing the results derived from the aforementioned non-asymptotic tolerance model with those obtained from a certain asymptotic model, the effect of a cell size on the boundaries of two fundamental dynamic instability regions will be evaluate. It will be shown that the length-scale effect plays an important role in the dynamic stability analysis of the biperiodic shells under consideration. Moreover, influence of differences between geometrical, elastic and inertial properties of the shell component materials on the boundaries mentioned above will be discussed.

Structure health monitoring of tunnel composite structures based on laser scanning data

abst. 2041
Repository

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Concrete composite structure is widely used in the tunnel shield segments, However, deformation and damages occur due to the influence of the environment and transportation loads, especially when the tunnel segments serve for a long time. Therefore, monitoring the health status of the structure is important for a safe operation of tunnel composite structure. Recently, terrestrial laser scanning is employed to collect the full-field surface data of the tunnel segments, and to obtain the deformation of the 2D profile. But, the research on the deformation of the whole tunnel in a 3D sense is still limited. This study focused on the full-field 3D deformation monitoring of tunnel structures with adaptive geometry reconstruction, which is reconstructed automatically from the point cloud data by means of free-form surface approximation. The surface model has an even higher accuracy than the raw data, since the adjustment is conducted in the approximation process, so that the geometric status as well as deformation, surficial imperfection and change trend is able to be reflected clearly in the geometric model. The current study focused on the geometry inspection and deformation monitoring of the composite structure, where the deformations of arbitrary points on the structure surface are detected and extracted from the model. The benefit is that the model can realize deformation analyses of arbitrary position on the surface of composite structure, in a preferred form of points, lines or pieces of surfaces. Therefore, it makes actually a sizable increase on the experiment data of the composite structure with only one experiment, and meanwhile solves the problem of the unreliable analysis results due to choosing unsuitable testing points. Moreover, the geometric model is complied with the FEM geometric model, which has a competence the integration analysis of the composite structures based on full-field data.

Comparison of attachment methods for optical fiber sensors in time dependent strain monitoring of thermoplastic composites

abst. 2175
Room 3
Tuesday
June 15
16h00

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Optical fibers are used for structural health monitoring in steel, concrete, polymer and composite structures. As noted previously, the effectiveness of strain transfer from the host structure to the optical fiber sensor is dependent on the chosen attachment method. The properties of the attachment layer affect the measured strain values, occasionally giving errors and lag during time dependent strain monitoring. In this paper, a thermoplastic polymer PA6 and short carbon and glass fiber reinforced PA6 composites produced by fused filament fabrication were initially loaded by a tensile strain of 2%. The specimens were thereafter monitored for one hour duration while the position of the cross-head of the test machine was fixed. Time dependent strain variation was monitored using optical fibers attached by bonding with different glues, thermoplastic fusion bonding, and in-situ embedding by 3-D printing. Mechanical strain in the specimen was measured in parallel by a contact extensometer. Our investigation compares alternative attachment methods for optical fiber sensors for using with thermoplastics and its composites without resorting to any special surface treatments. By testing attachments with widely different elastic moduli and composition, new knowledge for choosing the attachment method for tailored uses of optical fiber sensors is provided. The attachment layers with very low moduli can simulate a mechanically detached fiber, while stiff and thin attachments transfer mechanical strains from the host to the fiber sensor with very little loss. Cyanoacrylate glue turns out to be a reasonable low-loss adhesive option for bonding to thermoplastic composites. Meanwhile attachments created by the fusion of thermoplastics and from 3-D printing embedding give durable and reliable bonding but also less-uniform strain fields.

abst. 2197
Repository

Probabilistic Approach for Thermoelastic Signal Source Identification in Carbon Fiber/Epoxy Composite Materials using Digital Image Correlation

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The successful quantification of the small temperature changes detected in a composite structure under isentropic loading conditions into strain variations using Thermoelastic Stress Analysis (TSA) is strongly dependent upon the proper selection of an analytical thermoelastic model. The conventional approach for thermoelastic model selection relies on the information provided by local strain measurement techniques, such as strain gauges or extensometers, hence limiting the characterization of the structural thermoelastic behavior to a single model. Moreover, a deterministic approach to quantify the thermal and mechanical properties built-in the thermoelastic model equations has been traditionally considered. This methodology reveals unsatisfactory to account for the composite material's inherent heterogeneity and seize the full-field capabilities of infrared cameras. This work proposes an alternative local-based probabilistic approach for characterization of thermoelastic models in composite structures. Nodal displacements and thermal data collected from Digital Image Correlation and an infrared camera, respectively, are first interpolated to a mutual background mesh using a Radial Basis Function (RBF). Optimal shape parameters for minimizing the interpolation errors for both datasets are first obtained using the Leave One Out Cross Validation (LOOCV) method, followed by the implementation of a fast regularized forward center selection scheme to reduce the number of displacement data points for interpolation. Full-field displacements are converted into in-plane strains using finite differences. The resulting strain field is used as input to three analytical thermoelastic models (Resin-Rich Layer, Bulk and Homogeneous). Semi-empirical Halpin-Tsai and mechanics of materials-based micromechanical relations for Young's Modulus, Poisson ratios, density and coefficient of thermal expansion are introduced to account for the variability of volume fractions in the predicted thermoelastic response. Other thermo-mechanical properties of the composite material are treated as random variables with a normal distribution. Analytical solutions to the point-wise comparison between the thermoelastic response calculated for each model and measured with the infrared camera are obtained using the Lagrange Multiplier Method. The proposed concept is validated on carbon fiber/epoxy tensile coupons with four different stacking sequences subjected to in-plane tensile loading conditions. The proposed methodology is demonstrated to help circumvent inaccuracies of the conventional thermoelastic model identification process and improve the reliability of strain measuring capabilities in future TSA of composite materials.

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abst. 2231
Room 3
Tuesday
June 15
16h20

In-situ detection of aging effects in hybrid specimens using resonant inspection techniques - Part II: Correlating variation of frequency spectra with changes in the specimen

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Aging tests under cyclic temperature load help to evaluate the lifetime of multi-material parts. Additional mechanical loads then appear in these structures due to the different coefficients of thermal expansion of the joint materials. In previous publications, a test specimen for studying the ageing process of hybrid structures under temperature load was introduced and validated experimentally. It consists of a specially formed metal inlay fully surrounded by a potting material. When performing the ageing experiment, constantly monitoring the specimens in-situ would be preferred over just inspecting the specimens after predefined times, which is done at the moment. Implementing a measuring technique withstanding the harsh environment in the thermal chamber and being able to evaluate a high number of specimens at the same time would lead to a better understanding of the structure's ageing behavior. In a previous publication, a non-destructive measurement setup for obtaining the specimens' frequency spectra by using the Electromechanical Impedance (EMI) method was presented and experimentally validated. First measurements of the hybrid specimen showed a high degree of variation in the spectra after already a small number of temperature cycles. The aim of this work is to interpret the frequency spectra by finding correlations between their variation and changes appearing in the specimen during an ageing experiment. As the sensitivity of the measurement technique was shown to be very high, variations in the spectra can be caused by numerous specimen-related changes superposing each other. The influence of three main changes namely curing of molding resin, initiation and growth of cracks as well as the appearance of stresses is studied in this work. At first, the frequency spectra of simplified test pieces are obtained, whereby each is changed in a controlled manner with respect to only one of the three changes to identify the corresponding variation of the spectra. In the next step, the hypotheses created in this way are validated performing resonant measurements of prepared hybrid specimens in various ambient conditions. Concurrently, amount of change appearing in the specimens is constantly quantized using suitable measurement techniques. Multi-domain Finite Element Simulation using ANSYS, with which it is possible to change influencing factors (e.g. material parameters) independently and in a controlled manner, accompanies both steps. Finally, more general models of how the studied changes act on the corresponding frequency spectra are created to be tested on other structures in future work.

Thermal problems on Composite structures

abst. 2191
Room 2
Wednesday
June 16
11h00

Snap-through of composite sandwich beams with FG-CNTRC face sheets in thermo-mechanical loads

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Carbon nanotube (CNT) shows significant promises as a potential reinforcing constituent and multi-functional element in polymer matrix composites due to exceptional mechanical, electrical and thermal properties, while the stability of composite sandwich beams with functionally graded carbon nanotube reinforced (FG-CNTRC) face sheets has attracted much attention, however, the mechanism of structural instability under complex loading conditions remains poorly understood even controversial. This paper investigates on the snap-through behavior of composite sandwich beams with FG-CNTRC face sheets in thermo-mechanical loads. First, based on the Euler-Bernoulli beam theory and von-Karman geometric nonlinearity, considering the temperature-dependent material properties and its gradient variation along the direction of beam thickness, a nonlinear integro-differential governing equation of sandwich beam under thermo-mechanical loads is formulated by Zhang's two-variable method. Then, the approximate analytic solution under thermo-mechanical loads is obtained by the semi-inverse method of Nayfeh. Finally, the influence of CNT volume fraction, graded profile and mechanical load on the critical buckling temperature and postbuckling equilibrium paths of sandwich beams is studied. Numerical results show that our analytical predictions of critical buckling load and postbuckling path of sandwich beams under pure thermal or mechanical loads are in good agreement with the existing research results; the introduction of transverse mechanical load leads to the symmetry breaking of thermal stability of sandwich beams, which makes the instability change from bifurcation type to snap-through one; in addition, the CNT graded profiles and the mechanical load amounts and directions have significant effects on the critical buckling load and postbuckling path of sandwich beams. These results are helpful for clarifying the instability mechanism of composite structures under complex loading conditions, and providing theoretical basis and new ideas for structure stability design and its control.

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abst. 2204
Repository

Influence of Carbon Nanotubes CNT, Kind of Resin Matrix and Technology of Mixture Homogenization on Ablative and Dynamic Mechanical Properties of Epoxy Nanocomposites

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The present work investigates the thermo-protective ablative and dynamic mechanical properties of two kinds of epoxy resin modified with carbon nanotubes (1 vol.% or 5 vol.% of CNT) and homogenized mechanically or ultrasonically. The properties of epoxy nanocomposite samples were compared with nonmodified, cross-linked epoxy resins. Statistical methods for planning the experiments were also employed for investigated properties. All samples with dimensions of 10 x 25 x 35 mm have been subjected to combustion gases (burning mixtures of 35% propane and 65% butane) at a temperature above

1900ºC during 120 seconds. The effects of components on the maximum back side temperature ts_max and the average weight loss Ua under intensive heat flow conditions have been determined together with temperature distribution on the ablation surface of the sample tpa(t) using a thermographic camera. 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 made by epoxy resin called Epidian 5 (cross-linked by curing agent called TFF - triethylenetetramine) and containing 5 vol.% of CNT. The lowest maximum back side temperature ($ts_max = 36,5^oC$) was found in the nanocomposites N. 2 mechanically homogenized. Composite N. 6 was homogenized using ultrasounds and showed the lowest Ua (26,7%). A more stabilized ablative layer and limited erosion were obtained using higher content of CNT and ultrasound homogenization. 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. The samples were subjected to a sinusoidal stress in the dynamic mechanical analysis (DMA). The stress amplitude, deformation amplitude and phase lag were determined as a function of temperature or frequency. Polymer samples were tested for their viscoelastic response including complex modulus (M^*), storage modulus (M'), loss modulus (M'') and damping factor ($tan\delta$) and evaluated for their dependence on the composite components as well as the mixing technique. Dynamic mechanical analyzer measurements were carried out on an Instrument DMA SDTA861, Mettler Toledo. The tests were performed by using a compression deformation mode and also bending in a double-cantilever bending mode at 20°C during 60 minutes a maximum amplitude of the force of 40 N and a frequency 50 of Hz. In the compression mode, the highest value of the complex modulus M^* = 1030 MPa and a very low value of the damping factor $tan\delta$ = 0.02 were shown by the composite N.4 mechanically homogenized (Epidian 601 + TFF + 5% CNT). In the double cantilever bending mode, the highest value of the modulus M^* (ie 1250 MPa) was shown by the composite N.7 (Epidian 601 + TFF + 1% CNT) with the factor of damping $tan\delta$ = 0.05 and which was homogenized by ultrasound. Such values of both parameters prove the high stiffness (high M^*) and high elasticity (low $tan\delta$) of the composites. Both the modified cured resins obtained low values of the complex modulus and high values of the damping factor. This means that the modification with CNT increases the stiffness and elasticity of epoxy nanocomposites. Ultrasonic homogenization facilitates the dispersion of nanofillers in the resin and eliminates the formation of technological blisters, thus improving the mechanical properties of the structure.

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abst. 2089
Repository

Buckling Load Optimization of Straight-Fibre Variable Stiffness Composite Cylinders

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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 use a different approach to design VS composite cylinders, 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 variable stiffness (SFVS) composite laminate. A method developed at TU Delft to design SFVS laminates is modified to optimize the buckling load of composite cylinders. In this method, 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 modified method is applied to optimize the buckling load for composite cylinders. The buckling load of the optimised designs is evaluated using commercial finite element software. The effect of the number of design regions into which the cylinder is divided is considered. To conclude an outlook is given on how the modified method can be applied to the design of aerospace structures.

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