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Book of Abstracts

António J.M. Ferreira

Nicholas Fantuzzi

Michele Bacciocchi

Volnei Tita

Ana Neves

Welcome Address

The abstracts collected in this book represent the proceedings of the conference ICCS25 (25th International Conference on Composite Structures) , 19-22 July 2022. 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 24 editions of ICCS. As the previous ones, this event represents an opportunity for the composites community to discuss the latest advances in the various topics in composite materials and structures.

Conference chairs

António J.M. Ferreira, University of Porto, Portugal

Nicholas Fantuzzi, University of Bologna, Italy

Michele Bacciocchi, University of San Marino, San Marino

Volnei Tita, University of São Paulo, Brazil

Ana Neves, University of Porto, Portugal

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Bending behavior of additively manufactured SiC multilayered composites with porous structure

abst. 1146
Virtual Room 2
Wednesday
July 20
15h30

Zhijuan Zhong (19zjzhong@stu.edu.cn), Shantou University, China
Tao Zeng (taozeng@hrbust.edu.cn), Shantou University, China
Xiaotong Pan (xtpan1272@qq.com), Shantou University, China
Jianhua Wen (19jhwen@stu.edu.cn), Shantou University, China
Siwen Yu (sven.yu@qq.com), Harbin University of Science and Technology, China

SiC multilayered composites with porous structure were additively manufactured using direct ink writing (DIW). SiC multilayered composites with different volume of porosity in each layer were designed and fabricated. The microstructures of the SiC multilayered composites were characterized by a scanning electron microscope (SEM). Three-point bending tests were conducted to evaluate the effects of porosity change patterns on the bending behaviors. Experimental results indicated that the porosity of each layer has obviously influences on the bending strength of the SiC multilayered composites. The bending strength decreases as the index of exponent and power function increases. Elastic and plastic theory were used to predict the bending strength of the SiC multilayered samples with different microstructures by taking into account porosity in each layer. The bending strength predicted by plastic theory is closer to the experiment data than that predicted by elastic theory. This indicates that the SiC multilayered composite with gradient porous structure exhibits an inelastic behavior under bending loadings.

Investigation of the energy absorption capacity of hybrid three-dimensional lattice structures

abst. 1185
Repository

Gharehbaghi, Hussain (h.gharehbaghi@modares.ac.ir), Tarbiat Modares University, Iran
Farrokhabadi, Amin (amin-farrokh@modares.ac.ir), Tarbiat Modares University, Iran

The three-dimensional lattice structures are commonly used in different fields such as aerospace, transportation, and biomedical application because of their useful properties. The rational combination of materials and design has enabled the development of three-dimensional lattice structures with high energy absorption capacity. The present study aims to investigate the mechanical performance and energy absorption capacity of hybrid three-dimensional lattice structures with two materials and a combination of two structures. In the study, the combination of two three-dimensional lattice structures produced by using additive manufacturing with two different materials is proposed for the first time. Experimental and numerical studies have been conducted to analyze the energy absorption properties of a hybrid three-dimensional lattice structure. First, fused deposition modeling was used to manufacture the proposed three-dimensional lattice structures with two polymers. Several samples have been made for compressive testing. Quasi-static compression tests were conducted to analyze the mechanical properties and energy absorption capacity of the hybrid three-dimensional lattice structures. In the numerical study using Abaqus software version 6.14 with an explicit solver, the elasto-plasto-damage behavior was implemented into finite element code which tracks the nonlinear response of considered structures. This model is capable to investigate the differences in tensile and compressive properties

of the polymer materials as well. Due to the difference in compressive and tensile properties of the polymers, using the VUSDFLD subroutine, in the zones which are subjected to compression and tensile stresses, the compressive and tensile properties of the polymer are assigned to the elements respectively. The comparison of the load-displacement response of structures under the compressive loading has been compared. The numerical models exhibit an acceptable prediction about the linear and non-linear responses of the proposed three-dimensional lattice structure. Also, by employing the numerical approach as well as the topology optimization, the optimized three-dimensional lattice structures have been implemented to obtain the maximum stiffness and damage tolerance. The results reveal that not only does the use of hybrid structures provide more energy absorption and improve mechanical performance, but also the rational combination of two materials makes the hybrid three-dimensional lattice structure with the maximum energy absorption and stiffness, in comparison to those usual lattice structures with a single material. This proposed three-dimensional lattice structure would be interesting for multi-functional applications.

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abst. 1212
Room B035
Tuesday
July 19
15h10

EFFECTS OF FIBER DISTRIBUTION AND HEAT TREATMENTS ON THE OUT-OF-PLANE BEHAVIOR OF 3D PRINTED CONTINUOUS FIBER-REINFORCED THERMOPLASTICS

Carlos Medina (cmedinam@udec.cl), University of concepcion, Chile
Rodolfo Hermosilla (rhermosilla2016@udec.cl), University of concepcion, Chile
Andres de la Fuente (adelafuente2016@udec.cl), University of concepcion, Chile
Alexis Salas (alesalas@udec.cl), University of concepción, Chile
Manuel Melendrez (mmelendrez@udec.cl), University of concepción, Chile

Continuous fiber-reinforced 3d printed composite materials are developing technology. It has the facility to manufacture objects with complex geometries that 3D printing offers and with the mechanical properties that composite materials offer, however, they have certain disadvantages, where the main one corresponds to the amount of voids that are generated in these materials, reducing their mechanical performance, especially in the planes where the fiber does not provide resistance, through its thickness. Reducing these voids provides an improvement in the mechanical behavior of these materials. In the present work, mechanical tests are carried out to evaluate laminates the out-of-plane mechanical behavior by varying the number of matrix printed lamina between the continuous fiber reinforcing lamina. Which are evaluated with mechanical tests of out-of-plane tension, out-of-plane compression, and short beam bending. The results showed that the out-of-plane properties increase as the number of matrix laminas increases between the reinforcing laminas. Once the laminate with the best out-of-plane mechanical performance had been determined, the material was subjected to different heat treatments and its effect was evaluated with the short-beam bending test. The thermal treatments carried out are at temperatures of 100, 150, 175, and 200 °C for 1, 3, 6, and 8 hours for each temperature. Additionally, mass changes, dimensional changes, and voids are analyzed by micrographs. Based on the heat treatment, it is obtained by subjecting the 3d printed material to a heat treatment of 175 ° C for 6 hours, which generates an increase of 93.65% in the ILSS compared to the without heat treatment sample. Morphologically, heat treatment produces a negligible both mass loss and dimensional variation when the temperature and time increase. Regarding the voids, the micrographs showed that there is a decrease of up to 50% between the material with treatment vs that without treatment. Finally, the results show that an increment in the number of matrix laminas between reinforced laminas increases the out-of-plane mechanical performance and if the 3d printed composite material has a heat treatment the performance can be further improved due to reduced voids.

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abst. 1218
Repository

EM-absorbing structure with lightning strike protection using 3D printing reinforced method

So-Mang Hong (hope1229@gnu.ac.kr), Gyeongsang National University, Republic of Korea
Van-Tho Hoang (hoangvantho.ntu@gmail.com), Gyeongsang National University, Republic of Korea
Jin-Hwe Kweon (jhkweon@gnu.ac.kr), Gyeongsang National University, Republic of Korea

Radar absorbing structures (RAS) made by fiber-reinforced polymer composites are significantly vulnerable to lightning strikes due to their high electrical resistance compared to metallic materials. Hence, it is essential to consider a lightning protection system to avoid the potential risk of lightning strikes. In this study, RAS reinforced with a 3D printing method was designed and fabricated to protect these limitations in terms of the lightning strike impact damage. Multi-walled carbon nanotubes (MWCNTs) dispersed 3D filament was used as reinforcement in the composite, and metalized fibers were employed as the feedstock of 3D printing to reduce lightning strike damage. After being fabricated by the 3D printing method, the composite laminates were stroke by artificial lightning from an impulse current generator according to the SAE standard. Despite the damage to the laminates, the measured radar absorption performance was maintained. MWCNTs dispersed filament provided conductive paths which contribute to direct current, energy dissipation, and lightning strike protection (LSP) effects. The 3D printing method also achieved a sufficient level of electrical conductivity, which limited the damaged area and the depth of structures from a lightning strike. These findings illustrate that 3D printing RAS reinforced by electrically conductive material could be a promising candidate for a lightning strike protection solution.

Fabrication of Thermoplastic based fibre Composites on 3D Printed Substrate using Infrared based Automated Fibre Placement

abst. 1234
Virtual Room 2
Wednesday
July 20
15h10

Venkatesan, Chadurvedi (chadurvedi@mymail.sutd.edu.sg), Singapore University of Technology and Design, Singapore
Mohammad Faiz (mohammad_faiz@sutd.edu.sg), Singapore University of Technology and Design, Sinagpore
Muhammad Rhidwan (), Singapore University of Technology and Design, Sinagpore
Arlindo Silva (arlindo_silva@sutd.edu.sg), Singapore University of Technology and Design, Singapore

Manufacturing flat structures of carbon fibre reinforced thermoplastic composites with Automated Fibre Placement (AFP) have been proven to be successful. However, thermoplastic composite laminate layups on shapes with higher complexity, via automation, continues to be a major challenge especially when it comes to the tool path strategy planning. Precise robotic programming is necessary for the proper control of AFP during fabrication. In this work, experimental investigations were conducted to establish the ability of an Infrared-based AFP robot to place fibres onto 3D printed structures as its substrate. Fused deposition modelling (FDM) technology was used to manufacture these complex structures, which are made with high performance polymers in order to withstand high temperature and mechanical forces. Pressure distributions were analysed to assess layup quality. The challenges and tool path strategies which come with automated composite fabrication on complex structures are discussed.

Thermoplastic coating on fiber reinforced polymer composites by cold spray additive manufacturing

abst. 1333
Room B035
Tuesday
July 19
16h10

Anni, Ibnaj Anamika (anniib27@students.rowan.edu), Rowan University, United States of America
Kaminskyj, Madison (kamins95@students.rowan.edu), Rowan University, United States of America
Uddin, Kazi Zahir (uddink79@students.rowan.edu), Rowan University, United States of America
Bacha, Tristan (bachat9@rowan.edu), Rowan University, United States of America
Singh, Nand Kishore (singhnk@rowan.edu), Rowan University, United States of America
Stanzione, Joseph (stanzione@rowan.edu), Rowan University, United States of America
Haas, Francis (haas@rowan.edu), Rowan University, United States of America
Koohbor, Behrad (koohbor@rowan.edu), Rowan University, United States of America

Cold spray is emerging as a promising technique for coating and additive manufacturing of polymers and polymer-based composites. One of the most significant advantages of cold spray over other coating methods is its ability to quickly produce thick polymeric coatings on a wide range of substrates, including

but not limited to polymer-matrix composites. This work reports the cold spray coating of nylon 6 on fiber reinforced composite substrates. Deposition conditions are investigated by systematically varying the process parameters (impact velocity, temperature, carrier gas pressure, and flow rate) for two different substrates, woven glass fiber reinforced epoxy polymer (GFRP) and carbon fiber reinforced epoxy polymer (CFRP). Differential scanning calorimetry of the polymer powder is conducted to find a suitable temperature window for deposition. Parametric studies are performed to identify the optimal system pressure and powder flow rates leading to successful deposition of the powder particles on composite substrates. Scanning electron microscopy is used to observe and characterize the microstructural features of the deposited layers. It is observed that, upon impact, the particles undergo severe plastic deformation without damaging the reinforcing fibers in the composite substrate. Microstructural observations also reveal that the first (seeding) layer of nylon particles experience a higher degree of plastic deformation due to the impact on a stiff substrate. The large plastic deformation in the impacting particles plays a key role in enabling the adhesion to the substrate. The successive layers of deposited particles undergo less plastic deformation as these particles impact a comparatively softer layer of pre-deposited nylon. The underlying mechanisms of deposition are further explored using a multiscale finite element analysis. Results obtained in this work 1) demonstrate the feasibility of cold spray deposition of thermoplastic particles on fiber-reinforced composites, and 2) highlight the possibility of using the cold spray process as a promising alternative for repair and surface functionalization of fiber composites without imposing significant damage to the substrate.

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abst. 1344
Room B035
Tuesday
July 19
15h30

Two level homogenisation strategy for identification of thermal properties of composites obtained through additive manufacturing techniques

Catapano, Anita (anita.catapano@bordeaux-inp.fr), Bordeaux INP, I2M Laboratory, France
Izzi, Michele Iacopo (MicheleIacopo.IZZI@ensam.eu), Arts et Métiers Institute of Technology, I2M Laboratory, France
Aufiero, Simone (simauf95@gmail.com), University of Bordeaux, I2M Laboratory, France
Sommier, Alain (alain.sommier@u-bordeaux.fr), University of Bordeaux, I2M Laboratory, France
Pradere, Christophe (christophe.pradere@u-bordeaux.fr), CNRS, I2M Laboratory, France
Montemurro, Marco (marco.montemurro@ensam.eu), Arts et Métiers Institute of Technology, I2M Laboratory, France

Over the past decade, new manufacturing technologies such as additive manufacturing (AM) processes have made remarkable progress such that today researchers are experiencing a kind of paradox. Thanks to AM, it is possible to produce new materials and structures of complex shape, but there is still a lack of relevant mathematical formalism and reliable numerical models that can correctly describe their physical responses (at each scale of the problem) and that can be integrated into dedicated design/optimization strategies. Newer AM technologies such as fused filament fabrication (FFF) combined with continuous filament fabrication (CFF) make it possible to use different combinations of materials for both matrix and reinforcement. The mesostructure of the composite obtained from AM is a very specific one and depends mainly on the printing parameters of the machine such as the tow width and height. The determination of the thermomechanical behaviour of composites obtained by AM at different scales remains an open problem: more precisely the gradients of physical properties as well as anisotropy are the source of a different behaviour from that of conventional laminates. These gradients are due to the FA process, which introduces defects such as structured porosities, reach resin regions, yarns shape and arrangement, etc. Unfortunately, few works focusing on these aspects are available in the literature: these studies present only partial results, which do not satisfactorily describe the influence of defects on the behaviour of the composite. The lack of knowledge on the behaviour of AM composites, in terms of thermomechanical behaviour, constitutes a scientific barrier to be lifted to ensure a broadening of the use of these materials. In the proposed work we deal with the multi-scale modelling of composite materials obtained through AM to identify the thermal properties of each constituent. The proposed strategy is based on the use of experimental measurements of the macroscopic thermal properties of the material obtained through the so-called Flying-Spot infrared thermography. This technique is based on the use of scanning systems based on galvanometer mirrors which allow controlling the displacements of a laser spot over the surface of the specimen. A constant velocity Flying

Spot is used here to measure the in-plane thermal diffusivity of the anisotropic material. Then, these data are used as target to solve an optimisation problem of minimum distance between the macroscopic experimental data and those coming from a numerical two-level homogenisation of thermal properties of the composite. The first-level homogenisation concerns the microscale model of the yarn constituted of carbon-fibres and a thermoset matrix. The second-level homogenisation focuses on the mesostructure of the composite, which is constituted of the homogenised yarns embedded in a thermoplastic matrix. At this scale, the main process-induced defects are represented in the semi-realistic mesostructure, i.e., the structured porosities, the variable shape and arrangement of the yarns as well as the presence of broken yarns. The results of the proposed technique show the effectiveness of the Flying-Spot infrared thermography as a very reliable method to measure in-plane thermal diffusivity of anisotropic materials. Moreover, the two-level homogenisation strategy combined with ad-hoc algorithms for the semi-realistic generation of micro- and mesostructures reveal to be of fundamental importance for the proper identification of constituents properties of complex materials.

Advanced Numerical Techniques

abst. 1019
Repository

Nonlinear responses of bi-stable laminates with simply supported at four corners under impact loads

Y.X. Hao (bimhao@163.com), Beijing Information Science and Technology University, China

In this paper, a four layers asymmetric cross-ply bi-stable laminate composited by the carbon fiber reinforced resin matrix are considered. A novel configuration function that satisfies the simply-supported at the four corners is proposed to predict the equilibrium configuration. Applying the classical deformation plate theory, the von Karman strains, the minimum energy principle, the Newton-Raphson iteration method, the stable-state configurations described by curvature are obtained by checking the stability of each equilibrium solution. The validation is verified by the comparation the present results and those obtained from literatures. The side length-curvature solution curves of the bi-stable laminates and the critical snap through loads are solved. Then, equations of motion demonstrating the nonlinear dynamics of the system that expressed by two curvatures are derived. It is assumed that the incremental load loading, the decreasing loading, the sinusoidal loading, the step loading, the triangular loading and periodic loading are respectively applied on the bi-stable laminate. The snap-through behavior, the intra-well oscillations and inter-wall oscillations are studied by numerical simulation in detail.

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abst. 1061
Virtual Room 2
Tuesday
July 19
15h30

Dynamic response of a sandwich structure with thick-section core in thermal environments with general boundary conditions using variational asymptotic method

Li, Jinming (lijinming7177@126.com), Beijing Institute of Technology, China
Liu, Liu (liuliu@bit.edu.cn), Beijing Institute of Technology, China

A sandwich structure with thin fiber-reinforced composite face sheets bonded to a thick and porous core is used as an integrated thermal protection system (ITPS) for spacecraft reentry, which is generally exposed to dynamic loadings from sources such as jet efflux and turbulent fluid flow in thermal environments. The dynamic characteristics and response of the hybrid structure with general boundary conditions are investigated within the framework of the Reissner-Mindlin plate theory in thermal environments. The effective stiffness matrices including the extensional, coupling, bending, and transverse shear stiffness matrices are determined using the variational asymptotic method without invoking any ad hoc kinematic assumptions accurately. The temperature-dependent material properties for the core and face sheet are considered firstly in the homogenization analysis. The displacement field is expressed in simple algebraic polynomial forms, which can handle general boundary conditions in thermal environments. It is proposed that the static transverse displacement induced by the temperature gradient along the thickness direction can be included by introducing the initial geometric imperfection in the plate model. The convergence of frequencies and model shapes with respect to the number of the terms in the polynomial form of the displacement components are illustrated. The effects of the temperature-dependent properties, the temperature gradient, boundary conditions, and geometric parameters of the ITPS sandwich structure on the dynamic characteristics and response are elaborately investigated.

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abst. 1066
Virtual Room 2
Tuesday
July 19
15h50

Multiscale isogeometric analysis of thick sandwich structures using refined zigzag theory

Kheyabani, Aryan (aryankheyabani@sabanciuniv.edu), Faculty of Engineering and Natural Sciences, Sabanci University, Tuzla, Istanbul 34956, Turkey, Turkey
Massarwa, Eyass (eyassmas@post.tau.ac.il), Faculty of Engineering, Tel-Aviv University, 69978 Tel-Aviv, Israel, Israel
Kefal, Adnan (adnankefal@sabanciuniv.edu), Faculty of Engineering and Natural Sciences, Sabanci University, Tuzla, Istanbul 34956, Turkey, Turkey

Abstract: The complex mechanical behavior of thick composite and sandwich structures necessitates the development of methods for analyzing their structural response accurately in an efficient manner. In this study, a robust and computationally low-cost multiscale analysis approach is developed by integrating the Parametric High Fidelity Generalized Method of Cells (HFGMC) micromechanics and Isogeometric plate formulation based on the Refined Zigzag Theory (IG-RZT), for structural analysis of thick sandwich structures. The primary goal is to eliminate the need for conducting costly and macro-scale experiments necessary for determining orthotropic material properties of composite materials used for the face sheets. To this end, the parametric HFGMC is employed to predict the homogenized behavior of the fiber-reinforced face sheets based on their constituent material properties in the micro-level using a hexagonal repeating unit-cell (RUC) discretized into subcells. On the other hand, the RZT is utilized at the macro level to model a thick structure as a single layer by using kinematic variables through the thickness of the laminate independent of material layers. This efficiency is further improved by leveraging NURBS to model the structure in the macro scale in an exact form without a highly refined mesh; thereby, decreasing the number of degrees of freedom necessary. To assess the efficiency and accuracy of the proposed strategy, various case studies are taken into consideration. A simply supported laminate, under a sinusoidal pressure, with carbon/epoxy face sheets and different stacking sequences is analyzed to demonstrate the applicability of the present approach to layered structures with a high level of heterogeneity and anisotropy. Furthermore, a cantilever laminate composed of glass/epoxy face sheets is considered with different length to thickness ratios to show the suitability to thin/thick structures. Excellent agreements between the obtained results and the 3D reference solutions reveal the computational efficiency, high accuracy, and low cost of the improved approach. Keywords: Isogeometric analysis; multiscale homogenization; refined zigzag theory; composite structures.

Experimental and Numerical Failure Analysis of Thin-Walled Composite Plates Using Progressive Failure Analysis

abst. 1100
Room B032
Tuesday
July 19
12h10

Falkowicz Katarzyna (k.falkowicz@pollub.pl), Lublin University of Technology, Poland
Rozylo Patryk (p.rozylo@pollub.pl), Lublin University of Technology, Poland
Samborski Sylwester (s.samborski@pollub.pl), Lublin University of Technology, Poland
Debski Hubert (h.debski@pollub.pl), Lublin University of Technology, Poland

This study investigates the stability and failure analysis of thin-walled composite plate elements weakened by cut-out and subjected to axial compression. Tested plates were made of carbon fiber reinforced polymer (CFRP) composite material using the autoclave technique. The scope of the research included experimental tests on real samples and numerical calculations with using the finite element method in the ABAQUS® program. Both experimental tests and numerical analysis were performed over the full range of loading until structural failure. In experiments, postbuckling equilibrium paths and acoustic emission signals were measured, which allowed a comprehensive analysis of failure for the composite material. Numerical calculations were performed by progressive failure analysis, based on the initiation of the failure from the Hashin's theory and the further evolution of the failure based on the energy criterion. Numerical results of critical and post-critical state were compare with experimental research showing areas prone to failure of the material. 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 number 030/RID/2018/19).

A ps-FEM approach for the analysis of laminated shells

abst. 1116
Room B035
Thursday
July 21
10h40

Yan, Cheng Angelo (chengangelo.yan@polimi.it), Politecnico di Milano, Italy
Vescovini, Riccardo (riccardo.vescovini@polimi.it), Politecnico di Milano, Italy

Modern aircraft structures are designed with increasing amounts of composite materials in load bearing regions. Therefore, the availability of computational tools that can accurately detect internal load paths and stress distributions is of paramount importance to assist the design phase. In the context

of finite element methods, the p-version Finite Element Method (p-FEM) [1] has been successfully used in many works, see e.g. [2-3]. In this case, the order of interpolation is increased hierarchically with Legendre-based shape functions. This enables the quality of the solution to be improved, without changing the element size or the number of nodes. In general, high-order approximations offer an excellent tradeoff between cpu cost and accuracy of the solution but can be better replaced by low-order piecewise representations in the presence of discontinuities or for nonlinear formulations. For this reason, h-refinement is often considered, which generally requires the generation of time-consuming transition meshes. The mesh superposition technique, or s-version Finite Element Method (s-FEM) [4], has been proposed as a viable mean for overcoming this latter aspect. It is based on the definition of two incompatible meshes, a local and more refined mesh, which is overlaid on the global and coarser mesh, thus allowing for h-refinement to be performed straightforwardly in selective areas. In this work, an advanced numerical tool is presented, which combines the possibility of refining the solution both via p- and s-refinement (ps-FEM), thus avoiding the need to generate transitions between the coarser and finer meshes. Local effects in regions of interest – e.g., free edges, cutouts, sharp corners – can be investigated with relative ease by applying locally p- or s-refinement, or both simultaneously. This is achieved without the need of regenerating the global mesh, but by adding progressively higher-order terms in the polynomial expansion of the elements (p-refinement) and through hierarchical augmentation of the global stiffness matrix with the contribution of the local mesh (s-refinement). A finite element code based on a ps-FEM formulation which implements hierarchical shell elements is presented for the analysis of laminated composite structures. The hierarchical feature of the method allows for global/local analysis to be performed with reduced modeling effort, as well as cpu cost. Exemplary numerical tests are presented to demonstrate the potential of the approach in capturing very localized effects. Composite laminates with straight- and curvilinear-fiber configurations, see [5], are considered for this scope and results are compared with Abaqus finite element computations. References: [1] I. Babuska, B.A. Szabo, and I.N. Katz. "The p-version of the finite element method." SIAM Journal on Numerical Analysis, Vol. 18, No. 3, pp. 515-545, 1981. [2] H. Akhavan, P. Ribeiro and M.F.S.F. de Moura. "Large deflection and stresses in variable stiffness composite laminates with curvilinear fibers". International Journal of Mechanical Sciences, Vol. 73, pp. 14-26, 2013. [3] S. Yazdani and P. Ribeiro. "Geometrically non-linear static analysis of unsymmetric composite plates with curvilinear fibers: p-version layerwise approach". Composite Structures, Vol. 118, pp. 74-85, 2014. [4] J. Fish and S. Markolefas. "The s-version of the finite element method for multilayer laminates". International Journal for Numerical Methods in Engineering. Vol. 33, pp. 1081-1105, 1992. [5] Z. Gurdal and R. Olmedo. "Composite laminates with spatially varying [U+FB01]ber orientations: Variable sti[U+FB00]ness panel concept". Structural Dynamics and Materials Conference, Vol. 2472, 1992.

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abst. 1145
Repository

Research on the resistance of an orthotropic composite to the pressures caused by mechanical fasteners

Zakaszewska, Angelika (Angelika.Zakaszewska@wat.edu.pl), Military University of Technology, Poland
Godzimirski, Jan (Jan.Godzimirski@wat.edu.pl), Military University of Technology, Poland
Komorek, Andrzej (komman@op.pl), Polish Air Force University, Poland

Composite materials are widely used in many industries today. One of the problems with the use of these materials is the bonding of composite parts to each other as well as to metal parts. Gluing alone often does not provide sufficient strength, therefore they are replaced or reinforced (hybrid joints) with mechanical fasteners. Mechanical fasteners require holes that weaken the composite by reducing the cross-section and causing stress accumulation and transferring the load in the form of pressures on the walls of the opening. The aim of the research was to estimate the permissible pressures on the walls of the holes of the polymer carbon composite with orthotropic properties. Additionally, an attempt was made to estimate the value of the notch action factor influencing the static strength of the tested composite and to assess its sensitivity to the concentration of stresses caused by the opening for a mechanical connector. Although the tensile strength of the tested orthotropic composite material as well as its modulus of longitudinal elasticity were significantly dependent on the direction of the reinforcement arrangement, the values of the destructive pressures tested in different directions were comparable, of the order of 500 MPa. It has also been shown that due to the pressure, the centers

of the openings for mechanical fasteners should be moved away from the edge of the composite by a greater distance than when connecting metal parts. The estimated coefficient of notch action in the form of a 4 mm diameter hole, affecting the static strength, was about 1.255 for the material tested in the direction of fiber alignment and 1.085 for the material tested at the angle of 45°.

HOHWM for vibration, bending and buckling analysis of composite and nanostructures

abst. 1164
Virtual Room 2
Tuesday
July 19
16h50

Majak, Jüri (juri.majak@taltech.ee), Tallinn University of Technology, Estonia
Mehrparvar, Marmar (marmar.mehrparvar@taltech.ee), Tallinn University of Technology, Estonia
Arda, Mustafa (mustafa.arda@taltech.ee), Trakia University, Tallinn University of Tehnology, Turkey

Study is focused on development and application of the higher order Haar wavelet method (HOHWM) for structural analysis of composite and nanostructures. The HOHWM has shown high accuracy and good performance, but its application is limited to simpler problems like Euler-Bernoulli beams, ordinary differential equations with constant coefficients, etc. The effect of graded materials and different shear deformation theories applied, nonlocal effect, etc. need further attention. The accuracy, computational and implementation complexity need integrated approach. A number of case studies are considered covering FGM structures, nanostructures and FGM nanostructures. IN the case of all case studies the HOHWM has found as principal improvement of widely used HWM providing higher convergence rate, accuracy with marginally increased computational complexity. Extra challenge is extension of the HOHWM for solving fractional differential equations covering behavior of viscous materials.

Prediction of stress-strain behavior of fiber-reinforced woven composites via deep neural network

abst. 1173
Virtual Room 2
Tuesday
July 19
15h10

Dug-Joong Kim (kdj9207@gmail.com), Hanyang University, South Korea
Jeong-Hyeon Baek (jhbaek9489@gmail.com), Hanyang University, South Korea
Hak-Sung Kim (kima@hanyang.ac.kr), Hanyang University, South Korea

Recently, fiber reinforced composites have been widely applied for structural components in a various industry such as automotive, aerospace and marine due to their high strength and stiffness to weight ratio. Especially, woven composites have received increasing attention owing to their superior out-of-plane stiffness, toughness and manufacturability. To design and manufacture reliable composite structures, it is essential to analyze and predict the mechanical properties of woven composite materials. However, it still has difficulty to predict it due to its complexity of geometries and many factors affecting mechanical properties such as fiber volume fraction, strength of fiber and yarns, and yarn geometries. In the past decade, finite element simulation based on micro-mechanics have been developed to predict composite properties [1, 2]. It has been a promising method because composite properties could be cost-effectively predicted without experimental. Even though various simulation methods have been developed, it is still hard and costly because many simulations were demanded to predict each case which have a lot of variables. In this study, the deep-learning based prediction method for stress-strain curves of woven composites was developed by training multiscale simulations. For multi-scale simulation, the micromechanics failure criteria are assigned to each constituent. Then, the stress amplification factor (SAF) is adopted to transfer stress between micro and meso-scale simulation. In order to construct database for multi-scale simulation, stress-strain curves were obtained depending on composite structures (yarn width, space, height, and volume fraction) and mechanical properties of fiber and matrix. Consequently, database of multi-scale simulation was trained by deep-neural network (DNN). DNN used structures and mechanical properties of constituents as training input and stress-strain curve as training output. For cost-effective training, the number of points on the stress-strain curve was encoded by principal component analysis (PCA) to reduce the model size and computing time. Finally, the prediction of the stress-strain curve by DNN only takes 2 seconds which is far shorter than conventional FEM-based simulation, which accompanies complex procedures (modeling, meshing, calculating,

and etc.). Acknowledgments: This research was supported by Korea Institute of Energy Technology Evaluation and Planning(KETEP) grant funded by the Korea government(MOTIE)(20202020800360, Innovative Energy Remodeling Total Technologies(MV, Design, Package Solutions, and Testing Verifications Technologies) for the Aging Public Buildings). Reference: [1] Hwang, Y. T. et al., 2019, "Prediction of Non-linear mechanical behavior of shear deformed twill woven composites based on a multi-scale progressive damage model," Composite Structures, Vol. 224, No. 15, pp. 111019. [2] Ha, S. K. et al., 2008, "Micro-Mechanics of Failure (MMF) for Continuous Fiber Reinforced composites," Journal of Composite Materials, Vol. 42, No. 18, pp. 1873 1895.

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abst. 1182
Repository

Feasibility study of a jib crane using steel, aluminium and two composite materials.

Solazzi, Luigi (luigi.solazzi@unibs.it), Dipartimento di Ingegneria Meccanica e Industriale, Università di Brescia, Italy
Vaccari, Marco (m.vaccari001@studenti.unibs.it), Dipartimento di Ingegneria Meccanica e Industriale, Università di Brescia, Italy

The aim of this research is to design a jib crane by implementing innovative materials such as composite materials. The purpose is to evaluate the increase in the performance of a crane by adopting composite materials instead of the classic construction steel used to build the structure. The study is developed in a first analytical part and a subsequent numerical part, developed through finite element analysis. In particular, in the first phase, a jib crane is dimensioned with a load capacity of 500kg, a 5m long arm and the column has a height such that the altitude under the hook is 4m. The sizing was developed considering several aspects. First of all, the value of the maximum stress and therefore the relative safety coefficient is sufficiently high, thus also incorporating overstresses induced by the dynamic effects generated by the movement of the load or of the crane arm. Subsequently, the axial and flexural-torsional instability for the column and arm. The last parameter assumed, which proved to be the most binding, is the maximum displacement in correspondence to the load positioned at the end of the arm; at a regulatory level, this value must be lower than a reference value related to the length of the arm, the maximum permissible displacement, considering only the arm, was equal to 1/1000 of the useful length of the arm; also considering the contribution induced by the compliance of the column, this value was reduced to 1/100 of the length of the arm. The extent of these parameters was adopted as a lower constraint for the sizing of the new crane. This choice was compiled in order to obtain as a final product a structure with the same performance as the one designed in steel and which is reflected in those currently made of steel and currently on the market. The materials used for sizing and checking the crane are classic S275 construction steel, 6061 T6 aluminium and two composite materials, such as glass and carbon fibre-based composites. For the development of the new composite solution (glass and carbon fibers) it was decided to adopt a material already present on the market. This choice derives from the fact that on the market there are already products made with this material, essentially plates, plates and tubular. The construction of the crane, therefore, passes from the dimensioning of sections made up of slabs and assembled in some areas by bolting, while in others by gluing. From the preliminary results, it clearly emerges that the main constraint, in the use of composite materials and in particular in glass fiber instead of the classic construction steel, is given by the limitation of the bending. In fact, the pultruded composite materials, in general, have both a significant reduction in density and flexural stiffness related to Young's modulus. The reduction in the overall weight of the structure (column and arm) is very significant, which in the face of a capacity of 500kg goes from about 1100kg for the steel structure to about 800kg for the aluminium one, to about 700kg for the one in glass fibers at about 250kg for the one in carbon. In other words, the crane made of carbon fiber has about 21.5% of the weight of the one made of steel. In view of these excellent results, the study is under development both for the construction details for the purpose of creating specific components for the subsequent experimental tests and to generalize the results to other lifting equipment.

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abst. 1190
Poster

Numerical analysis of bridged-crack in concrete

Upnere Sabine (sabine.upnere@rtu.lv), Riga Technical University, Latvia

The study describes the development of a numerical model to investigate the formation of cracks in cement reinforced with basalt fibers. An open-source computing platform has been used to solve mathematical equations. Numerical models are created using finite element code. They take into account the bridging effects of the fibers, which significantly affect the crack opening and propagation in the brittle-matrix fiber-reinforced element. A four-point bending test is analyzed. The obtained numerical results are compared with laboratory experiments.

Non-ordinary state-based Peridynamics for fracture analysis of functionally graded structures

abst. 1204
Room B035
Tuesday
July 19
17h30

Vieira, Francisco (francisco.sousa.vieira@tecnico.ulisboa.pt), IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Portugal
Araujo, Aurelio (aurelio.araujo@tecnico.ulisboa.pt), IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Portugal

In Peridynamics (PD) the natural appearance of cracks and their propagation is allowed due to the nonlocal character of this theory. The classical partial differential equations are reformulated into integro-differential equations, which also makes this theory easy to implement numerically using meshless point colocation schemes. As it is well known there is high interest in the prediction of damage in composites, including functionally graded materials and structures. Due to its characteristics, PD is a very good candidate to solve this class of problems. Non-ordinary state-based (NOSB) PD is a special kind of peridynamic models as they can recast local continuum mechanics models through the so called correspondence models. Up to date, to the authors' knowledge, no publication in the known literature has addressed FG structures using NOSB PD. This work presents a NOSB PD approach to the analysis of functionally graded structures. A bond-associated stabilization technique is used and the influence of the discretization parameters is studied. An implicit peridynamic model is used in quasi-static crack propagation analyses which guarantees equilibrium when convergence is reached. Two different benchmark tests are presented as well as other more practical examples. Results illustrate the performance of these models and compare successfully against reference solutions.

HOHWM for solving fractional differential equations. Applications to composite structures

abst. 1206
Virtual Room 2
Tuesday
July 19
17h10

Mehrparvar, Marmar (marmar.mehrparvar@taltech.ee), Tallinn University of Technology, Estonia
Majak, Jüri (Juri.Majak@ttu.ee), Tallinn University of Technology, Estonia
Arda, Mustafa (mustafa.arda@taltech.ee), Tallinn University of Technology, Estonia
Karjust, Kristo (kristo.karjust@ttu.ee), Tallinn University of Technology, Estonia

Nowadays, fractional calculus appears in wide range of engineering applications covering description of the stress-strain relationship for viscoelastic materials, fractional dumping, fractional non-local material models, etc. According to PJ.Torvik and RL. Bagley: The fractional derivative appears naturally in the behavior of real materials. Thus, there is some basis for suspecting that the utility of constitutive relationships involving fractional derivatives for describing the behavior of real materials may not be just a happy coincidence. In the current study, the higher order Haar wavelet method (HOHWM), introduced recently by authors, is extended for solving fractional differential equations. The Caputo derivative based approach is utilized. Several algorithms for wavelet expansion and for determining compulsory integration constants are derived. The case studies considered cover local and nonlocal FGM structures.

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abst. 1215
Virtual Room 2
Tuesday
July 19
16h10

Prediction of Transverse Permeability of Unidirectional Fiber Reinforced Composites with Electric-Hydraulic Analogy

Bae, Sangyoon (sybae36@kaist.ac.kr), Korea Advanced Institute of Science and Technology, Republic of Korea
Jo, Hyeonseong (hyeonseongjo@kaist.ac.kr), Korea Advanced Institute of Science and Technology, Republic of Korea
Kim, Seong Su (seongsukim@kaist.ac.kr), Korea Advanced Institute of Science and Technology, Republic of Korea

Continuous fiber reinforced composites are applied to various fields, such as aerospace, automobiles, and sports industries because of their high specific stiffness and strength compared to conventional materials for weight reduction. However, voids generated during the composite material manufacturing process are a key issue that must be resolved for reliability design in the application fields. To minimize the defects in composite materials, understanding the flow of resin during the fabrication process is very important. In the transverse direction, the flow path is more sensitive to the fiber arrangement and the permeability has a high coefficient of variation at different representative volume element (RVE) of the same fiber volume fraction. This study suggests the prediction algorithm for transverse permeability of unidirectional continuous fiber reinforced plastics (CFRP). The cross-sectional shape of RVE is considered to reflect fiber arrangement. The valid fiber pairs having flow resistance are selected and the distance between them are used as a factor to quantitatively express the resistance of resin flow in RVE. The equivalent length is used as a factor to express the change of resin flow according to fiber arrangement. The permeability prediction code is created by grafting the Electro-Hydraulic analogy. Transverse permeability of CFRP is calculated from various fiber volume fraction of RVEs and compared with the results of computation fluid dynamics (CFD) simulation. The code for permeability prediction was composed of MATLAB and Python, the CFD simulation was performed by using ANSYS Fluent.

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abst. 1294
Room B035
Tuesday
July 19
15h50

Influence of post-consolidation to remove void content on material properties of continuous carbon-fibre reinforced additively manufactured specimens in tensile and bending testing

Sieberer, Stefan (stefan.sieberer@jku.at), Johannes Kepler University Linz, Austria
Savandaiah, Chethan (c.savandaiah@wood-kplus.at), Wood K Plus - Kompetenzzentrum Holz GmbH, Austria
Schagerl, Martin (martin.schagerl@jku.at), Johannes Kepler University Linz, Austria

Continuous carbon-fibre (CCF) additive manufacturing (AM) of composite structures has significant potential for production of optimised structures. Fibres can be placed in direction of load paths and variation in the curvature and density of fibres is possible. Optimal design depends on knowledge of material properties of the final structure, and despite the availability of manufacturer data on material stiffness and strength, the printed part is subject to some process variation which is not considered in the data of single fibre filament. In this study, tensile and 4-point bending testing of printed CCF AM specimens is performed according to ASTM standards for samples printed on a commercially available AM printer system with proprietary fibre material used. The specimens were tested (i) as-printed and (ii) after a post-consolidation step, which consisted of compaction pressing under elevated temperatures in order to reduce the process induced void content of the printed specimens. Although not required as post processing for thermoplastic composite, the post-consolidation can reduce process-induced voids in the printed parts and improve upon consistency of standardised print quality for upscale series production. Test results show consistent results for stiffness and strength in fibre direction within the samples with only small standard deviation. In contrast to previous results obtained with CCF from a different manufacturer, there is only small gain from the post-consolidation step on the material properties elastic modulus in fibre direction and strength in fibre direction. This is potentially because of the initially already low void contents in the printed specimens. Differences between the tensile and the bending test methods show up in both, modulus and strength results. The differing results are a

consequence of the specimen printing layout and the method of load introduction to the tensile and bending specimens. The results show that more realistic results for modulus are obtained by tensile testing, and better estimation of the strength by bending testing. Correction factors can be introduced to better compare both methods. In conclusion, the difference between as-printed and post-consolidated specimens of one CCF AM material is shown and discussed, and two testing methods are compared. Either of the two test methods may be used for printed material property evaluation, however the tensile test is better suited for modulus estimation, whereas the bending test can give better results for strength of the printed material.

A meshless crack propagation algorithm extended to mode II loading of adhesive joints

abst. 1298
Virtual Room 2
Tuesday
July 19
17h30

Gonçalves, Diogo (costa.goncalves.diogo@gmail.com), Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial, Portugal
Sánchez-Arce, Isidro (isidrodjsa@gmail.com), Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial, Portugal
Ramalho, Luís (lramalho@inegi.up.pt), Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial, Portugal
Campilho, Raul (raulcampilho@gmail.com), Instituto Superior de Engenharia do Porto, Portugal
Belinha, Jorge (job@isep.ipp.pt), Instituto Superior de Engenharia do Porto, Portugal

A fracture propagation algorithm is extended to the mode II fracture propagation in adhesively bonded joints. Therein, End Notched Flexure (ENF) specimens bonding aluminium adherents with the brittle AV138® adhesive were experimentally tested to characterize the adhesive joint and validate the numerical application. Regarding the numerical analysis, the Radial Point Interpolation Method (RPIM), a meshless method, is considered to obtain the specimen's mechanical response at each crack tip increment. Using the RPIM allows a flexible discretization of the problem domain with a set of unstructured nodes, providing accurate and convergent structural analyses. Additionally, meshless methods expedites the development of the geometric crack tip propagation algorithm. The present numerical application demonstrates the proficiency of the present fracture propagation algorithm to analyse the mode II fracture propagation in adhesively bonded joints.

Modeling Crash Safety of Lithium Batteries, from Electrodes to Battery Packs

abst. 1351
Room B035
Tuesday
July 19
17h10

Sahraei, Elham (elham.sahraei@temple.edu), Temple University Electric Vehicle Safety Lab, United States
Gilaki, Mehdi (mehdi.gilaki@temple.edu), Temple University Electric Vehicle Safety Lab, United States

Lithium-ion batteries have been used extensively in the past decade in a variety of applications from portable devices to airplanes and electric vehicles. Battery packages used in electric vehicles experience dynamic loadings, shocks, and large deformations during normal operation as well as in a crash scenario. It is of paramount importance to battery manufacturers and the automotive industry to better understand how the cells deform under such loadings and what conditions might damage a cell and lead to failure. This talk will focus on the experimental methods used to characterize material properties of lithium-ion batteries under large mechanical loading. Then deployments of these material models for simulating crash response of batteries will be discussed. The models that will be discussed are capable of predicting the profile of deformation and the onset of short circuit in batteries in the cases of mechanical abusive loads.

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abst. 1370
Room B035
Tuesday
July 19
16h30

Establishing properties of the SVE boundary in computational homogenization of random media.

Wojciechowski, Marek (mwojc@p.lodz.pl), Lodz University of Technology, Faculy of Civil Engineering, Architecture and Environmental Engineering, Poland

The paper is related to the concept of generalized boundary conditions (GBC) used for identifying the effective behavior of random composites. With the GBC approach, the apparent macroscopic properties of the composite are computed numerically, by applying a combination of minimal kinematic and spring-like boundary conditions on the statistical volume elements (SVEs). The results computed on the set of realizations of SVEs are then properly averaged. Such an approach has a couple of advantages: it provides intermediate homogenization results, located between the usual uniform kinematic and uniform static loading, no periodicity assumptions are made on the geometry, and a single parameter can be adjusted to achieve good homogenization results, even for small SVEs [1]. One of the challenging tasks when using this method is establishing the material constants for the boundary springs-like constraints. This is done primarily by exploiting the local information about the material the boundary crosses. However, the other option is to use the self-consistent approach, where the spring constants are computed using the "homogenized" material parameters. Both approaches will be presented and discussed and illustrative numerical examples will be given. Also, some comparisons with other numerical homogenization methods will be presented. References: [1] M. Wojciechowski "On Generalized Boundary Conditions for Mesoscopic Volumes in Computational Homogenization", Composite Structures, in revise.

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abst. 1372
Room B035
Tuesday
July 19
16h50

Numerical and experimental studies of the influence of curing and residual stresses on buckling in thin-walled, CFRP square-section profiles

Paweł Czapski (pawel0czapski@gmail.com), Lodz University of Technology, Poland

The study provides the first comprehensive experimental and numerical study of thin-walled, carbon fibre square-section columns subjected to static compression. The profiles were manufactured from unidirectional prepreg tape of Hexcel AS4 high-strength carbon fibres in HexPly® 8552 thermoset resin with ply angles [45/−45/45/−45]s. The dimensions of the columns were: (height × width × length) 80 mm × 80 mm × 240 mm and the wall thickness was 0.92 mm. Advanced Finite Element Models (FEM) of the residual stresses generated during production were used as a basis for simulations of static compression. The deformation predicted by these models showed excellent agreement with 3D scans of the columns. These results also highlighted the residual stress concentrations generated at sample corners during production. It was found that the residual stresses from the autoclaving process significantly enhance the buckling load performance (by 35%) and that the models provide an effective comparison with the experimental results (<10% error). This demonstrates the importance including residual stresses in FEM of buckling, but also highlights residual stress tailoring as a route to significantly enhance the buckling load capacity of carbon fibre systems used in industrial applications.

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abst. 1414
Virtual Room 2
Wednesday
July 20
10h40

GEOMETRICALLY EXACT FINITE-ELEMENT ANALYSIS FOR MICROSTRUCTURED COMPOSITE AS COSSERAT CONTINUUM

Shi, Farui (), State Key Laboratory of Coal Mine Disaster Dynamics and Control, Chongqing University; School of Resources and Safety Engineering, Chongqing University, Chongqing; DICAM Department, University of Bologna, China; Italy
Fantuzzi, Nicholas (nicholas.fantuzzi@unibo.it), Dicam Department, University of Bologna, Italy
Li, Yong (), State Key Laboratory of Coal Mine Disaster Dynamics and Control, Chongqing University; School of Resources and Safety Engineering, Chongqing University, China
Trovalusci, Patrizia (patrizia.trovalusci@uniroma1.it), DISG Department, Sapienza University of Rome, Italy
Wei, Zuoan (), State Key Laboratory of Coal Mine Disaster Dynamics and Control, Chongqing University; School of Resources and Safety Engineering, Chongqing University, China

The non-local effect related to the microstructures becomes vital nowadays, due to the increasing usage of microstructured materials such as lightweight concrete and honeycomb materials. Most of such composite materials and structures result in having a nonlinear behavior under applied loads. Therefore, it is aimed to investigate the geometrically exact behavior of the anisotropic material with microstructures. The total Lagrangian finite element formulations are employed for a nonlinear anisotropic Cosserat continuum. The obtained results are compared to the results of the corresponding nonlinear anisotropic Cauchy continuum and linear results of the two models are also presented. Different equivalent anisotropic materials are used by homogenizing a composite consisting of different hexagonal microstructured geometries. The scale effect, which only appears in Cosserat model, is also investigated by changing the size of microstructures with respect to the macro scale. A 2D plane cantilever beam problem is analyzed. The results show that both nonlinear Cosserat and Cauchy models can produce a more realistic behavior, especially for the large deformation case. A scale effect occurs for the microstructures analyzed using Cosserat theory. Cosserat and Cauchy models have similar behaviors for the smaller scales, as the scale increases, the difference between these two models becomes larger. Different anisotropic materials show different nonlinear behaviors due to their peculiar constitutive behaviors. In the present analysis, different nonlinear load-displacement curves are carried out according to material scales and microstructures. These curves appear to be slightly nonlinear or highly nonlinear according to the theory and material configuration selected. Convergence and accuracy of the present nonlinear total Lagrangian finite element implementation demonstrates to be valuable for the solution of the present problems. Keywords: Geometrical nonlinear; Cosserat theory; Total Lagrangian formulation; Anisotropic material; Scale effect

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Analysis of Wood and Natural Fibre Composites

abst. 1101
Room B035
Tuesday
July 19
12h50

Numerical modelling of bending properties of 3D-printed biocomposites

Zarna, Chiara (chiara.zarna@ntnu.no), Norwegian University of Science and Technology, Norway
Chinga-Carrasco (gary.chinga.carrasco@rise-pfi.no), RISE PFI AS, Norway
Echtermeyer, Andreas T. (andreas.echtermeyer@ntnu.no), Norwegian Univeristy of Science and Technology, Norway

Biocomposite, lightweight products could be a more sustainable alternative to conventional products made from fossil-based materials. Wood fibres are cost-efficient, lightweight, renewable and can serve as reinforcement or filler material for thermoplastic biopolymers. Wood fibre reinforced biopolymers can be processed via 3D-printing. Fused deposition modelling (FDM) is the most used 3D-printing technique for processing biocomposites. FDM is highly flexible, comparatively fast, and affordable. Therefore, FDM is most applicable for prototyping, design evaluations and testing of complex structures. In this work recycled wood fibre-PLA/PHA (30/70 wt.%) filament was used to print dogbone and cylindrical specimens for material characterization based on tensile and compression test. As an application example, biocomposite plates were FDM-printed in one piece and 3-point-bending tested. Such plates could serve as primarily test specimens for evaluation of different product designs. The bending properties of the FDM-printed plate was also modeled by FEA using material data obtained from the physical tensile and compression tests. Three different material models were used for the FE analysis. An isotropic linear elastic, a hyperelastic and a bi-modular material model were compared. For validation of the three models, the physical 3-point-bending tests of the FDM-printed plates were used. When comparing the three material models, the bi-modular material model turned out to be the most accurate one. The error between the simulation results and results obtained from physical tests where about 2% for calculating the flexural modulus. The linear elastic and hyperelastic material models overestimated the flexural stiffness significantly. FDM-printed structures tend to have a lower elastic modulus in compression than in tension. This is most likely caused by voids created during the printing process. Having a good model that predicts performance based on basic data allows exploring other designs with fairly good confidence without testing.

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abst. 1107
Repository

Novel hybrid polymer adhesives for laminated materials based on hardwood

Holeček, Tomáš (holecekt@fld.czu.cz), Czech University of Life Sciences Prague, Czech republic
Sikora, Adam (sikoraa@fld.czu.cz), Czech University of Life Sciences Prague, Czech republic
Cvejn, Daniel (cvejnd@fld.czu.cz), Czech University of Life Sciences Prague, Czech republic
Mitterpach, Jozef (mitterpach@fld.czu.cz), Czech University of Life Sciences Prague, Czech republic
Šedivka, Přemysl (sedivka@fld.czu.cz), Czech University of Life Sciences Prague, Czech republic
Lexa, Martin (lexa@fld.czu.cz), Czech University of Life Sciences Prague, Czech republic
Niemz, Peter (peter.niemz@bfh.ch), ETH Zürich, Switzerland
Sandberg, Dick (dick.sandberg@ltu.se), Luleå University of Technology, Sweden
Źółtowska, Sonia (zoltowska@fld.czu.cz), Czech University of Life Sciences Prague, Czech republic

Gluing hardwood with standard adhesives often appears problematic; therefore, their broader use in practice is limited. On the other hand, using hardwood in laminated beams would be undoubtedly beneficial because mechanical properties would reduce construction dimensions compared to commonly used materials. The highly heterogeneous and porous structure of the hardwood surface as well as high tannin content in heartwood, restrict the use of standard structural PUR adhesives. Using modified adhesives is one of the possibilities to overcome these problems. This work deals with the application of two PUR adhesives based on polymetric polymeric methylene diphenyl diisocyanate ($C15H10N2O2$) and polymeric hexamethylene diisocyanate ($C8H12N2O2$) into the composition of layered wood-based materials. For these specific PUR adhesives, was used four different methods of application of thermosets (without, in the form of a fine powder, together with deep penetration based on acrylate in the liquid and cured state). Such a combination of particular adhesive with thermoset increases adhesive parameters, especially for hardwood. Above glass transitions point Tg of the thermoset resin, a 3D network between thermoset and particular PUR is formed as a novel species which appears highly thermally

and adhesively stable. This protocol has been verified on glued surfaces of several difficult-to-glue types of wood such as oak (Quercus robur), beech (Fagus sylvatica), and Acacia (Robinia pseudoacacia). Contact profilometer measurements followed by the analysis of the depth of adhesive penetration using an electron microscope were the main methods to characterize the junction. A tensile shear strength test using a joint test according to European norm EN 302-1 was used to determine the mechanical properties of the adhesives used. The results of tensile shear strength tests are determined based on the classification standard EN 15425. Based on the collected results, it is possible to confirm the positive effect of adhesives modified by thermosets on the overall strength of the glued joints in the longitudinal direction of the laminates. The work results show that the modified PUR adhesives can be used for gluing difficult-to-glue wood in the composition of glued laminated beams.

Mechanical characterization and modelling of poplar plywood.

abst. 1128
Room B035
Tuesday
July 19
13h10

PEIGNON Axel (peignon.axel@gmail.com), Université de Toulouse, Institut Clément Ader (UMR CNRS 5312), France
CASTANIE Bruno (bruno.castanie@insa-toulouse.fr), Université de Toulouse, Institut Clément Ader (UMR CNRS 5312), France
EYMA Florent (florent.eyma@iut-tarbes.fr), Université de Toulouse, Institut Clément Ader (UMR CNRS 5312), France
CANTAREL Arthur (arthur.cantarel@iut-tarbes.fr), Université de Toulouse, Institut Clément Ader (UMR CNRS 5312), France
SERRA Joel (joel.serra@isae-supaero.fr), Université de Toulouse, Institut Clément Ader (UMR CNRS 5312), France

The application of wood in the transport industry is not recent [1] but it could become a solution to modern environmental issue. Thanks to its lower cost and its low carbon footprint, wood might be a good alternative to many materials [2]. However, due to its nature, its mechanical properties are heterogenous the dispersions of its properties are expected [3]. It is therefore essential to remove all doubts related to the use of wood as a structure material in transportation like automotive [4] or aircraft [5]. In order to continue the work carried out by the ICA members since 2014 [6], a tensile test campaign on poplar layers is performed. This campaign aims to understand and identify the mechanical properties of poplar and its behaviour or not as a laminate material. 130 specimens with various stacking were made: [0°], [0°]2, [0°]3, [90°]2, [90°]3, [45°]2, [45°]3 and [0°/90°/0°]. These tensile tests highlight the effect of the adhesive on the mechanical properties and failure modes of the specimens. The results are compared with the literature [7], while highlighting the dispersion present in such a laminate. In addition, the use of image correlation to find the average orientation of the plies is used in order to link it to the dispersion of the measured mechanical properties and develop an enhanced finite element model.
References: [1] B Castanié, C Bouvet, M Ginot. Review of composite sandwich structure in aeronautic applications. Composites Part C: Open Access, 2020, 100004. [2] C. Mair-Bauernfeind, M. Zimek, R. Asada, D. Bauernfeind, R. Baumgartner, et T. Stern, « Prospective sustainability assessment: the case of wood in automotive applications », The International Journal of Life Cycle Assessment, vol. 25, p. 2027-2049, oct. 2020, doi: 10.1007/s11367-020-01803-y. [3] R Guélou, F Eyma, A Cantarel, S Rivallant, B Castanié. Crashworthiness of poplar wood veneer tubes. International Journal of Impact Engineering, Volume 147, January 2021, 103738 [4] https://woodcar.eu/ [5] https://aura-aero.com/ [6] J. Susainathan, F. Eyma, E. DE Luycker, A. Cantarel, et B. Castanie, Numerical modeling of impact on wood-based sandwich structures, Mechanics of Advanced Materials and Structures, vol. 27, n[U+1D52] 18, Art. n[U+1D52] 18, sept. 2020, doi: 10.1080/15376494.2018.1519619. [7] R. J. Ross et F. P. Laboratory. USDA Forest Service., Wood handbook: wood as an engineering material, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI, FPL-GTR-190, 2010. doi: 10.2737/FPL-GTR-190.

Applications of Composites

abst. 1047
Virtual Room 2
Thursday
July 21
09h40

Strengthening of RC Beams using SRG: Effect of Flexural SRG Strengthening on the Shear Contribution of Concrete

Wakjira, Tadesse (twakjira@qu.edu.qa), Qatar University, Qatar
Ebead, Usama (uebead@qu.edu.qa), Qatar University, Qatar

The amount of internal longitudinal reinforcement influences the shear capacity of reinforced concrete (RC) beams, particularly, the contribution of concrete to the shear capacity of the beam, Vc. Besides, flexural strengthening of RC beams using inorganic composites; particularly, steel reinforced grout has been shown to enhance the flexural capacity and stiffness of the strengthened beams. However, the effect of flexural strengthening on the shear capacity of RC beams strengthened with inorganic composites has not yet been examined. Therefore, the current study aims to investigate the effect of external flexural reinforcement (SRG) on the shear capacity of RC beams deficient in shear. This will examine the efficacy of SRG bonded to the soffit of the beam particularly when the sides of the beams are not accessible. Hence, twelve RC beams without stirrups, which were divided into three groups based on their internal longitudinal reinforcement ratio were constructed and tested under a three-point bending test to investigate the effect of flexural strengthening on the shear capacity of the strengthened beams. Besides, the effect of the reinforcement ratio of SRG as external flexural reinforcement was investigated. The test results showed a significant effect of the external flexural reinforcement on the shear capacity of the strengthened beams. Up to 58% increase in the shear capacity, Vc, of the strengthened beams over the control beam was observed. Finally, an analytical model was proposed to predict the shear capacity of the strengthened beams considering the effect of external flexural reinforcement.

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abst. 1177
Repository

Evaluation of the effect of different physiotherapy activities on 45o tibial oblique fracture when fixed with composite and metallic implant

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

Tibia is a long bone that carries most of the weight during daily activities while tibial fractures are the most common type of fractures. While the healing period of the tibia is around 4 months which does not guarantee complete healing of the fractured region. Composite implants due to their tunable mechanical properties provide better healing performance because metallic implants, on the other hand, have difference in mechanical stiffness, which gives rise to the stress shielding phenomenon and do not allow the bone to achieve its maximum strength. In this study, we developed a sophisticated bone fracture healing simulation technique when the fracture is fixed with different metallic and composite bone plates. Blood vessel development coupled with biphasic mechanoregulation (MR) algorithm is simulated while the cell and tissue phenotypes distribution along the callus region is presented. Further using different physiotherapy practices we estimated the effect on the early development of the fractured region. Walking, running, cycling, jogging, and walking with the help of crutches have a profound effect on the fractured region while for complete healing different daily exercise duration of all those activities are usually suggested by physiotherapists. By developing different exercise routines for the patients with tibia fractures fixed with bone plates we estimated their effects on fracture healing and suggested the best exercise routine for utmost fracture healing of the tibia. In the end, we compared the healing performance of composite and metallic bone plates and provided the best bone plate for fractured tibia with 45o oblique fracture.

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abst. 1199
Room B032
Wednesday
July 20
10h40

Amine functionalized multi-walled carbon nanotube/hydrogen-rich benzoxazine nanocomposites for cosmic radiation shielding with increased mechanical properties and resistance to space environment

Ji-Hun Cha (jihundd@kaist.ac.kr), Korea Advanced Institute of Science and Technology (KAIST), KOREA

Chun-Gon Kim (cgkim@kaist.ac.kr), Korea Advanced Institute of Science and Technology (KAIST), KOREA

Recently, in the new space era, the problem of cosmic radiation is being highlighted. Small satellites, in which the private sector actively participates, are mainly manufactured using commercial off-the-shelf (COTS) as satellite electronic devices to reduce development costs. Compared to space-only electronic equipment, COTS is cheaper and has high performance, but it has a problem of being vulnerable to cosmic radiation. These problems make it difficult for COTS to sustain missions for a long time in space and reduce reliability due to radiation accumulation. NASA aims to send humans to Mars by 2030. The most fatal disease that astronauts receive in future interplanetary manned space flights is health problems caused by cosmic radiation. Although the issue of the effects of cosmic radiation on the human body that astronauts receive for a long period of time is constantly being debated, it is generally known that astronauts cannot avoid radiation as high as the recommended dose of the International Radiation Defense Commission. Therefore, with current technology, manned missions to Mars require astronauts to take serious risks of cosmic radiation. In order to solve these problems, replacing the materials of satellites or spacecraft with radiation shielding materials provides the advantages of increasing the lifespan and reliability of electronic equipment and lowering the cancer incidence rate in astronauts. Hydrogen is the most effective element for cosmic radiation shielding. Therefore, a material containing a large amount of hydrogen element has been proposed as a cosmic radiation shielding material. Hydrogen-rich benzoxazines developed by Iguchi et al. have more hydrogen than other thermosetting resins. Although it is known that the cosmic radiation shielding performance of a large number of benzoxazines is excellent, the mechanical properties have not been reported yet, and the space environmental resistance has not been reviewed. For the first time in this study, the mechanical properties and resistance to space environments of hydrogen-rich benzoxazines were tested.Satellites in low-Earth orbit are exposed to harsh environments such as high-energy atomic oxygen, thermal cycles, ultraviolet radiation, ultra-high vacuum, and high-energy impacts from micrometeorite particles. In particular, in general low-Earth orbit satellite structures, the erosion of the polymer material on the surface of the spacecraft due to the collision of high-energy atomic oxygen is an important issue. Multi-walled carbon nanotubes (MWCNT) can not only improve atomic oxygen resistance, but also improve the mechanical properties of polymers. We proposed a study of adding MWCNTs to hydrogen-rich benzoxazine to improve the mechanical properties of hydrogen-rich benzoxazine, and confirmed an additional increase in atomic oxygen erosion resistance. In a previous study, amines bound during curing of benzoxazines had a positive effect on curing of benzoxazines, which resulted in improved mechanical properties. Therefore, in this study, it was determined that MWCNTs grafted with amine groups could be dispersed in benzoxazine to effectively disperse MWCNTs and have a positive effect on curing. With reference to the previous literature, hydrogen-rich benzoxazines were prepared. We used chloroform as a solvent to disperse MWCNTs in benzoxazine, and dispersed MWCNTs through a sonicator. MWCNT/benzoxazine was finally cured in a heated vacuum oven at 130°C for 7 hours. Two types of MWCNTs (pristine MWCNT and NH2-MWCNT) were added to benzoxazine, and their tensile properties and space environmental resistance were evaluated. NH2-MWCNTs showed higher tensile performance than pristine MWCNTs. In particular, 0.8wt% of NH2-MWNCT showed the highest tensile performance. Compared to pristine benzoxazine, the tensile strength increased by about 20% and the tensile strength increased by 30%. We judged that this phenomenon could have a positive effect on the curing of benzoxazines by amine groups added to MWCNTs and could effectively contribute to the dispersion of MWNCTs. An integrated space environment test taking into account atomic oxygen and thermal cycling, ultraviolet light, and ultra-high vacuum was performed on MWCNT/benzoxazine. In the space test, mechanical properties degradation of about 10% was observed. The addition of MWCNT could suppress the erosive effect by atomic oxygen rather than the pristine state. The higher the amount of MWCNT added, the lower the total mass loss in the integrated space environment. As a result of analysis through OLTARIS, a cosmic radiation dose program, benzoxazine is judged to be able to reduce radiation dose by about 10% compared to epoxy. Through these experimental results, NH2-MWNCT/hydrogen-rich benzoxazine was able to confirm sufficient space application potential as a future cosmic radiation shielding material.

A CFRP/GFRP hybrid composite support for double-wall LNG pipe system

abst. 1211
Room B032
Wednesday
July 20
10h20

Hong, Hyunsoo (flud159@kaist.ac.kr), KAIST, South Korea
Kim, Woe Tae (iro_ot3p66@kaist.ac.kr), KAIST, South Korea
Kim, Seong Su (seongsukim@kaist.ac.kr), KAIST, South Korea

The double-wall pipes, consisting of the inner and outer pipes, are mainly used to transport liquefied natural gas (LNG) in LNG ships. The inner pipe transports LNG, and the outer pipe serves as the second layer of protection and monitors whether the inner pipe leaks. Between the inner and the outer pipes, the support with the specific structural stiffness and safety is required because it supports the self-weight of the LNG or reduces the vibration that occurs when the LNG moves. In this study, a support for double-wall pipe system of LNG vessel was designed by using hybrid composite materials that are fabricated by combining carbon fiber reinforced plastics (CFRP) and glass fiber reinforced plastics (GFRP) with outstanding specific material properties. Through finite element analysis (FEA), deformation according to the shape of the support and composite stacking conditions was analyzed. The structural stiffness of each support model was compared and structural safety was investigated through the Hashin failure criteria. As a result, the model with the required structural stiffness and safety could be obtained. Based on the FEA results, CFRP/GFRP hybrid composite support was fabricated and installed to the double-wall pipe system. Through the deformation test of the composite support in double-wall pipe system using a universal test machine (UTM), it was confirmed that the required structural stiffness was satisfied even in various loading direction.

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abst. 1334
Room B032
Wednesday
July 20
09h40

FRCM confinement as a repair technique for seismically damaged RC columns

Toska, Klajdi (klajdi.toska@dicea.unipd.it), University of Padua, Italy
Hofer, Lorenzo (lorenzo.hofer@dicea.unipd.it), University of Padua, Italy
Faleschini, Flora (flora.faleschini@dicea.unipd.it), University of Padua, Italy
Zanini, Mariano Angelo (marianoangelo.zanini@dicea.unipd.it), University of Padua, Italy
Pellegrino, Carlo (carlo.pellegrino@dicea.unipd.it), University of Padua, Italy

This paper experimentally investigates the effectiveness of confinement through carbon fiber reinforced cementitious matrix (CFRCM) to adequately repair seismically damaged reinforced concrete (RC) columns. Two real scale RC columns were initially subjected to cyclic lateral loading while under a constant vertical load to induce seismic-like damage. To restore the initial strength and ductility, damaged elements were repaired through CFRCM confinement and tested again under the same loading protocol. During the loading history, cracks, displacements, vertical and horizontal load and fiber strains were carefully monitored. Results are presented in terms of load-displacement curves, curvature development and strength and lateral stiffness degradation for both undamaged and repaired elements. Test results proved the effectiveness of FRCM confinement to repair RC elements damaged due to excessive lateral loading restoring both strength and ductility of the repaired elements.

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abst. 1342
Poster

Comparison of carbon fiber recycling methods and the effect of different nano reinforcement into the integrity of the recovered fibers.

Alexis Salas (alesalas@udec.cl), Universidad de Concepción, Chile
Elizabeth Berrio (), Universidad de Concepción, Chile
Andres Diaz (), Universidad de Concepción, Chile
Daniel Palacio (), Universidad de Concepción, Chile
Carlos Medina (), Universidad de Concepción, Chile
Manuel Melendrez (), Universidad de Concepción, Chile

Over the years, the use of carbon fiber in the automotive, aerospace, and energy industries has generated an increase in the global demand for these materials, causing problems with the management of the waste produced. The objective of this work is to compare the recycling process by pyrolysis

with a microwave thermolysis process, and then evaluate different nano-reinforce in recycled fibers. Two nano reinforcements are evaluated, carbon nanotubes by the poptube technique and SiO2 by hydrolysis. To determine the effectiveness of these methods, thermogravimetric analysis (TGA), Raman spectroscopy, infrared spectroscopy (FT-IR), X-ray diffraction (XRD), atomic force microscopy (AFM), and scanning electron microscopy (SEM) are evaluated. Finally, the micromechanical property for all fibers is evaluated using a single fiber test. The carbon fiber is successfully recovered using both methods, the results obtained indicate that excess temperature and power generate damage to the surface of the fibers, increase the ratio in the D and G Raman bands (12% for microwaves and 24% for pyrolysis), in addition to the fact that there is an increase in surface roughness as the processes become more aggressive (15% for microwaves and 3% for pyrolysis). Although at a morphological level microwave thermolysis generates a greater change in the fiber surface, it is a process 50% faster than pyrolysis and requires more research. Regarding the nano reinforcement, in both recycled fibers the growth of these is observed, being reflected in the Raman spectrum with the appearance of the G' band, however, it is necessary to improve the homogeneity and dispersion on the surface of the fibers. On the other hand, the nanoparticles of SiO2 are obtained in the size of 50-250 nm and they are distributed on the surface of fibers. It's observed in SEM images the presence of nanotubes and nanoparticles of SiO2, the different sizes these nanoparticles fill in the different cavities present in the surface fiber coming from of the previous recycling process. Finally, the maximum tensile strength is lower in recycling fibers compared whit the original fibers and the nano reinforcement improved this behavior.

Axial compressive behaviour of FRP-confined seawater sea-sand concrete with recycled FRP bars as coarse aggregate

abst. 1371
Repository

Gao, Ze Yu (gaozy@hust.edu.cn), School of Civil and Hydraulic Engineering, Huazhong University of Science and Technology, China
Zhang, Shi Shun (shishun@hust.edu.cn), School of Civil and Hydraulic Engineering, Huazhong University of Science and Technology, China
Nie, Xue Fei (niexuefei@hust.edu.cn), School of Civil and Hydraulic Engineering, Huazhong University of Science and Technology, China
Li, Shan (lishan@whu.edu.cn), School of Civil Engineering, Wuhan University, China

Due to the widespread use and non-biodegradable nature of fiber-reinforced polymer (FRP) composites, FRP waste is becoming a serious environmental concern. Cutting FRP waste into small discrete pieces and replacing the coarse natural aggregate (NA) in concrete (referred to as FRP recycled aggregate or FRP-RA) has been suggested as a feasible solution to FRP waste recycling. The excellent corrosion resistance of FRP makes it promising to combine this new type of aggregate (FRP-RA) with seawater sea-sand concrete (SSC). The present study aims at investigating the axial compressive behaviour of FRP-confined SSC with FRP-RAs. The used FRP-RAs are short cylinders with a length-to-diameter ratio of 1 which were cut from glass FRP (GFRP) bars with different diameters (including 6 mm, 10 mm, 16 mm, 19 mm and 25 mm). A total of 96 cylinders with a diameter of 150 mm and a height of 300 mm were tested under axial compression, with the studied parameters being the type of concrete, the replacement ratio of FRP-RA, as well as the type and thickness of FRP. Four replacement ratios of FRP-RA (i.e., 0%, 33%, 66% and 100% by volume) were adopted when making normal concrete (NC)/SSC cylinders. In order to investigate the effect of different FRP confinement, two types of FRP sheets [carbon FRP (CFRP) and GFRP] and FRP thickness (1-layer and 2-layer) were used. The test results showed that there was no obvious difference between SSC and NC with FRP-RAs; compared with SSC without FRP-RAs, SSC with FRP-RAs showed reduced strength and elastic modulus, and the degree of reduction increased with the increase of replacement ratio of FRP-RA; after FRP confinement, the strength of SSC with FRP-RAs was enhanced significantly, and the enhancement increased with the increase of FRP confinement stiffness; the ultimate axial strain of FRP-confined SSC with FRP-RAs increased compared with that of SSC without FRP-RAs under the same FRP confinement condition, and the increase was more obvious under low FRP confinement stiffness. Moreover, a theoretical model was proposed for FRP-confined SSC with FRP-RAs, on the basis of the model for FRP-confined NC. The prediction from the proposed model agreed well with the test results.

abst. 1389
Room B032
Wednesday
July 20
10h00

Influence of composite patch thickness on pipe repair and their relationship to failure pressure

Reis, J.M.L. (jreis@id.uff.br), Universidade Federal Fluminense - UFF, Brazil
Costa, A.R. (alexander_rodrigues@id.uff.br), Universidade Federal Fluminense - UFF, Brazil
da Costa Mattos, H. S. (heraldo_mattos@id.uff.br), Universidade Federal Fluminense - UFF, Brazil

The present paper is concerned with the repair of through-wall corrosion damage in metallic pipes using a bonded composite patch. The focus is on the analysis of the influence of the thickness of the patch on the effectiveness of the repair. The goal is to assure that the pipe won't leak once the repair is completed. The main motivation for the study presented on this paper is the corrosion damage in produced water pipelines used in offshore oil exploitation. Since offshore platforms are hydrocarbon atmospheres, any repair method using equipment that may produce heat and/or sparkling is forbidden. Usually a composite sleeve is used to stop leakage. The main motivation for this study is to show that only a bonded composite patch can be sufficient to avoid leaking (no composite sleeve is necessary), but the effectiveness of the repair is strongly dependent on the thickness. Normally, most studies are concerned with the bonded area, but experimental results show that the failure pressure using patches with the same area but with different thicknesses can be very different. Burst tests have been performed on API 5L grB steel hydrostatic specimens with a 25,4 mm hole repaired with 100 mm X 100 mm patches.

Auxetic materials and structures

Design and tests on modified 3D auxetic structures

abst. 1036
Virtual Room 1
Tuesday
July 19
15h30

Wang, Suian (suian.wang@umanitoba.ca), University of Manitoba, Canada
Wu, Nan (nan.wu@umanitoba.ca), University of Manitoba, Canada

Based on the traditional two dimensional (2D) re-entrant hexagonal honeycomb, a modified three dimensional (3D) reentrant lattice structure was proposed. The topology and mechanical properties are closely related with design parameters including reentrant angle and strut cross section. Additive manufacturing was used to fabricate five groups of resin samples with different design parameters, including a set of non-auxetic samples. These samples were applied quasi-static compression to investigate the effect of the design parameters on the deformation and energy absorption behaviour of the proposed structure. The experiment results show that the proposed 3d reentrant honeycomb obviously performs NPR during the compression deformation, which leads to a better performance in overall energy absorption compared to the non-auxetic structures. The cross section area and shape are noticed to have significant effects on energy absorption during compression of such strut 3D reentrant structure. The comparison between results from different reentrant angles, strut cross areas, and cross section shapes will provide a reference for future optimal design of the structure.

Auxetic Tubular Structures: Opportunities and Challenges

abst. 1314
Virtual Room 1
Tuesday
July 19
15h10

Ren, Xin (xin.ren@njtech.edu.cn), Nanjing Tech University, China
Zhang, Xiang Yu (shirey@163.com), Nanjing Tech University, China
Luo, Chen (1538588843@qq.com), Nanjing Tech University, China
Han, Dong (handongxuexi@163.com), Nanjing Tech University, China

Auxetic materials and structures have attracted increasing attention because of their extraordinary mechanical properties. As a new type of auxetics, auxetic tubular structures have been significantly studied in diverse fields, including mechanical and medical engineering. In this paper, design methods and advanced manufacturing technologies of auxetic tubular structures are extensively introduced, including various types of cellular auxetic tubes, nonporous and porous auxetic tubes, macro and micro auxetic tubes. Moreover, auxetic behaviour, mechanical properties and potential applications of auxetic tubular structures are elaborated. Finally, the challenges and opportunities on the auxetic tubes are discussed to inspire future studies.

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

abst. 1038
Virtual Room 2
Wednesday
July 20
11h30

Higher order theories for the static and free vibration analysis of doubly-curved shells of innovative materials enforced with general boundary conditions

Viscoti, Matteo (matteo.viscoti@unisalento.it), University of Salento, Italy
Dimitri, Rossana (rossana.dimitri@unisalento.it), University of Salento, Italy
Tornabene, Francesco (francesco.tornabene@unisalento.it), University of Salento, Italy

Recent years have seen the advance of structures with complex geometries in several engineering fields. The applications stem from visionary architectural buildings, mechanical appliances and so on. On the other hand, computational efficient methods are required for the static and dynamic analysis of these structures [1]. In this context, the geometrical feature of the structure allows the assessment of a bi-dimensional general formulation for doubly-curved shells. Moreover, the employment of the Higher Order Shear Deformation Theories (HSDTs) [2], combined with an efficient homogenization technique [3-4] for the lamination scheme, leads to a generalized formulation of the structural problem. Moreover, a general non-uniform Winkler-Pasternak foundation is contemplated. General external constraints are obtained from an in-plane and out-of-plane dispersion of linear elastic springs along the edges of the physical domain. The fundamental set of equations is then numerically tackled in a strong form employing the Generalized Differential Quadrature (GDQ) method [2]. In the post-processing stage, the three-dimensional response of the structure is recovered employing a procedure based on the equilibrium equations, as well as the constitutive relationships. The accuracy of the solution is checked with success in an extensive set of significative case studies. In particular, the static and dynamic solution is compared to that obtained from refined three-dimensional Finite Element simulations of zero-, singly- and doubly-curved structures infilled with generally anisotropic materials. After that, some parametrical investigations are assessed, in which the sensitivity of the main geometric and mechanical governing parameters on the structural response is outlined. REFERENCES: [1] Tornabene F., Viscoti M., Dimitri R., Reddy J.N., Higher order theories for the vibration study of doubly-curved anisotropic shells with a variable thickness and isogeometric mapped geometry, Composite Structures, (2021), 113829. [2] Tornabene F., Bacciocchi M., Anisotropic Doubly-Curved Shells. Higher-Order Strong and Weak Formulations for Arbitrarily Shaped Shell Structures, Esculapio, Bologna, 2018. [3] Tornabene F., Viscoti M., Dimitri R., Aiello M.A., Higher-Order Modeling of Anisogrid Composite Lattice Structures with Complex Geometries, Engineering Structures, 244 (2021), 112686. [4] Tornabene F., Viscoti M., Dimitri R., Aiello M.A., Higher Order Formulations for doubly-curved shell structures with a honeycomb core, Thin-Walled Structures, 164 (2021), 107789.

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abst. 1119
Room B035
Wednesday
July 20
09h40

A-posteriori evaluation of transverse stress components in beams, plates and shells

Augello, Riccardo (riccardo.augello@polito.it), Politecnico di Torino, Italia
Carrera, Erasmo (erasmo.carrera@polito.it), Politecnico di Torino, Italia
Pagani, Alfonso (alfonso.pagani@polito.it), Politecnico di Torino, Italia
Scano, Daniele (daniele.scano@polito.it), Politecnico di Torino, Italia

The theory adopted to solve the three-dimensional (3D) continuum problem strongly affects the stress calculation in the case of one-dimensional (1D) and two-dimensional (2D) structures (i.e. beams, plates and shells). In particular, the evaluation of the transverse stress components results to be very dependent upon the employed approximations. As an example, classical theories, such as Euler-Bernoulli for 1D elements and Kirchhoff's plate theory for 2D structures, do not allow for a-posteriori evaluation via the Hooke's law of transverse stresses, which are neglected. Only the in-plane stresses can be calculated. Evolutions of such classical theories were developed, for instance the Timoshenko beam theory for beams and the Reissner-Mindlin shear deformable 2D theory, in which a-posteriori evaluation of the shear stresses is possible, although not convenient. In fact, Hooke's law would lead to a constant

distribution of the transverse shear stresses, violating the homogeneous conditions at the top and bottom edges of the structure. On the other hand, an alternative a-posteriori approach is available to evaluate the transverse shear components. Such technique involves the indefinite equilibrium equations of 3D elasticity. Basically, the in-plane stresses are integrated in the thickness directions. A proper evaluation of the 3D stress field is important especially in case of layered composite structures, which are characterized by non-continuous mechanical material properties in the thickness direction. In fact, due to higher values of Young's moduli orthotropic ratio (EL/ET and EL/Ez, L denotes the fibre directions while T and z are two-direction orthogonal to L) and the lower transverse shear moduli ratio (GLT/EL and GTT/EL), higher transverse shear and normal stress deformability in comparison to isotropic cases appears. Consequently, an accurate evaluation of the interlaminar continuous transverse shear and normal stresses is required for a proper modelling and, thus, design of composite structures. In order to carry out such analyses, the Carrera Unified Formulation is adopted. This methodology, according to which the 3D displacement field can be evaluated as an arbitrary expansion of the unknowns evaluated through finite element method, is extremely suitable for this analysis. In fact, the expansion used to evaluate the displacement field is treated as an user input, i.e. one can choose the theory to be adopted for the analysis of beams, plates and shells. As a matter of fact, one can evaluate the shear stress component using low- to higher-order theories and compare the results. Benchmarks of composite beams, plates and shell structures are considered to assess the proposed model. The obtained results using the indefinite equilibrium equations using low-order theories are compared with those evaluated with higher-order Hooke's law ones and with literature and references, where available. Different polynomials are used for this purpose, including Taylor, Lagrange and Jacobi. The results demonstrate the reliablity of the model and the efficiency of adopting the indefinite equilibrium equations when using low-order theories.

Free vibration analysis of arbitrary laminated composite and sandwich shells via a meshless formulation and FSDT

abst. 1134
Repository

Chen Wei (w.chen@st.gxu.edu.cn), Guangxi University, China
Chen Si Ya (chen.siya@foxmail.com), Guangxi University, China
Teng Xiao Dan (xdteng@gxu.edu.cn), Guangxi University, China
Peng Lin Xin (penglx@gxu.edu.cn), Guangxi University, China

A meshless analysis for arbitrary laminated composite and sandwich shells based on 3D continuous shell theory is presented in this paper. The moving-least squares (MLS) approximation are used not only for the interpolation of the shell geometry, but also for the approximation of field variables. Transverse shear strains are considered with the first order shear deformation theory (FSDT). Numerical integration of the stiffness and mass matrix are estimated by using the simple Gaussian integral in the convected coordinate system. The essential boundary conditions are imposed by the full transformation method due to that the MLS approximation does not satisfy Kronecker delta condition. The meshless governing equations on the free vibration of the arbitrary laminated composite and sandwich shells is derived by the Hamilton's principle. To show the convergence, accuracy and effectiveness of the proposed formulation and discretization, some benchmark problems taken from previous literatures are considered. Numerical results show that the proposed meshless formulation is accurate and useful in the simulation of the free vibration behaviors of arbitrary laminated composite and sandwich shells.

Finite deformation analysis of laminated shell via the discontinuous Galerkin method

abst. 1144
Virtual Room 2
Wednesday
July 20
11h50

Guarino, Giuliano (giuliano.guarino@unipa.it), Department of Engineering, University of Palermo, Italy
Milazzo, Alberto (alberto.milazzo@unipa.it), Department of Engineering, University of Palermo, Italy

In this work, we propose a novel formulation for the large displacements and post-buckling response analysis of laminated composite shell structures. In order to accurately recover the solution in the case of multilayered shells, the covariant components of the displacement field are approximated through the thickness using high-order structural theories. The non-linear two-dimensional total Lagrangian formulation is obtained starting from the Principle of Virtual Displacements for the three-dimensional elasticity assuming a linear constitutive relationship between the second Piola–Kirchhoff stress tensor and the Green-Lagrange strain tensor. The discontinuous Galerkin method is used in combination with a Newton-Raphson linearization scheme to solve the non-linear problem. High-order elements are employed to obtain high accuracy with limited computational effort. Several numerical tests are performed on shell structures with different shapes and lamination sequences. To show the accuracy of the proposed approach, the results are compared with benchmarks taken from the literature or obtained using the Finite Element Method available on commercial software.

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abst. 1147
Virtual Room 2
Wednesday
July 20
12h10

A theoretical model to investigate the buckling/stress-failure competitive behavior of laminated plates under compression-shear combined loads

Pian, Rong (pr1133@buaa.edu.cn), School of Astronautics, Beihang University, China
Liu, Fengrui (frliu@buaa.edu.cn), School of Astronautics, Beihang University, China
Zhao, Libin (lbzhao@buaa.edu.cn), School of Mechanical Engineering, Hebei University of Technology, China
Wang, Linjuan (wanglj@buaa.edu.cn), School of Astronautics, Beihang University, China

The performance of composite laminated plates under in-plane loads is the focus of structural design of aerospace vehicles. However, few studies have focused on the buckling and stress failure competitive behavior of laminated plates under axial compression, shear and compression-shear combined loads. In the current study, a competitive behavior analysis model is established, which contains the linear buckling analysis based on the principle of minimum potential energy and the stress failure analysis based on the classical laminated plate theory with Hashin-type criteria. The accuracy of the model was verified by comparing the analytical results with data in the literature. And then, parametric studies were carried out under different material systems, ratios of plate aspect and side length to thickness. The results under various compression-shear load ratios were presented in the form of curves, and the changes of buckling and failure modes were also concerned. By comparing the results of different cases, valuable suggestions are provided for the design of composite laminated plates under compression-shear combined loads.

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abst. 1157
Repository

Global buckling behavior of sandwich beam with graded lattice core

He Zhang (1569658794@qq.com), Shantou University, China
Tao Zeng (taozeng@stu.edu.cn), Shantou University, China
Guodong Xu (xuguodong@stu.edu.cn), Shantou University, China

This paper present a sandwich structure with asymmetric grade lattice and investigate its global buckling behavior. The equivalent shear modulus of unit cells in the structure are obtained by theoretical analysis and the equivalent shear modulus curve along the direction of gradient was given by multiform fitting. The critical global buckling load of the study object is solved based on the Allen sandwich beam theory and the energy method. In addition, the eigenvalue buckling analysis was performed on the study object using ABAQUS finite element software. The theoretical results were compared with the simulation results to verify the correctness of the theoretical approach. Several geometric parameters are discussed to investigate the accuracy of the theoretical approach.

Buckling and Vibration Behaviour of the Debonded Stiffened Hygrothermally Stable Laminated Composite Panel Under the Influence of Non-Uniform Edge Loads.

abst. 1228
Virtual Room 2
Wednesday
July 20
12h30

Kalgutkar, Akshay Prakash (akshaykalgutkar1@gmail.com), Indian Institute of Technology Bombay, India
Banerjee, Sauvik (sauvik@civil.iitb.ac.in), Indian Institute of Technology Bombay, India

T- stiffeners are widely used in the aerospace, civil, and marine industries because they provide better resistance to buckling modes. However, in addition to external loading, these panels are subjected to extreme temperature and moisture conditions during their service and may undergo damage as a result of stresses developed due to hygrothermal and mechanical loading. Thereby, to analyse the structure, an investigation is carried out to understand the buckling and dynamic behaviour of the stiffened laminated composite panel that is debonded at the plate-stiffener flange interface subjected to non-uniform edge load under the influence of a hygrothermal environment. The investigation is carried out by employing a reliable and computationally efficient finite element (FE) formulation. It is important to note that a large amount of experimental investigation is available on the hat stiffened panel. In contrast, quite a few studies are available on the debonded stiffened panel using an analytical or semi-analytical approach and by employing Finite element software. In the past investigation, the stiffened panel was modelled using a 3D- brick element or a 2-D shell element, which would increase the computational cost. However, in the current investigation, the skin and the stiffener flange are modelled using a 9-noded heterosis plate element to avoid the shear locking problem. The web of the stiffener is modelled using a 3-noded isoparametric beam element by incorporating the torsion correction factor, which will slightly reduce the computational cost. The current model applies the displacement continuity condition at the plate-flange interface in the bonded region to emphasise the stiffener flange's nodal displacement in relation to the plate's nodal displacement. However, in the debonded region, a dummy independent node is created, and the fictitious spring is inserted between the parent and the dummy nodes to prevent the interpenetration of nodes. The current investigation is carried out on the three schemes of hygrothermally stable laminates that were considered based on the earlier researcher's observation. The lamina scheme (/90-)s is the configuration that induces equal normal non-mechanical stress resultants and zero non-mechanical shear and moment resultants. (-67.5/22.5)s is the lamina scheme with an optimal shear extension co-efficient, whereas (77.5/-12.5)s is the lamina scheme with an optimal value between the bending stiffness and compliance. As the stress developed by the environmental and operational conditions is highly non-uniform in nature, a dynamic approach is used to calculate the buckling parameter of the stiffened panel by employing two sets of boundary conditions. Initially, a study is conducted to determine an optimal stiffener configuration with improved performance based on the vibration and buckling behaviour. Detailed parametric investigations are then carried out to examine the effect of debonding size, debond position, aspect ratio and stiffener depth to width ratio on the buckling and vibration performance of the optimal stiffened panel subjected to non-uniform edge load under the influence of hygrothermal environment. It is observed that moisture significantly influences the panel's performance than the temperature. The panel's performance drops suddenly when the hygrothermal load approaches the critical temperature or moisture level. Furthermore, there is no discernible effect of hygrothermal load on the panel performance with small size debond. However, as the debond size increases, there is a substantial drop in the panel's behaviour.

A new mixed model based on the enhanced-Refined Zigzag Theory for the analysis of thick multilayered composite plates

abst. 1231
Room B035
Wednesday
July 20
10h00

Sorrenti, Matteo (matteo.sorrenti@polito.it), Politecnico di Torino, Department of Mechanical and Aerospace Engineering, Corso Duca degli Abruzzi, 24 10129 Torino (TO), Italia
Gherlone, Marco (marco.gherlone@polito.it), Politecnico di Torino, Department of Mechanical and Aerospace Engineering, Corso Duca degli Abruzzi, 24 10129 Torino (TO), Italy

The Refined Zigzag Theory (RZT) has been widely used in the numerical analysis of multilayered and sandwich plates in the last decay. It has been demonstrated its high accuracy in predicting global

quantities, such as maximum displacement, frequencies and buckling loads, and local quantities such as through-the-thickness distribution of displacements and in-plane stresses [1,2]. Moreover, the C0 continuity conditions make this theory appealing to finite element formulations [3]. The standard RZT, due to the derivation of the zigzag functions, cannot be used to investigate the structural behaviour of angle-ply laminated plates. This drawback has been recently solved by introducing a new set of generalized zigzag functions that allow the coupling effect between the local contribution of the zigzag displacements [4]. The newly developed theory has been named enhanced Refined Zigzag Theory (en-RZT) and has been demonstrated to be very accurate in the prediction of displacements, frequencies, buckling loads and stresses. The predictive capabilities of standard RZT for transverse shear stress distributions can be improved using the Reissner's Mixed Variational Theorem (RMVT). In the mixed RZT, named RZT(m) [5], the assumed transverse shear stresses are derived from the integration of local three-dimensional equilibrium equations. Following the variational statement described by Auricchio and Sacco [6], the purpose of this work is to implement a mixed variational formulation for the en-RZT, in order to improve the accuracy of the predicted transverse stress distributions. The assumed kinematic field is cubic for the in-plane displacements and parabolic for the transverse one. Using an appropriate procedure enforcing the transverse shear stresses null on both the top and bottom surface, a new set of enhanced piecewise cubic zigzag functions are obtained. The transverse normal stress is assumed as a smeared cubic function along the laminate thickness. The assumed transverse shear stresses profile is derived from the integration of local three-dimensional equilibrium equations. The variational functional is the sum of three contributions: (1) one related to the membrane-bending deformation with a full displacement formulation, (2) the Hellinger-Reissner functional for the transverse normal and shear terms and (3) a penalty functional adopted to enforce the compatibility between the strains coming from the displacement field and new "strain" independent variables. The entire formulation is developed and the governing equations are derived for cases with existing analytical solutions. Finally, to assess the proposed model's predictive capabilities, results are compared with an exact three-dimensional solution, when available, or high-fidelity finite elements 3D models. References: [1] Tessler A, Di Sciuva M, Gherlone M. Refined Zigzag Theory for Laminated Composite and Sandwich Plates. NASA/TP-2009-215561 2009:1–53. [2] Iurlaro L, Gherlone M, Di Sciuva M, Tessler A. Assessment of the Refined Zigzag Theory for bending, vibration, and buckling of sandwich plates: a comparative study of different theories. Composite Structures 2013;106:777–92. https://doi.org/10.1016/j.compstruct.2013.07.019. [3] Di Sciuva M, Gherlone M, Iurlaro L, Tessler A. A class of higher-order C0 composite and sandwich beam elements based on the Refined Zigzag Theory. Composite Structures 2015;132:784–803. https://doi.org/10.1016/j.compstruct.2015.06.071. [4] Sorrenti M, Di Sciuva M. An enhancement of the warping shear functions of Refined Zigzag Theory. Journal of Applied Mechanics 2021;88:7. https://doi.org/10.1115/1.4050908. [5] Iurlaro L, Gherlone M, Di Sciuva M, Tessler A. A Multi-scale Refined Zigzag Theory for Multilayered Composite and Sandwich Plates with Improved Transverse Shear Stresses, Ibiza, Spain: 2013. [6] Auricchio F, Sacco E. Refined First-Order Shear Deformation Theory Models for Composite Laminates. J Appl Mech 2003;70:381–90. https://doi.org/10.1115/1.1572901.

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abst. 1320
Room B035
Wednesday
July 20
10h40

Numerical stability analysis of composite beam-type structures considering coupled shear deformation effects

Turkalj, Goran (goran.turkalj@riteh.hr), University of Rijeka Faculty of Engineering, Croatia
Banic, Damjan (dbanic@riteh.hr), University of Rijeka Faculty of Engineering, Croatia
Lanc, Domagoj (dlanc@riteh.hr), University of Rijeka Faculty of Engineering, Croatia

A free shear-locking beam model for numerical stability analysis of composite beam-type structures is presented. The incremental equilibrium equations for a straight fourteen-degree-of-freedom beam element are derived within the framework of updated Lagrangian formulation. In this, the nonlinear displacement field of a thin-walled cross-sections, accounting for the restrained warping and the large rotations effects, is applied. The applied shear-deformable beam formulation accounts for the flexural-torsional coupling appearing when a non-symmetric cross-section is considered. Cross-section properties are calculated using the reference modulus, which enables to model various cross-ply cross-sectional wall configurations. The numerical algorithm is implemented in a computer program and validated through several benchmark examples.

Multilayered Beams, Plates and Shells Elements based on Jacobi Polynomials

abst. 1390
Room B035
Wednesday
July 20
10h20

Scano, Daniele (daniele.scano@polito.it), Politecnico di Torino, Italy
Augello, Riccardo (riccardo.augello@polito.it), Politecnico di Torino, Italy
Carrera, Erasmo (erasmo.carrera@polito.it), Politecnico di Torino, Italy
Pagani, Alfonso (alfonso.pagani@polito.it), Politecnico di Torino, Italy

During the last years, layered composite materials have been used in many applications, e.g. in aerospace, biomedical and automotive fields. The continuous development of sophisticated components led to increasingly complex structural designs that require reliable analyses. Their main issue is represented by the anisotropy of such structures, which causes intricate mechanical phenomena. For instance, the shear stresses must fulfil interlaminar continuity at each layer interface and transverse discontinuous mechanical properties cause the zig-zag distribution of displacement fields. The coupling between the in-plane and out-of-plane strains also represents a challenging topic. In this work, a hierarchical Jacobi expansion is presented for the static analysis of multi-layered structures. Jacobi polynomials belong to the family of classical orthogonal polynomials and they have the property to generate a vast class of polynomials changing the two parameters alfa and beta, e.g. Legendre and Chebyshev. In addition, the finite element method is applied to provide numerical solutions, whereas the Carrera Unified Formulation is used to generate the stiffness matrices in a compact and straightforward way. Thanks to the capabilities of CUF, both layer-wise and equivalent single layer approaches can be employed in order to obtain the desired degree of precision and computational cost. Furthermore, shear stresses can be calculated using Hooke's Law or 3D indefinite equilibrium equations. The latter allows to employ lower-order theories while more accurate results. Benchmarks of composite beams, plates and shell structures are considered to assess the proposed model. Different kind of pressures and geometrical boundary conditions are considered. The obtained results are compared with reference solutions, where available, and classical models. Results clearly show that desired degree of precision can be decided, simply choosing the approach and the order of the polynomials. Finally, it is demonstrated that the parameters alfa and beta do not alter the obtained results, for a given polynomial order.

Composite Structures

abst. 1008 **Repository**

Vibration reduction on functionally graded beams using linear and nonlinear tuned mass damper

G.G. Sheng (jeffery710@163.com), Changsha University of Science and Technology, China

The nonlinear dynamics of functionally graded (FG) beams with tuned mass damper (TMD) have been studied based on the von Kármán nonlinear theory and Euler-Bernoulli beam theories. The coupled nonlinear mode equations of FG beams with tuned mass damper are obtained using Hamilton's principle and Galerkin's method. The goal is to find the optimal damper parameters of tuned mass damper (location, stiffness, and damping), and to compare the effectiveness of linear and nonlinear dampers. The performance of the tuned mass damper in vibration reduction is estimated through the maximum amplitude of vibration.

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abst. 1014 **Repository**

Viscoelastic vibration of graphene reinforced nanocomposite curved panels

Karami, Behrouz (karamibehrouz@yahoo.com), Islamic Azad University, Iran
Ersoy, Hakan (hakanersoy@akdeniz.edu.tr), Akdeniz University, Turkey
Civalek, Ömer (civalek@yahoo.com), China Medical University, Taiwan

It is known that Polymer composites are considered to be one of the key promising candidates employed in the biomedical, aerospace, automotive, mechanical, civil, and architectural sectors. Moreover, they have been applicable in manufacturing micro/nano electromechanical systems (MEMS/NEMS) such as actuators and sensors which provide high reliability as well as low energy consumption. Considering carbon-based nanofillers inside isotropic/-polymeric matrices could be improved effectively the properties of composites in terms of thermal, optical, and mechanical. Several unique usages in special engineering devices whose low frequency as well as force generation, and also short dynamic range have the matter of great importance, have been found for polymer-based composites. In this research tries to investigate the wave phenomenon in nanoshell made of graphene nanoplatelets (GNPs) reinforced nanocomposites. The effective material properties are estimated through the Halpin–Tsai micromechanical model and a modified rule of mixture. A virtual work of Hamilton statement is employed to obtain the governing motion equations and then a harmonic solution based on an analytical procedure is developed to find the wave response. Afterwards, a parametric study is performed to analyze the effects of the linear spring and damper coefficients, small-scale parameters, different curves, radius to thickness ratio, GNP's weight fraction as well as its number of layers on the phase velocity response of the GNPs reinforced doubly curved nanoshell with various shape panels in a visco-Winkler medium. It should be underlined that wave propagation analysis, as a multi-physics problem, has importance in structural health monitoring, blood flow, and drug delivery, design of micro/nanostructures and other fields in which movement of waves is a key point. Furthermore, considering the fact that shell structures are more complex lightweight three-dimensional solids due to their curvature modeled in curvilinear coordinate, a question would be that the geometry and viscoelastic foundation how alter the size-dependent behavior of GNPs reinforced nanocomposite curved panels. In the present article, the second-order shear deformation theory in curvilinear coordinate in conjunction with a non-classical continuum theory including two small-scale parameters to estimate softening-stiffness/hardening-stiffness mechanisms is developed for wave propagation behavior of embedded doubly-curved nanoshell made of GNPs reinforced nanocomposites in viscoelastic foundation. The effective material properties of the structure are obtained via the Halpin-Tsai approach and also a rule of mixture. In the meantime, the equation of motion for the continuous system of the shell with the belongings is derived via Hamilton's principle, and afterwards solved via an analytical solution method. After validation of the model, the model will be examined wave characteristics of GNPs reinforced nanocomposite curved viscoelastic panels to demonstrate the influence of the contributed parameters.

Effects of different nanomaterials and steel fibres on compressive and splitting behaviour of ultra-high performance concrete

abst. 1016
Repository

Jian-He Xie (jhxie@gdut.edu.cn), School of Civil and Transportation Engineering, Guangdong University of Technology, China
Kun-Hong Huang (), School of Civil Engineering and Transportation, South China University of Technology, China
Yuan Feng (), School of Civil and Transportation Engineering, Guangdong University of Technology, China

Adding nanomaterials and steel fibre is a promising solution to enhance the performance of ultra-high performance concrete (UHPC). This study aims to investigate the effects of different nanomaterials and steel fibres on the compressive and splitting behaviour of UHPC. Three types of nanomaterials including nano-SiO2 (NS), nano-CaCO3 (NC) and carbon nanofibers (CNF) were considered. The dosages of NS and NC were 0%, 2%, and 4%, by the mass of binder, while the dosages of CNF were 0%, 0.15%, and 0.3%. In addition, two types of steel fibers including straight fibre and hooked-end fibre were used in the UHPC. A series of compressive and splitting tests were conducted to examine the influence of these experimental variables on the fluidity, splitting strength, compressive strength, stress-strain relation, elastic modulus, Poisson's ratio, toughness and failure mode of the UHPC. In addition, the enhancement mechanism was studied by SEM. The results show that the hooked-end steel fibre rather than the straight steel fibre provided better compressive and splitting strength for the UHPC. The addition of all the tested nanomaterials reduced the flowability and increased the compressive and splitting strength of the UHPC with the increase of their contents. The test results indicated that the optimal dosages of both NS and NC to enhance compressive and splitting strengths were 2%. When the content of NS or NC was more than 2%, the mechanical properties decreased slightly due to the agglomeration effect of nano particles. The compressive and splitting strength increased with the increase of the CNF content up to 0.3%. The coupling effect of CNF and steel fibres improved the splitting strength greatly. The SEM images showed that the microstructure was more homogenous and dense for specimens with nanomaterials as compared to the reference specimen. Nanomaterials demonstrated nucleation and filling effects and resulted in more compact of the joint between cement matrix and steel fiber or aggregate. Moreover, the analytical models for the stress-strain relation suggested in the literature were considered for UHPC with nanomaterials, and appropriate parameters were derived from the experimental data. Keywords: ultra-high performance concrete, nanomaterials, steel fibres, splitting, compression, stress-strain relation

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On the dynamics of nanocomposite skew plates resting on point supports

abst. 1024
Repository

Żur, Krzysztof Kamil (k.zur@pb.edu.pl), Bialystok University of Technology, Poland
Kiani, Yaser (y.kiani@aut.ac.ir), Shahrekord University, Iran
Ferreira, Antonio J.M. (ferreira@fe.up.pt), University of Porto, Portugal

In many practical applications, boundary conditions on the edges of plate structures are not continuous where only a portion or a point of the edge is restrained. Also there are many cases where the interior domain of the plate is located on point supports. The solution method for such cases is very complicated than the regular type of edge supports. In the present investigation, vibration behavior of skew plates which are located on point supports is investigated. The point supports may be on the edges on even in the plate domain. A nanocomposite laminated skew plate reinforced with graphene platelets is considered. Weight fraction of graphene platelets may be different in the layers which results in a piecewise functionally graded media. The elasticity modulus of the composite is estimated by the Halpin-Tsai rule which also captures the dimensions of the nano-reinforcement. Total strain and kinetic energies of the skew plate are established using the first-order shear deformation theory of plates. By means of the general idea of Ritz method whose shape functions are defined with the aid of Chebyshev polynomials, the elements of mass and stiffness matrices are obtained. To impose the effects of point supports with arbitrary numbers and arbitrary locations, the method of Lagrange multipliers is adopted. According to this technique, the number of degrees of freedom in the system increases with the number

of point supports. Using the developed formulation and solution method, the in-plane and out-of-plane frequencies of the plate as well as the mode shapes will be obtained with high accuracy. Numerical results are devoted to showing the effects of a number of nanocomposite layers, the weight fraction and the distribution pattern of graphene platelets, position and number of point support, geometric parameters, and the boundary conditions on the natural frequencies of the skew plate.

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abst. 1025
Virtual Room 1
Wednesday
July 20
15h50

Micro-macro modelling of laminated composite reservoir

Kormanikova, Eva (eva.kormanikova@tuke.sk), Technical University of Kosice, Slovakia
Kotrasova, Kamila (kamila.kotrasova@tuke.sk), Technical University of Kosice, Slovakia

This article has a multidisciplinary character. It combines the scientific field of micro-macro modelling of reinforced polymer composite laminates applied in the seismic response area of a rectangular composite tank filled with liquid. The calculation of the seismic response of the laminate composite rectangular tank is carried out at three levels. Within the micro-level, the material characteristics are calculated using a fictitious periodic microstructure model. A classical theory of laminates is used to obtain effective material characteristics by using a representative laminate volume element at the meso-level. At the macro level, a seismic response of a laminate composite rectangular tank filled with liquid is solved for the region of Slovakia.

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abst. 1026
Repository

On the wave dispersion characteristics in functionally graded porous nanobeams

Faghidian, S. Ali (faghidian@srbiau.ac.ir), Islamic Azad University, Iran
Żur, Krzysztof Kamil (k.zur@pb.edu.pl), Bialystok University of Technology, Poland
Reddy, J.N. (jnreddy@tamu.edu), Texas AM University, USA
Ferreira, A.J.M. (ferreira@fe.up.pt), University of Porto, Portugal

Dispersion characteristics of flexural waves in a functionally graded (FG) porous nano-sized beam are analytically examined. To account for the shear deformation and rotary inertia, kinematics of the beam is assumed to be consistent with the Timoshenko-Ehrenfest model. Elastic parameters of the functionally graded porous beam is considered to be symmetric with respect to the centroidal axis of the beam and described by the modified Voigt rule of mixtures. An appropriate porosity model is introduced wherein the applied porosity distribution function comprises the accumulations of porosity along with the volume of voids. The size-dependent response of the nano-beam is realized in the framework of the higher-order nonlocal gradient theory. The integro-differential constitutive laws of the stress resultant fields are established via an abstract variational approach and, reinstated with the equivalent differential relations equipped with non-standard boundary conditions. The closed-form solution of the phase velocity of flexural waves is analytically determined. A comprehensive parametric study is performed to investigate effects of higher-order strain gradient theory, higher-order nonlocality, porosity distributions, and functionally graded material constituents on the wave dispersion response of thick nano-beams. The ensuing numerical results are graphically illustrated and discussed. The established results of the flexural wave dispersion detect new benchmarks for numerical analyses and can be effectively exploited in design and optimization of composite nano-structural elements of advanced nano-electro-mechanical systems.

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abst. 1027
Repository

Investigation on various section GFRP profile strengthening concrete-filled GFRP tubular columns

Zhang, Xiaoyong (cheungxiaoyong@163.com), College of Civil Engineering, Fuzhou University, Fuzhou, China (350116)

Axial compression tests and numerically investigates were presented to investigate the behavior of circular winding concrete filled GFRP tubular columns with inner various section shapes of pultruded GFRP including angle section pultruded GFRP (LG-CFGT), channel section pultruded GFRP (CG-CFGT) and I section pultruded GFRP (IG-CFGT). A total of 72 columns including three groups of 24 LG-CFGT columns, 24 CG-CFGT columns and 24 IG-CFGT columns with different concrete strength, different winding GFRP tubular thickness and different column heights were tested. The failure mode, ultimate capacity, ductility, and stiffness of columns were mainly analyzed. Besides, strain development of the three groups' columns during the test was investigated according to the strain measurement of eight columns. Based on mechanical mode and test results of core concrete being confined with GFRP tube, the calculate formula was presented in this study to predict the ultimate capacity of various section GFRP profile strengthening concrete-filled GFRP tubular columns. The calculated results were greatly consistent with the test results. In addition, the finite element model was proposed in this study, and was validated by comparing with the test results.

Behavior of square GFRP tube filled with seawater and sea sand concrete beam

abst. 1033
Repository

Zhang, Xiaoyong (cheungxiaoyong@163.com), College of Civil Engineering, Fuzhou University, China
Xu Zhijun (xxzzjj911@163.com), College of Civil Engineering, Fuzhou University, China
Yao Zhu (skinyao@163.com), College of Civil Engineering, Fuzhou University, China
Wenyuan Kong (18096646672@163.com), College of Civil Engineering, Fuzhou University, China
Xiang Lin (), College of Civil Engineering, Fuzhou University, China
Chao Zhang (), College of Civil Engineering, Fuzhou University,
Yu Chen (yuchen@fzu.edu.cn), College of Civil Engineering, Fuzhou University, China

The behavior of square GFRP tube beams filled with seawater and sea sand concrete under the four-point test was studied with 48 specimens. The main test parameters of this study included cross section size, GFRP tube thickness, and sea sand replacement ratio. The failure process of the specimen during the four-point test was studied. The reslut indicated that the effect of GFRP tube strengthening core concrete on the failure process was significant. There was no apparent elastoplastic stage before the specimen failed, thus the failure mode was brittle under test, which could be found from the load-displacement curve. In addition, the effects of these test parameters on the ultimate capacity, flexural rigidity, and ductility were analyzed in this study. The test results indicated that the effects of GFRP tube thickness on the ultimate capacity and flexural rigidity were significant. The replacement of normal concrete with sea sand concrete had no obvious negative effect on the mechanical properties of the GFRP tube beams filled with concrete. Furthermore, the calculated formula of the ultimate capacity of the GFRP tube beams filled with seawater and sea sand concrete was proposed in this study. The calculated results were compared with the test results, which indicated that the calculated formula was greatly agreed with the test.

Axial crushing after aggressive environmental aging of GFRP composite tubes

abst. 1040
Room B035
Thursday
July 21
13h10

Sebaey, Tamer (tsebaey@psu.edu.sa), Prince Sultan University, Saudi Arabia

Composite structures are currently being used in several industries. During its service time, laminated composite structures might be installed in very aggressive conditions, which affects its response to different loading schemes. In the current paper, composite tubes are subjected to two aggressive environmental condition: seawater and agricultural soil. The time considered for this study is 24 weeks (almost 6 month), where specimens were tested each 8 weeks under axial compression. The results showed degradation in the peak load, as a result of the ber-matrix debonding triggered during the aging period. On the other hand, the crush force effciency, the energy absorbed and the speci c energy absorbed were improved by aging. The formation of Calcium and Magnesium layer on the surface of the specimens was concluded by SEM and EDX analysis, for the specimens aged in seawater.

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abst. 1043
Repository

Test and numerical analysis of 7021-T6 high strength aluminum alloy channel embedded in reinforced concrete structure

Zhang, Xiaoyong (cheungxiaoyong@163.com), College of Civil Engineering, Fuzhou University, China
Chen, Yu (kinkingingin@163.com), College of Civil Engineering, Fuzhou University, China
Feng, Gang (fuzhouelite@126.com), College of Civil Engineering, Fuzhou University, China

Test and numerical analysis of 7021-T6 high strength aluminum alloy channel embedded in reinforced concrete structure were carried out in the study. The vertical tensile test, transverse shear test and longitudinal shear test were conducted with nine specimens. The mechanical performances including the vertical tensile property, transverse shear property and longitudinal shear property of the specimens were analyzed. Based on the test results, 207 numerical models of 7021-T6 high strength aluminum alloy channel embedded in reinforced concrete structure were analyzed, including the numerical models of 108 specimens under vertical tensile load and 27 specimens under longitudinal shearing load. According to the numerical analysis results, it was suggested that the anchor plate thickness and notch thickness of the 7021-T6 high strength aluminum alloy channel embedded in reinforced concrete structure should not be less than 5mm. It was recommended to use the tooth angle of the standard basic rack as the production standard. In addition, the comprehensive coefficient K and calculated formula of the ultimate bearing capacity of the 7021-T6 high strength aluminum alloy channel embedded in reinforced concrete structure in the tensile state was proposed. Finally, the transverse shear capacity of 7021-T6 high strength aluminum alloy channel embedded in reinforced concrete structure was calculated and analyzed by establishing the mechanical model.

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abst. 1053
Repository

Surface quality after milling of II and III-layer hybrid sandwich structures

Doluk, Elżbieta (e.doluk@pollub.pl), Lublin University of Technology, Poland

Sandwich structures are an example of a special group of engineering materials that are becoming more and more popular due to their specific properties. Their relatively low weight makes them applicable in many fields of technology. The complexity of this type of material causes many difficulties during its processing. One of them is insufficient surface quality after cutting. Therefore, an attempt was made to determine the effect of the presence of a tool coating and the machining strategy on the surface quality after circumferential milling of II and III-layer sandwich structures consisting of a metal alloy and a polymer composite. The surface quality was defined by the material height difference. The materials forming the structure were 2024 aluminum alloy (Al) and carbon epoxy composite (CFRP). In the experiment, a circumferential milling using a 2-blade carbide cutter was used. The results showed that the tool coating and the CFRP/Al configuration caused an increase in the material height difference for both tested thicknesses of the sandwich structures. The lowest material height difference value was obtained after milling the II-layer structure with an uncoated tool in the Al/CFRP configuration, while the highest material height difference value was observed after machining the III-layer structure with a TiAlN coated tool using the CFRP/Al strategy.

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abst. 1080
Repository

The critical state of laminate plates with cut-out and asymmetric layer lay-out

Wysmulski Pawel (p.wysmulski@pollub.pl), Lublin University of Technology, Poland
Falkowicz Katarzyna (k.falkowicz@pollub.pl), Lublin University of Technology, Poland
Debski Hubert (h.debski@pollub.pl), Lublin University of Technology, Poland

The subject of the study was a thin-walled plate weakened by a central hole, which was subjected to axial compression. It was made of a carbon-epoxy laminate with an asymmetrical layer lay-out. The research included the analysis of critical and postcritical state using experimental and numerical methods. As a result of tests carried out on physical plates, work paths (P-u) were determined in the

postcritical range, which were then used to determine the critical loads using the straight-lines intersection approximation method. In parallel, numerical analysis were carried out using the finite element method, using linear analysis of eigenvalue problems, the results of which led to the determination of critical loads for the developed numerical model. The second stage of calculations involved carrying out a non-linear analysis of the structure with an initiation of geometric imperfection corresponding to the buckling form of the plate. The numerical results were compared with the experimental results, showing that the developed numerical model of the structure is correct. Numerical simulations were carried out using ABAQUS® software. 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).

Study on mechanical behavior of pultruded GFRP columns in axial compression

abst. 1097
Repository

Yao Zhu (skinyao@163.com), Fuzhou, China
Xiaoyong Zhang (cheungxiaoyong@163.com), Fuzhou, China
Wenyuan Kong (200520033@fzu.edu.cn), Fuzhou, China
Yu Chen (yuchen@fzu.edu.cn (Y. Chen).), Fuzhou, China

This paper investigates the mechanical properties of pultruded glass fiber reinforced polymer (GFRP) columns in axial compression. The main test parameters of this study include cross section size, GFRP tube thickness, height-width ratio and width-thickness ratio. The failure modes, ultimate bearing capacity, initial stiffness and ductility coefficient were obtained. Of interest was the effect of height-width ratio on failure characteristics of pultruded GFRP columns. With the increase of height-width ratio, the failure characteristics of local buckling tended to be tearing up from the corner of square GFRP tube at the loading end. In addition, the effects of tested parameters on the ultimate bearing capacity, initial stiffness and ductility coefficient were analyzed in this study. The experimental results indicated that the effects of GFRP tube thickness on the ultimate bearing capacity and initial stiffness were significant. The ultimate bearing capacity of specimens was greatly enhanced by the increase of GFRP tube thickness. Besides, the ductility coefficient was slightly improved with the increase of height-width ratio. Furthermore, the design approaches of ultimate bearing capacity of pultruded GFRP columns were proposed. Based on comparison of the predictions from design approaches and experimental results, the design approaches achieved sufficient accuracy in predicting the ultimate bearing capacity of pultruded GFRP columns.

Assessment of chemical resistance of low density polyethylene modified with natural filler.

abst. 1112
Repository

Głogowska, Karolina (k.glogowska@pollub.pl), Department of Technology and Polymer Processing, Faculty of Mechanical Engineering, Lublin University of Technology, Poland
Pączkowski, Przemysław (przemyslaw.paczkowski@umcs.pl), Department of Polymer Chemistry, Institute of Chemical Sciences, Faculty of Chemistry, Maria Curie-Sklodowska University in Lublin, Poland

A growing interest in environment protection resulted in numerous studies devoted to advanced materials made of natural raw materials, such as polymer-matrix composites. The production of materials based on renewable and natural waste materials has become the area of interest for many scientists all over the world dealing with materials engineering and polymer processing. Compared to the widely popular mineral filler and glass and carbon fibers, the addition of natural fillers and fibers to the polymer matrix can be more beneficial owing to their low cost, low density and environmental friendliness due to rapid biodegradation. The increased use of natural materials in producing composite materials has led to the creation of a new class of materials called biocomposites. This term refers to materials in which at least one phase, i.e., matrix or reinforcement/filler, is made of natural materials. One example

of such materials are plant fibers which, depending on the plant species, can be produced from pips, stems, leaves or fruit. Composite materials are produced using fibers made from stems and leaves, e.g., wood, cotton, wool, silk, kenaf, etc. Fillers either naturally occur in the form of fine particles or are subjected to grinding. In the literature of the subject one can find numerous examples of natural fillers, including rice bran, banana powder, argan nut shell, vanilla, wood powder, switch grass, and many more. The objective of this study is assessment of chemical resistance of low density polyethylene modified with natural filler. The natural filler used in the tests were pumpkin seed hulls obtained from a company dealing with the purification and sales of pumpkin seeds. Hulls are a waste material produced by the mechanical hulling and purification of pumpkin seeds. The main component of pumpkin seed hulls are mixtures of polysaccharide substances (cellulose, hemicellulose, pectin, gum, slime mold) and non-polysaccharide substances (lignin). The fillers were first ground to powder using a grain mill. After that, fractions with different particle sizes were separated using a sieve shaker for particle sizing. This led to the production of a fraction with the grain size ranging between 0.2mm and 0.4mm. 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. 1113
Virtual Room 1
Wednesday
July 20
13h10

THE BEHAVIOR OF MULTI BOLTED CONNECTION IN PULTRUDED GFRP: ON STRENGTHENING BY GLASS FIBER SHEETS

Tran Quang Duc (tran.quang.duc.wq@tut.jp), Toyohashi University of Technology, Japan
Phan Viet Nhut (phan.viet.nhut.yu@tut.jp), Toyohashi University of Technology, Japan
Matsumoto Yukihiro (matsumoto.yukihiro.lp@tut.jp), Toyohashi University of Technology, Japan

Multi-bolted connections are typically used to connect the Pultruded GFRP (PGFRP) members in the civil engineering field. As a result, the load-carrying capacities of PGFRP structures are usually affected by the connection strengths. Recently, research on the improvement of strengths of PGFRP connections has attracted many researchers. In this study, 48 types of multi-bolted PGFRP connections, including non-strengthened specimens and specimens strengthened by glass fiber sheets (GFSs), were experimentally tested to characterize the failure modes and failure loads. The effects of strengthening are measured with three kinds of GFSs: 0/90 degree, plus or minute 45 degree and chopped strand mat (CSM). Two end-distance/diameter ratio cases were applied (e=2d and e=3d), and three kinds of bolt numbers were used: 2, 4, and 5. The effects of the tightening forces on the connection strengths were also considered in this study. The experimental results show that GFSs could significantly improve the strengths of multi-bolted connections. The connection strengths were increased when the tightening forces were applied for the connections. In addition, the integration equations were proposed to predict the connection strengths of multi-bolted PGFRP connections with and without GFS strengthening.

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abst. 1115
Repository

MODELLING OF THE EFFECT OF THE MICROSTRUCTURE SIZE ON VIBRATIONS OF PERIODIC SLENDER BEAMS

Jędrysiak, Jarosław (jarek@p.lodz.pl), Łódź University of Technology, Department of Structural Mechanics, Poland

The main objects of considerations in this contribution are slender elastic beams, which have a periodic microstructure along their axis (the x-axis). Beams of this kind are consisted of many identical small elements, called periodicity cells. The cell length l is treated as the microstructure parameter. Partial differential equations describe dynamic and/or stability problems of such beams. These governing equations have highly-oscillating, periodic and non-continuous functional coefficients in x, unfortunately. Thus, they are not a good tool to investigate mechanical problems of these beams. Hence, different simplified approaches, introducing effective properties of the beam, are proposed to derive governing equations with constant coefficients. Between them it should be mentioned methods based on the asymptotic homogenization, cf. [6]. Modelling of the problems of dynamics or stability of periodic beams are considered in many papers. Between various approaches it could be distinguished the theory

of Floquet-Blochcan, as often applied in the waves analysis. Vibrations of the Euler-Bernoulli beam were analysed using this theory in [1]. Some analytical approaches and/or the finite element method were applied to evaluate strength and buckling of sandwich beams with variable properties of cores, e.g. [3]. Unfortunately, the effect of the microstructure size on the beam behaviour is usually neglected in the governing equations of the above mentioned models. In this contribution the differential equations of periodic beams, having highly-oscillating, periodic, non-continuous functional coefficients, are replaced by equations with constant coefficients, using the tolerance modelling, cf. [8]. This approach was applied for the analysis of thermomechanical problems of periodic composites and structures in a series of papers, e.g. for dynamic response of micro-periodic beams under moving load [7], for vibrations of thin periodic plates [4], for geometrically nonlinear vibrations of periodic beams [2]. This note is a certain continuation of the paper [5], where tolerance models equations of similar beams were derived in extended forms. Here, it is also shown the effect of the microstructure on vibrations of a simply supported periodic beam. Keywords: Periodic beams; Microstructure; Tolerance modelling; Vibrations; Stability. References: [1] CHEN, T. (2013) Investigations on flexural wave propagation of a periodic beam using multi-reflection method, Archive Of Applied Mechanics 83, 315-329. [2] DOMAGALSKI, Ł., JĘDRYSIAK, J. (2016) Nonlinear vibrations of periodic beams, Journal of Theoretical and Applied Mechanics 54, 1095 1108. [3] GRYGOROWICZ, M., MAGNUCKI, K., MALINOWSKI, M. (2015) Elastic buckling of a sandwich beam with variable mechanical properties of the core, Thin-Walled Structures 87, 127-132. [4] JĘDRYSIAK, J. (2009) Higher order vibrations of thin periodic plates, Thin-Walled Structures 47, 890-901. [5] JĘDRYSIAK, J. (2021) Non-asymptotic modelling of dynamics and stability for visco-elastic periodic beams on a periodic damping foundation, Composite Structures 259, https://doi.org/10.1016/j.compstruct.2020.113442. [6] KOLPAKOV, A.G. (1991) Calculation of the characteristics of thin elastic rods with a periodic structure, Journal of Applied Mathematics and Mechanics 55, 358-365. [7] MAZUR-ŚNIADY, K., ŚNIADY, P. (2001) Dynamic response of a micro-periodic beam under moving load – deterministic and stochastic approach, Journal of Theoretical and Applied Mechanics 39, 323-338. [8] WOŹNIAK, C., MICHALAK, B., JĘDRYSIAK, J. (EDS). (2008) Thermomechanics of microheterogeneous solids and structures. Tolerance averaging approach, Lodz Univ. Techn. Press, Lodz, Poland.

A BI-AXIALLY ZERO POISSON'S RATIO MORPHING SKIN SYSTEM

abst. 1143
Room B032
Tuesday
July 19
12h30

Kölbl, Michael (mkoelbl@ethz.ch), ETH Zürich, Laboratory of Composite Materials and Adaptive Structures, Switzerland
Ermanni, Paolo (permanni@ethz.ch), ETH Zürich, Laboratory of Composite Materials and Adaptive Structures, Switzerland

Structural skins for aeronautical applications must withstand high loads, inhospitable environments and provide a high local out-of-plane stiffness in combination with a smooth and closed aerodynamic surface. To broaden the applicability of morphing skins and simultaneously fulfil their contradicting requirements, a layered, bi-axially morphing skin (LMS) concept, based on stiff, overlapping platelet stacks was recently developed. The LMS can be applied to morphing scenarios with two-dimensional strain states, such as camber morphing transition regions, and it can undergo strains up to 30%. However, a structural support must be developed for counteracting the decrease of out-of-plane stiffness and sagging of the LMS when applied over large morphing areas. In this work, a bi-axially zero Poisson's ratio metastructure which provides structural support to the skin is combined with a modified LMS. The metastructure's design idea is based on alternating, planar double-walled corrugations (DWC) in both in-plane directions. As mass is critical for aeronautical applications, the metastructure is manufactured from corrugated thin-ply CFRP composite strips, stiffened with CFRP sandwich at the bases of the DWCs. By selectively bonding the strips with the CFRP sandwich and subsequently arranging them in a grid like pattern, the alternating corrugation pattern of the metastructure is created which results in bi-axial zero Poisson's ratio. The height of the strips, and therefore the height of the lattice can be chosen freely. The modified LMS is a highly anisotropic structural metamaterial based on stiff overlapping platelets interconnected by the underlying metamaterial. Combining the lattice structure with the overlapping platelets results in high out-of-plane stiffness, two-dimensional in-plane compliance and large bi-axial deformability of the skin. The overlapping platelets provide a closed, albeit not perfectly smooth surface. The anisotropy and the mechanical properties of the morphing skin system will be quantified experimentally and numerically. A comparison to a conventional LMS which simply consists of compliantly connected platelets without underlying metastructure will be performed. A morphing skin with high out-of-plane stiffness and a close to zero Poisson's ratio in both in-plane directions, fully decouples the in-plane deformations and can expand the applicability of morphing skins. Therefore, the presented skin system is a candidate as structural skin for applications beyond UAV size and for simultaneous span and camber morphing, enhancing the efficient flight envelope of morphing wings.

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abst. 1149
Virtual Room 1
Wednesday
July 20
16h10

Investigation of bond strength and laminate quality of fibre-metal laminate made of laser-structured Aluminium sheet and CFRP reinforcement

Wu, Shuang (shuang.wu@uni-paderborn.de), Paderborn University, Chair of Automotive Lightweight Design (LiA), Germany
Delp, Alexander (alexander.delp@tu-dortmund.de), TU Dortmund University, Chair of Materials Test Engineering (WPT), Germany
Freund, Jonathan (Jonathan.Freund@dlr.de), German Aerospace Centre, Institute for Material Research, Germany
Haubrich, Jan (Jan.Haubrich@dlr.de), German Aerospace Centre, Institute for Material Research, Germany
Tröster, Thomas (thomas.troester@uni-paderborn.de), Paderborn University, Chair of Automotive Lightweight Design (LiA), Germany
Walther, Frank (frank.walther@tu-dortmund.de), TU Dortmund University, Chair of Materials Test Engineering (WPT), Germany

With increasing demands on environmental protection and the reduction of CO2 emissions in the automotive sector, the development of innovative lightweight design strategies for vehicles is a significant research focus. Therefore, fibre-reinforced plastics (FRP) are increasingly being used because of their high lightweight potential. For enhanced material utilisation and cost reduction, FRP is often applied on metal structures according to the load cases. To produce such hybrid structures, the "hybrid prepreg press process" was investigated at the Chair of Automotive Lightweight Design at the University of Paderborn. It is an intrinsic manufacturing process in which the joining and shaping of the metal and FRP components will take place simultaneously, and therefore reduce cycle times. As part of a DFG-funded collaborative research project "HerKoLas", the process parameters of the prepreg pressing process are being further narrowed down and optimised, so that a component-like structure such as a hat profile made of laser-structured aluminium sheets and a thermoset CFRP prepreg can be formed simultaneously. In this presentation, the results of the basic investigations are presented and discussed. 3-point bending tests were carried out to investigate the influence of the consolidation parameters (temperature, pressure, and time) on the mechanical properties of the CFRP-laminate and the laminate quality was evaluated at the microscopic level. Results so far show that the flexural strength increases with the increased pressure and the laminate quality is improved. To determine the bond strength between the aluminium sheet and the CFRP-laminate, the Edge Shear test was used. In addition, thermal deformation in the fibre-metal-laminate due to different thermal expansion was also considered. For this purpose, different manufacturing strategies were used to handle the challenge. Finally, all the test results are then evaluated based on statistical methods to determine the best set of parameters for the subsequent manufacturing of complex structures.

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abst. 1154
Poster

The hydro-mechanical behaviour of biaxial woven fabric-reinforced Composites: Effect of weaving patterns

CHILALI, Abderrazak (chilalilism@gmail.com), National Preparatory School of Engineering Studies, Algeria

The present work aims at analysing the effect of weaving architecture on the hydro-elastic behaviour of biaxial woven fabric-reinforced composites. Three popular biaxial woven fabrics were considered: plain, twill and satin weaves. The composite heterogeneity is taken into consideration by modelling the yarn undulation with two geometric paths: sinusoidal and elliptical undulation. Only the diffusion across the thickness of the fibre strands is considered since the diffusion principally occurs across the thickness of the aged composites. The finite element simulations allowed to show the distribution at saturation of the von Mises stress through the 2D models of different woven fabric-reinforced composites. The distribution at saturation of the swelling deformation is also depicted. The obtained results reveal high mechanical stress concentrations for all especially at the fibre-matrix interface generated due to the moisture expansion mismatch between fibres and matrix.

Stochastic perturbation-based finite element model for structural responses of the graded composite structures with random material properties

abst. 1217
Repository

Amir, Mohammad (amiramu26@gmail.com), Mechanical Convergence Technology Institute, Hankyong National University, Anseong-si, Gyeonggi- do 17579, Republic of Korea, Republic of Korea
Talha, Mohammad (talha@iitmandi.ac.in), School of Engineering, Indian Institute of Technology Mandi, Himachal Pradesh, 175005, India, India
Kim, Sang-Woo (swkim@hknu.ac.kr), School of ICT, Robotics Mechanical Engineering, Hankyong National University, Anseong-si, Gyeonggi-do 17579, Republic of Korea, Republic of Korea

The graded composite structures have the great potential to be used in various engineering fields such as aerospace, mechanical, and marine engineering. Manufacturing graded composite structures is a quite complex and challenging task because it requires large numbers of design criteria that necessitate a smooth fluctuation of material properties in the structures. Meanwhile, graded composite structures often do not fully reflect the required gradient to the exact specification. Therefore, there are inherent uncertainties in the material and geometric properties of the structure, which leads to stochasticity in the micro and macro mechanical behavior of the graded composite structures. Thus, stochastic analysis of these structures having randomness in the material properties is crucial in order to ensure a safe and reliable design. The first-order perturbation technique is one of the most commonly used methods for the stochastic analysis of composite structures having low variability. In the present study, the probabilistic finite element model has been developed in conjunction with the first-order perturbation technique (FOPT) to assess the dispersion in the structural responses. The present formulation is validated using an independently developed Monte-Carlo simulations (MCS) model. The present probabilistic finite element model based on the first-order perturbation technique gives satisfactory results up to 20% variability.

Compression after impact behavior of STF-impregnated fabric composite subjected to low-velocity impact

abst. 1224
Repository

Lim, Jaehyeong (jhlim@hknu.ac.kr), Institute of Mechanical Convergence Technology, Hankyong National University, Anseong-si, Gyeonggi- do 17579, Republic of Korea, Republic of Korea
Kim, Sang-Woo (swkim@hknu.ac.kr), School of ICT, Robotics Mechanical Engineering, Hankyong National University, Anseong-si, Gyeonggi-do 17579, Republic of Korea, Republic of Korea

The carbon fiber reinforced polymer (CFRP) composite structures are susceptible to damage caused by unexpected impacts in various environments during manufacturing, in-service operations, maintenance, etc., which can lead to significant degradation in the residual strength of composite structures. Therefore, the evaluation of the degradation in residual strength using a compression after impact (CAI) test should be considered as one of the important issues for the design of composite structures. Meanwhile, a shear thickening fluid (STF) is a type of non-Newtonian fluid, including the shear thickening effect (STE), which can sharply increase the viscosity at the specific shear rate or shear stress. This study investigated the STE of STF, shear viscosity, and stress according to shear rate, using a

rotational rheometer. Moreover, an STF-impregnated fabric composite (STFFC) plate was proposed and fabricated by inserting the STF-impregnated woven carbon fabric into the CFRP laminate. Then, the low-velocity impact (LVI) and CAI tests were conducted for STFFC plates and fabric composite (FC) plates, and their responses were examined.

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abst. 1227
Repository

On crashworthiness behaviors of 3D printed multi-cell filled thin-walled structures under extreme temperature conditions

Yisen Liu (liuyisen@csu.edu.cn), Central South University, China
Kui Wang (kui.wang@csu.edu.cn), Central South University, China
Jin Wang (jin.wang@csu.edu.cn), Central South University, China
Jiangyang Xiang (xiangjiangyang@csu.edu.cn), Central South University, China
Yong Peng (yong_peng@csu.edu.cn), Central South University, China

In this study, based on additive manufacturing technique of fused deposition modeling, hexagonal thin-walled structures with different internal filling shapes and filling densities were fabricated using carbon-fiber-reinforced polyamide. The effects of filling densities and filling shapes on the crushing behaviors of the structures were investigated. Experimental results showed that with the increase of filling density, the specific energy absorption exhibited an upward trend while the crushing force efficiency increased first and then decreased. Hexagonal filled structures exhibited more stable deformation modes than those for circular and triangular filled structures. With the increase of strain rate, the thin-walled structures showed higher force levels during axial compression. In addition, compared with axial compression, the specific energy absorption and crushing force efficiency of structures under axial impact decreased significantly. The failure mode of thin-walled structures changed from ductile damage mode to brittle fracture mode with the decrease of temperature, and the peak crushing force increased significantly.

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abst. 1241
Poster

Drop reliability of Sn-MWCNT composite solder with IPL soldering

Kang, DongGil (jeanne9910@skku.edu), school of advanced materials scienceengineering, Sungkyunkwan univ., Republic of Korea
Noh, TaeJun (hokujoon@g.skku.edu), school of advanced materials scienceengineering, Sungkyunkwan univ., Republic of Korea
Jung, SeungBoo (sbjung@skku.edu), school of advanced materials scienceengineering, Sungkyunkwan univ., Republic of Korea

The reflow process is a high-temperature process that utilizes thermal energy and causes warpage and thermal damage problems. In order to overcome this problem, several alternative temperature processes have been studied. One of these alternative soldering process, is Intense Pulsed Light soldering, which enables large area soldering with short process time of several microseconds. Since lead-free solder was found to be harmful to the environment and human body, many lead-free solders have been studied. Among those lead-free solders, the Sn-3.0Ag-0.5Cu solder alloy composition has been commonly used, because of its excellent mechanical properties and reliability. In this study, because of the properties of MWCNT that can prevent the propagation of cracks in the solder, Sn-MWCNT and SAC305 composite material was synthesized to enhance drop reliability. Experiment condition of IPL soldering was different pulse widths (2, 2.25, and 2.5 ms) and pulse number. The bonding strength was analyzed through a ball shear test, and drop test was performed by JESD22-B110 standard. The microstructure and fracture surface of the solder were observed using a scanning electron microscope. Under the influence of Sn-MWCNT, the shear strength and drop reliability of Sn-MWCNT composite solder were higher than SAC305 solder without added Sn-MWCNT in all evaluation conditions.

Hybrid geometry projection method for additively manufactured fiber-reinforced composite laminate

abst. 1243
Room B032
Tuesday
July 19
12h50

Gandhi, Yogesh (yogesh.gandhi@unibo.it), University of Bologna, Italy
Minak, Giangiacomo (giangiacomo.minak@unibo.it), University of Bologna, Italy
Aragón, Alejandro (A.M.Aragon@tudelft.nl), Delft University of Technology, The Netherlands
Norato, Julian A. (julian.norato@uconn.edu), University of Connecticut, USA

Continuous fiber fused filament fabrication (CF4) allows the layer-by-layer printing of fiber-reinforced composites (FRC) with a spatial in-plane variation of the fiber orientation and fiber volume fraction, thus expanding the design space for variable and constant stiffness laminates. Because of these offered degrees of freedom, computational design tools such as topology optimization (TO) are essential to thoroughly obtain optimized layout designs that take advantage of FRC materials' anisotropic properties. Thus, we present a simultaneous topology and stacking sequence optimization for composite laminate structures. The method combines the geometry projection (GP) method and the solid isotropic material with penalization (SIMP) to effectively achieve the concurrent placement of FRC material in each lamina. In this method, the GP method represents the fiber bundles by considering endpoint locations of the isotropic bar's medial axes and their out-of-plane thicknesses. Furthermore, the isotropic matrix material is considered at each design point using SIMP formulation. Therefore, the multi-material method is termed as hybrid geometry projection (HGP) method. In addition, lamination parameters (LPs) are used as design variables to extend the approach to account for the anisotropic behavior of composite laminate. Finally, numerical problems are provided to demonstrate the applicability of the proposed method considering only in-plane laminate stiffness.

Structural Analysis of a Temporary Shelter with Shape Memory Effect

abst. 1253
Room B032
Tuesday
July 19
13h10

Silva, Ana Rita (up201506013@fe.up.pt), Faculdade de Engenharia da Universidade do Porto, Portugal
Parente, Marco (mparente@fe.up.pt), Faculdade de Engenharia da Universidade do Porto/INEGI/LAETA, Portugal
Marques, António T. (marques@fe.up.pt), Faculdade de Engenharia da Universidade do Porto/INEGI/LAETA, Portugal
Areias, Bruno (bareias@fe.up.pt), Faculdade de Engenharia da Universidade do Porto/INEGI/LAETA, Portugal
Rangle, Bárbara (brangel@fe.up.pt), Faculdade de Engenharia da Universidade do Porto, Portugal
Alves, Fernado J. Lino (falves@fe.up.pt), Faculdade de Engenharia da Universidade do Porto/INEGI/LAETA, Portugal
Costa, Alice (), Faculdadaea de Engenharia da Universidade do Porto, Portugal
Figueiredo, Miguel (mfiguei@fe.up.pt), Faculdadaea de Engenharia da Universidade do Porto, Portugal
Esteves, José Luís (jesteves@fe.up.pt), Faculdadaea de Engenharia da Universidade do Porto, Portugal

This paper presents studies, from a structural point of view, a previously developed sheltering solution, characterized by an origami structure printed in a shape memory polymer activated by heat — DiAPLEX MM45-20. A fast and easy-assembly shelter is essential to displaced people that suffer from the loss of their house. A thorough investigation on temporary housing was held. From the most commonly used shelters to newly developed ones, their characteristics, advantages, and drawbacks were analyzed. Humanitarian organizations establish guidelines and requirements for temporary shelters in documents such as The Sphere Handbook. A review on DiAPLEX MM45-20 showed the need for a material characterization to determine the Elastic Modulus, as well as to understand the influence of the printing direction on this property. This material shows a shape memory effect, which means the shelter can be closed for transportation reasons and then, later on, heated to 45°C and it will deform back to its initial shape. In order to validate the shelter previously developed, the loads applied to the shelter were calculated according to the Eurocode: overload, self-weight, wind, and snow. Then, using the Finite Element Method and ABAQUS ®, several solutions — reinforced material, the addition of

pillars, reinforcement with a skeleton of bars and a sandwich structure — were analyzed with the goal of achieving the requirement defined by Eurocode in terms of maximum displacement, having in mind the shelter's mass. The sandwich structure solution is the most promising one and, consequently, a sensitivity analysis was performed in order to understand how to achieve the optimal structure to apply to the shelter.

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abst. 1263
Room B032
Wednesday
July 20
17h30

Study of structural features and electric conductivity in bi-metallic composite conductors

Kocich, Radim (radim.kocich@vsb.cz), Faculty of Materials Science and Technology, VŠB–Technical University of Ostrava, Czech Republic
Kunčická, Lenka (kuncicka@ipm.cz), Institute of Physics of Materials, Czech Academy of Sciences, Czech Republic
Kačor, Petr (petr.kacor@vsb.cz), Department of Electrical Power Engineering, VŠB–Technical University of Ostrava, Czech Republic

This study is focused on determining the relations between electric properties and selected structural features for newly designed Al/Cu composite conductors manufactured via room temperature rotary swaging process. After swaging, the final composite bi-metallic conductors were subjected to two post-process annealing treatments. The structure analyses evaluating the effects of thermomechanical processing were performed via scanning and trans-mission electron microscopies. The electric properties of the composites were numerically simulated using models designed according to the real conditions and subsequently experimentally verified. Both, direct and alternate current were used for verification. The results showed that the electric resistivity was affected particularly by the structure development such as bimodal grain size, presence of twins, and, last but not least, dislocations density. Mutual proportion of Al and Cu across the area of the bi-metallic conductor cross-section was among the influencing factors too. The results revealed that fabrication of the composite via the technology of rotary swaging introduced more advantageous combinations of electric and mechanical properties than conventional manufacturing techniques. Among others, the design of the composite has favourable effect on decreasing the power losses during alternating current transfer and that the substructure development affected favourably the electric resistance of the conductor. The lowest specific electric resistivity of 20.6 m×10-9 was measured for the composite conductor after annealing treatment at 350 °C, which imparted significant degree of structure restoration. Applied annealing at 250 °C caused the occurrence of relatively small restored grains with randomized preferential orientations and substantial deterioration of electric properties.

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abst. 1265
Repository

Theoretical Model for Novel FRP-UHPC Hybrid Bars

Yu-Yi Ye (yuyiyet@163.com), Guangdong University of Technology, China
Jun-Jie Zeng (jjzeng@gdut.edu.cn), Guangdong University of Technology, China

Fibre-reinforced polymer (FRP)-confined ultra-high performance concrete (UHPC) encased FRP bar (referred to as FRP-UHPC hybrid bars or steel-free hybrid bars) have been proposed to address the issue that the compressive strength of FRP bars is much inferior than their tensile strength as a result of fibre buckling. The central FRP bars in hybrid bars perform a much better compressive behaviour than a bare FRP bar under compression; and the hybrid bars exhibit an elastic-strain hardening stress-strain behaviour based on existing studies. To facilitate design of hybrid bar-reinforced structural members, this paper develops a theoretical model for hybrid bars under axial compression for the first time, with the average stress-strain behaviour of the FRP-confined UHPC, the FRP tube and the central FRP bar within a hybrid bar being properly estimated. A modified three-portion stress-strain model is proposed for the FRP-confined UHPC, and a simplified model accounting for the biaxial behaviour of the FRP tube is adopted to determine the stress-strain behaviour of the FRP tube. Additionally, the central FRP bar in hybrid bars is modelled by a polyline. Predictions based on the theoretical model are in line with the test results.

Mainshock-aftershock Seismic Performance of GFRP-jacketed RC Bridge Piers: Experimental and Numerical Studies

abst. 1271
Virtual Room 1
Wednesday
July 20
16h50

Hossain, Md. Mosharef (mosharef.ce@gmail.com), The University of British Columbia, Canada
Wakjira, Tadesse G. (tadiegw@mail.ubc.ca, twakjira@qu.edu.qa), The University of British Columbia, Canada
Alam, M. Shahria (shahria.alam@ubc.ca), The University of British Columbia, Canada

This study investigated the seismic performance of shear-deficient reinforced concrete (RC) bridge piers repaired and retrofitted with glass fiber reinforced polymer (GFRP) jacket subjected to a combined axial loading and repeated sets of lateral cyclic loading to represent the condition of post-earthquake aftershocks that may cause the collapse of already damaged bridges. Experimental and numerical results of GFRP repaired and retrofitted deficient RC bridge piers were used to assess the efficacy of GFRP jackets. Two deficient RC bridge piers were initially designed that represent the pre-1970 bridge design code having much less confinement. The first column was tested until failure without GFRP jacket to act as a reference. The damaged bridge pier was then repaired and retrofitted with GFR. Another deficient column was retrofitted with GFRP jacket before it is subjected to any loading. The results of the experimental and numerical analysis revealed the efficacy of the GFRP system to improve the performance of deficient and damaged RC bridge piers subjected to aftershocks. The GFRP jacket enhanced the lateral strength of the retrofitted bridge piers by 27%. Moreover, the strengthening system significantly improved the drift capacity of the pier.

Effects of clearance fits on composite single lap bolted joints

abst. 1277
Repository

Singh, Baij Nath (singhbaij03@gmail.com), Indian Institute of Technology (ISM) Dhanbad, India
Ranjan, Vinayak (ranjan@rowan.edu), Rowan University, U.S.A
Hota, R.N. (rnhota@iitism.ac.in), Indian Institute of Technology (ISM) Dhanbad, India

High weight sensitivity of aircraft structures have resulted into increased usage of composites. Assembly of these aircraft structures calls for different joining techniques such as co-curing, co-bonding or bolted joints. But in order to have accessibilities in many regions, bolted joints are preferred over co-cured or co-bonded joints. The thesis work represents an approach for establishing a non-linear contact analysis methodology for composite single lap joint. The study was carried out in two stages. In the first stage, different parametric studies were carried out for an isotropic single lap joint and a composite single lap joint which helped in understanding contact parameters and contact output. At the end of first stage, final contact interaction properties were finalized for the given problem. In the second stage of clearance fit were modeled with four different clearance values (0 µm, 20 µm, 40 µm and 60 µm) using the finalized contact interactions. The author would like to mention here that the composite single lap joint used is as per standards ASTM D5961/D5961 M-10. Here non-linear contact behavior of the lap joint is simulated using ABAQUS CAE 2019 as a pre- and post- processor and ABAQUS as a solver. Comparison of contact forces, contact stresses along contact paths with respect to radial angle with varying clearance showed good approximation with previous deduction deduced from various literatures, i.e. there is corresponding reduction in contact area, contact forces, contact pressure, contact shear stress but there was correspondingly higher increase in radial and von mises stress of paths in contact due to increase in clearance from 0 µm to 60 µm.

Axial Compressive Behavior and Model Assessment of FRP-confined Seawater Sea-sand Concrete-Filled Stainless Steel Tube Stub Columns

abst. 1282
Repository

Jun-Jie ZENG (jjzeng@gdut.edu.cn), Guangdong University of Technology, China
Jinjing Liao (liaojj@gdut.edu.cn), Guangdong University of Technology, China

Concrete-filled steel tube (CFST) columns have corrosion issues in coastal/offshore constructions. Thus, an FRP-confined seawater sea-sand concrete (SSC)-filled stainless stain tube (SST) column (F-SSCFSST) is proposed to mitigate the corrosion problems. Meanwhile, using SSC can also relieve the overexploitation on river-sand. The axial compressive behavior of F-SSCFSST columns is investigated in this study through testing 12 pairs of specimens (two duplicates in a pair) including 6 pairs of F-SSCFSST, 4 pairs of SSCFSST, and 2 pairs of unconfined concrete. The SST thickness, the FRP thickness, and the concrete strength are the key parameters. F-SSCFSST specimens exhibited strain hardening response with the full activation segment as a second ascending line. The SST confinement was insignificant that increasing the SST thickness led little difference in strength index and axial strain enhancement ratio. While the strength index and strain enhancement ratio increased almost linearly with the FRP thickness. Increasing concrete strength would result in a smaller strength index and axial strain enhancement ratio due to the brittleness of high strength concrete. In addition, the performances of seven load capacity prediction models and two ultimate axial strain estimating equations were evaluated using the test results. With minor modifications, Lam and Teng's model had the best performance in predicting the load carrying capacities of the specimens with an average absolute error at only 3.9%.

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abst. 1300
Repository

Effects of high pulling speeds on mechanical properties and morphology of pultruded flat laminates

Vedernikov, Alexander (aleksandr.vedernikov@skoltech.ru), Skolkovo Institute of Science and Technology, Russia
Gemi, Lokman (lgemi@erbakan.edu.tr), Necmettin Erbakan University, Turkey
Madenci, Emrah (emadenci@erbakan.edu.tr), Necmettin Erbakan University, Turkey
Özkılıç, Yasin Onuralp (yoozkilic@gmail.com), Necmettin Erbakan University, Turkey
Yazman, Şakir (syazman@selcuk.edu.tr), Selçuk University, Turkey
Bondareva, Julia (J.Bondareva@skoltech.ru), Skolkovo Institute of Science and Technology, Russia
Evlashin, Stanislav (S.Evlashin@skoltech.ru), Skolkovo Institute of Science and Technology, Russia
Akhatov, Iskander (I.Akhatov@skoltech.ru), Skolkovo Institute of Science and Technology, Russia
Safonov, Alexander (A.Safonov@skoltech.ru), Skolkovo Institute of Science and Technology, Russia

Pultrusion is a highly efficient manufacturing process that allows to produce composites having constant cross section. Economic efficiency of the pultrusion might be significantly increased when high pulling speeds are utilized, however, the structural performance of such composites must not be compromised. This experimental study of pultruded glass/vinyl ester composites analyzed the correlations between morphology, flexural, interlaminar shear mechanical properties of pultruded flat laminates, and values of regular/high pulling speeds. Four batches of 150 $\times$ 3.5 mm flat laminates were produced at pulling speeds of 0.2, 0.6, 1, and 1.4 m/min. Optical and Scanning electron microscopies were used to analyze the effects of regular and high pulling speeds on the morphology of flat laminates. Raman and Fourier-transform infrared spectroscopies were utilized for the analysis of the composites' chemical uniformity and property variation as functions of pulling speed. Flexural and interlaminar shear properties were determined in both 0° and 90° fiber orientations. Growth of pulling speed results in decrease of mechanical propertis and their greater variability. The observed difference in the strength characteristics of flat laminates is explained by the presence of bubbles/bubbles/voids, bundles, delaminations, matrix cracks, as well as an increase in their size and density with growth of the pulling speed. The outcomes of this investigation are of high importance for the better understanding of high speed pultrusion.

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abst. 1330
Virtual Room 2
Wednesday
July 20
12h50

On nonlinear behavior of small-scale composite beams

Vaccaro, Marzia Sara (marziasara.vaccaro@unina.it), Department of Structures for Engineering and Architecture, University of Naples Federico II, Italy
Barretta, Raffaele (rabarret@unina.it), Department of Structures for Engineering and Architecture, University of Naples Federico II, Italy
Marotti de Sciarra, Francesco (marotti@unina.it), Department of Structures for Engineering and Architecture, University of Naples Federico II, Italy

A wide class of advanced ultra-small devices, such as miniaturized actuators, sensors, switches and storage systems, are based on nano-enhanced beams undergoing large configuration changes to absolve their working mechanism (see e.g. [7, 5, 4]). Thus, a challenging topic in scientific literature concerns geometrically nonlinear analysis of miniaturized structures made of nanocomposite materials [6, 2, 3]. Design and optimization of such systems require a proper modeling of size effects since it is well-acknowledged that when dealing with micro/nano-structures there are long-range interactions that cannot be overlooked [1]. At the same time, a refined assessment of constitutive properties of nanofillers is needed since scale effects also influence constitutive features of nano-enhancers. The present work aims at providing a consistent approach to tackle applicative problems dealing with nano-enhanced small-scale beams undergoing large displacements. Properties of nanofillers are first evaluated exploiting a novel approach inspired by Homogenization Theory. Then, effective constitutive properties of nanocomposite are investigated. Size effects on mechanical behavior of nanocomposite beams are modeled following consistent nonlocal methodologies. Finally, an effective solution procedure is exploited to solve exemplar geometrically nonlinear beam problems and to evaluate the effect of nanofillers and length-scale parameter on structural responses. References: [1] Abazari, A.M., Safavi, S.M., Rezazadeh, G., Villanueva, L.G., 2015. Modelling the size effects on the mechanical properties of micro/nano structures. Sensors 15, 28543–28562. [2] Fang, C., Chen, X., Zhang, J., Xia, X., Weng, G.J., 2021. Monte Carlo method with Bezier curves for the complex conductivity of curved CNT-polymer nanocomposites. International Journal of Engineering Science 168, 103543. [3] Lee, S., Jung, J., Kim, Y., Kim, Y., Ryu, S., 2021. Multiscale modeling framework to predict the effective stiffness of a crystalline-matrix nanocomposite. International Journal of Engineering Science 161, 103457. [4] Ling, M., Zhang, X., 2021. Coupled dynamic modeling of piezo-actuated compliant mechanisms subjected to external loads. Mechanism and Machine Theory 160, 104283. [5] Pinskier, J., Shirinzadeh, B., Al-Jodah, A., 2021. Design and evaluation of a dual-stage, compensated stick-slip actuator for long-range, precision compliant mechanisms. Sensors and Actuators A: Physical 331, 113007. [6] Sun, Y., Hu, Y., Liu, M., 2021. Elasto-plastic behavior of graphene reinforced nanocomposites with hard/soft interface effects. Materials and Design 199, 109421. [7] Verotti, M., Berselli, G., Bruzzone, L., Baggetta, M., Fanghella, P., 2021. Design, simulation and testing of an isotropic compliant mechanism. Precision Engineering 72, 730–737.

Integral elasticity theories for composite structures

abst. 1331
Repository

Vaccaro, Marzia Sara (marziasara.vaccaro@unina.it), Department of Structures for Engineering and Architecture, University of Naples Federico II, Italy

Pinnola, Francesco Paolo (francescopaolo.pinnola@unina.it), Department of Structures for Engineering and Architecture, University of Naples Federico II, Italy

Barretta, Raffaele (rabarret@unina.it), Department of Structures for Engineering and Architecture, University of Naples Federico II, Italy

Marotti de Sciarra, Francesco (marotti@unina.it), Department of Structures for Engineering and Architecture, University of Naples Federico II, Italy

Since first contributions in [1, 2], Nonlocal Continuum Mechanics provides still open questions concerning consistency of integral theories of internal and external elasticity. In the present work, well-posedness of nonlocal continuum problems is analysed and discussed with reference to applicative structural schemes involving composite materials. First, a variational approach is adopted to derive a consistent nonlocal formulation of elasticity for inflected functionally-graded beams. Starting from the obtained abstract formulation, strain- or stress-driven integral theories of internal elasticity and displacement- or reaction-driven integral theories of external elasticity are derived. It is shown that, when dealing with internal elasticity, adoption of strain-driven nonlocal theory [3] leads to ill-posed structural problems since incompatibility arises between constitutive and equilibrium requirements [4]. Stress-driven integral theory of internal elasticity [5] provides instead well-posed nonlocal continuum problems and thus can be effectively exploited to model size-dependent mechanical behaviors. On the contrary, in the framework of integral theories of external elasticity, nonlocal models based on a reaction-driven formulation provides ill-posed structural problems due to incompatibility between constitutive and kinematic conditions [7, 8]. Instead, it is proven that displacement-driven nonlocal theory of

external elasticity [9] provides a consistent and well-posed nonlocal methodology. Nonlocal problems of composite continua are finally solved and discussed. Benchmark results are illustrated and commented upon. References: [1] Kr ¨oner, E., "Elasticity theory of materials with long range cohesive forces", International Journal of Solids and Structures 3(5), 731–742 (1967). [2] Rogula, D., "Introduction to nonlocal theory of material media", Nonlocal theory of material media, CISM courses and lectures, D. Rogula ed., Springer, Wien, 268, 125–222 (1982). [3] Eringen, A.C., "On differential equations of nonlocal elasticity and solutions of screw dislocation and surface waves", Journal of Applied Physics 54, 4703 (1983). [4] Romano, G., Barretta, R., Diaco, M., Marotti de Sciarra, F., "Constitutive boundary conditions and paradoxes in nonlocal elastic nanobeams", International Journal of Mechanical Sciences 121, 151–156 (2017). [5] Romano, G., Barretta, R., "Nonlocal elasticity in nanobeams: the stress-driven integral model", International Journal of Engineering Science 115, 14–27 (2017). [6] Wieghardt, K., " ¨Uber den Balken auf nachgiebiger Unterlage", Zeitschrift f ¨ur Angewandte Mathematik und Mechanik 2, 165–184 (1922). [7] van Langendonck, T., "Beams on deformable foundation", Memoires AIPC 22, 113–128 (1962). [8] Sollazzo, A., "Equilibrio della trave su suolo di Wieghardt", Tecnica Italiana 31, 187–206 (1966). [9] Vaccaro, M.S., Pinnola, F.P., Marotti de Sciarra, F., Barretta, R., "Elastostatics of Bernoulli–Euler beams resting on displacement-driven nonlocal foundation", Nanomaterials 11, 573 (2021).

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abst. 1354
Repository

Noise reduction response of additively manufactured structure

Dddaman, Snita (mrd7819@gmail.com), NUT, India
Kmar, Nan (mrd1978@rediffmail.com), ,
Shrvast, Bhvna (mrd7819@gmail.com), ,

Noise reduction response of additively manufactured panel is investigated. The 3D printed samples of a special class of Poly Lactic Acid (SPLA) having porosity are subjected to acoustic tests. Different perforations with varying cross sections are realised through fused deposition modelling based additive manufacturing processing route. The different perforations explored in the panels are divergent, convergent, divergent and convergent, convergent and divergent and the two perforations of different dimeters. The impedance tube technique is utilised to evaluate sound transmission loss and sound absorption. For a given frequency range, perforations of cross section having variations has the better noise reducing capabilities. The divergent and divergent convergent exhibited lower sound transmission losses as compared to other cross sectional varying perforations. The design of soundproof panels is prominently governed by the geometrically varying cross sections in perforating panels.

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abst. 1391
Repository

Performance of a lightweight concrete-bamboo composite beam

Moy, Charles K.S. (cloo8000@uni.sydney.edu.au), Xi'an Jiaotong-Liverpool University, China

The construction industry is moving towards more sustainable materials, and although that presents many challenges, efforts are being made to use less conventional and more sustainable materials. From that perspective, this work studies the behaviour of a newly designed lightweight composite beam comprised of lightweight concrete and bamboo layers as reinforcement. A few variations are presented to study the most efficient configuration and the failure mode. In summary, reasonable strength and ductility were achieved for the tested specimens, and the bamboo was able to resist both moment and shear forces under four-point bending tests. Most importantly, the failure and fracture behaviours were very instructive for the future design of such composites for use as structural members.

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abst. 1397
Virtual Room 1
Wednesday
July 20
16h30

On the use of Double – Double advanced material processing for the design of a composite fuselage barrel.

Di Caprio, Francesco (f.dicaprio@cira.it), Italian Aerospace Research Centre, Italy

Tsai, Stephen W. (), Department of Aeronautics and Astronautics, Stanford University, USA
Riccio, Aniello (aniello.riccio@unicampania.it), University of Campania "Luigi Vanvitelli", Department of Engineering, Italy
Russo, Angela (angela.russo@unicampania.it), University of Campania "Luigi Vanvitelli", Department of Engineering, Italy

Nowadays, the problem of pollution is strongly considered in the transportation industry, which is one of the major contributors to fuel emission and, therefore, to global pollution. In the aeronautical field, the legislation on exhaust emissions is becoming increasingly severe, hence, the reduction of airplane structural weight is seen as one of the possible solutions to decrease the fuel consumption and emissions for future vehicles. To improve lightweight aerospace design, metallic components are expected to be replaced by composite parts (mainly Carbon Fibre Reinforced Polymers), resulting in structures with superior performances and considerably lower weight. Despite the real potential, in terms of weight/stiffness and weight/strength characteristics, of composite materials, the classical design approach, which assumes symmetric and balanced laminates, still have major limitations. Hence, in this paper, the new family of Double-Double (DD) laminates [1-2], characterized by an homogenized mechanical behaviour, arbitrary choice of lamination angles and easy of production, are used to redesign a composite fuselage barrel starting from a traditional [0,90,+45-45]ns quad composite stacking sequence. The Lam search optimization tool [2-4] in combination with A Finite Element platform has been used to find the best DD angles configuration and the best thickness distribution fulfilling the strength requirements and considerably reducing the structural weight if compared to the standard composite quad design approach.

Flexural Behavior Evaluation of Repaired High Strength Geopolymer Concrete

abst. 1403
Room B032
Wednesday
July 20
12h50

Tashan, Jawdat (jawdat.tashan@ukh.edu.krd), University of Kurdistan Hewlêr, Iraq

CO2 is released into the atmosphere during the manufacture of ordinary Portland cement (OPC). To replace OPC in high-strength Portland cement concrete (HSPC), ground granulated blast furnace slag (GGBS) is utilized. GGBS is a by-product of the blast furnace used for iron manufacturing. It has a high silicate gel content and is used with an alkaline solution to produce good concrete. This paper investigates the load-deformation behavior of high-strength reinforced geopolymer concrete (HSGC) beams that were tested in flexure and were repaired by injecting epoxy. Six beams were placed using HSGC and HSPC. The original and repaired HSGC beams were tested, and deflections were measured. As a repair technique, crack injection is employed. All beams were evaluated for failure under static stresses, then repaired with epoxy resin injection and re-tested for flexural strength. The maximum deflection, ultimate load, cracking load, and crack pattern were all determined. For both the original and repaired beams, load versus deflection graphs were generated. The flexural behavior of a repaired HSGC beam constructed with GGBS was clearly demonstrated in this experimental study. The findings suggest that the restored HSGC beams' strength is equivalent to that of the original beams. The total strength of the beam has been recovered. The cracks do not re-open after retesting. Instead, new nearby cracks developed, and the repaired beams showed greater ductility than the original beams.

Impact characteristics of Quartz fiber/PEEK-MWNTs folded core sandwich radar-absorbing thermoplastic composites

abst. 1405
Virtual Room 2
Thursday
July 21
15h10

Ji-Sub Noh (jisubnoh12@gnu.ac.kr), Gyeongsang National University, Republic of Korea
Byeong-Su Kwak (bs.kwak@gnu.ac.kr), Gyeongsang National University, Republic of Korea
Jin-Hwe Kweon (jhkweon@gnu.ac.kr), Gyeongsang National University, Republic of Korea
Young-Woo Nam (ywnam@gnu.ac.kr), Gyeongsang National University, Republic of Korea

Many studies have been conducted on the impact behavior of radar absorbing structures in which multi-walled carbon nanotubes (MWNTs) are dispersed based on macro-scale, but there is an insufficient study based on micro-scale. Effective multi-scale modeling that connects the local microscopic properties (e.g., nanoparticles) to the macroscopic properties is required to evaluate the effect of MWNTs on composite structures' mechanical properties. So, this study aims to assess the impact characteristic of the radar absorbing folded core sandwich structure combining MWNTs using multi-scale modeling. The folded core consisted of Quartz fiber and Polyether ether ketone (PEEK) with excellent mechanical properties, and MWNTs were dispersed in PEEK to improve mechanical and electrical properties. The folded core was designed to implement radar-absorbing structures in the bandwidth of 4.0 - 18 GHz. In order to derive effective properties on composite materials with MWNTs, micro-modeling was carried out by Mori-Tanaka's mean-field homogenization theory. The impact analysis was conducted in LS-Dyna to evaluate the impact response of folded core sandwich structures using effective properties. The designed radar-absorbing folded core exhibited -10 dB microwave absorption in the almost target frequency range. The impact analysis results have shown that the proposed folded core has good impact resistance. Acknowledgement: This work was supported by the National Research Foundation of Korea (NRF) Grant funded by the Ministry of Science and ICT (NRF-2017R1A5A1015311) and by research on material durability evaluation according to long-term exposure to natural and operational environment conditions of Korea Aerospace Industries, LTD. (4747000157)

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abst. 1406
Virtual Room 2
Thursday
July 21
15h30

Electromagnetic wave absorption characteristics of radar absorbing structure based on ceramic matrix composites in Ultra-high temperature

Shin, Joon-Hyung (jhshin@gnu.ac.kr), Gyeongsang National University, Republic of Korea
Dong-Young Shim (sim_0523@gnu.ac.kr), Gyeongsang National University, Republic of Korea
Kweon, Jin-Hwe (jhkweon@gnu.ac.kr), Gyeongsang National University, Republic of Korea

In this paper, a single-layer radar absorbing structure (RAS) for ultra-high temperature microwave absorption was proposed by using ceramic fiber/aluminosilicate-Sendust composite. The ceramic fiber and aluminosilicate resin, with excellent heat and oxidation resistance, were used to fabricate the RAS applicable at ultra-high temperatures. The flake-shaped Sendust particles were dispersed in the aluminosilicate resin to increase the electrical properties of the matrix system. The microstructure characterization, phase identification, and magnetic properties of Sendust particle were examined by scanning electron microscope (SEM), X-ray diffraction (XRD), and vibrating sample magnetometer (VSM), respectively. The dielectric properties of ceramic fiber/aluminosilicate-Sendust composite were measured in X-band (8.2-12.4 GHz). To acquire an optimal design of the single-layer RAS, the Cole-Cole plot and complex permittivities of specimens with different Sendust contents were used. Then, the microwave absorption performance of fabricated RAS was measured by a free space measurement system at different temperatures from room temperature to ultra-high temperature. The results show that the radar absorbing performance of the proposed RAS was maintained until ultra-high temperatures. On the basis of test results, it was proved that the proposed RAS could be a promising candidate applicable to structures exposed to ultra-high temperature environments. Acknowledgement: This work was supported by the National Research Foundation of Korea (NRF) Grant funded by the Ministry of Science and ICT (NRF-2017R1A5A1015311 and NRF-2020R1C1C1006166).

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abst. 1407
Virtual Room 2
Thursday
July 21
15h50

Radar absorbing composite structures using periodic pattern surface with lightning strike protection and its application to leading edge

Shim, Dong-young (sim_0523@gnu.ac.kr), Gyeongsang National University, Republic of Korea
Shin, Joon-hyung (jhshin@gnu.ac.kr), Gyeongsang National University, Republic of Korea
Kang, Young-hun (rkd9368@gnu.ac.kr), Gyeongsang National University, Republic of Korea
Kwoen, Jin-hwe (jhkweon@gnu.ac.kr), Gyeongsang National University, Republic of Korea
Nam, Young-woo (ywnam@gnu.ac.kr), Gyeongsang National University, Republic of Korea

In this study, a periodical pattern surface was proposed in order to introduce lightning protection and excellent electromagnetic wave absorption performance in the X-band multifunctional structure. The absorption performance of proposed structure was numerically and experimentally characterized. It was confirmed that the absorption performance of proposed structure exhibits more than 90% in the X-band. The lightning strike on the outermost surface of the proposed structure was carried out under different current peak of waveform A (from 60kA to 180kA). Afterward, the lightning strike protection performance was evaluated by the damage area via X-ray CT and C-scan analyses. The radar absorbing performance and lightning strike protection were significant. When the proposed structure was applied to the leading edge of the wing-shaped structure, the simulated echo RCS level showed a reduction of about 10 dB in most of the X-band, in both polarizations. From these results, it was verified that proposed in this study can be applied to the aircraft leading edge structure.Acknowledgement:This work was supported by the National Research Foundation of Korea funded by the Ministry of Science and ICT under Grant (2022M1A3C2074536, Space HRD Center).

Development of microwave absorption heating and sound absorption folded core sandwich composite structure with Quartz/PEEK-MWCNTs

abst. 1408
Virtual Room 2
Thursday
July 21
16h10

Jun-Hyeok Hwang (hjh5382@gnu.ac.kr), Gyeongsang National University, Republic of Korea
June-Woo Kwak (june1378@gnu.ac.kr), Gyeongsang National University, Republic of Korea
Jin-Hwe Kweon (jhkweon@gnu.ac.kr), Gyeongsang National University, Republic of Korea
Young-Woo Nam (ywnam@gnu.ac.kr), Gyeongsang National University, Republic of Korea

In this paper, microwave absorption heating and sound absorption folded core sandwich composite was investigated. The sandwich structure consisting of core and skins was fabricated using quartz/PEEK thermoplastic composite dispersed multi-walled carbon nanotubes (MWCNTs). Additionally, the pores of folded core were filled with polyurethane foam coated graphene oxide. The folded core sandwich composite was designed with 99% microwave absorption and heating performances at 2.45 GHz. This microwave heating folded core sandwich composite was transformed of microwave energy to thermal energy through molecular frictional force and dielectric loss. The heating performance was evaluated using horn antenna machine and Multiphysics simulation. The heating test and simulation results demonstrated that the proposed microwave heating folded core sandwich composite has great microwave absorption performance and heating performance. The sound absorption performance was confirmed using impedance tube machine. As the result, the graphene oxide-coated polyurethane foam has improved sound absorption performance in the low-frequency band. On the basis of test results, it was proved that the sandwich structure proposed in this paper could be a good heating and sound absorption element. Acknowledgement: This work was supported by the National Research Foundation of Korea (NRF) Grant funded by the Ministry of Science and ICT (NRF-2017R1A5A1015311) and he National Research Foundation of Korea funded by the Ministry of Science and ICT under Grant (2022M1A3C2074536, Space HRD Center).

Low-velocity impact response of aluminum alloy corrugated sandwich beams used for high-speed trains

abst. 1410
Virtual Room 1
Wednesday
July 20
10h40

Yu, Zhenhao (yuzhenhao_tpl@163.com), State Key Laboratory of Traction Power, Southwest Jiaotong University, China
Liu, Kai (liukai_tpl@163.com), State Key Laboratory of Traction Power, Southwest Jiaotong University, China
Zhou, Xiongfei (zhouxiongfei_2018@126.com), State Key Laboratory of Traction Power, Southwest Jiaotong University, China
Jing, Lin (jinglin@swjtu.edu.cn), State Key Laboratory of Traction Power, Southwest Jiaotong University, China

The low-velocity impact response of A6N01S-T5 hollow extruded aluminum alloy corrugated sandwich beams used for the carbody of high-speed trains, under drop-weight impact was investigated in this study. Failure mechanism map of corrugated sandwich beam under low-velocity impact was obtained by theoretical analysis, which was verified by experimental and finite element simulation results. Typical deformation mode, load-displacement response and energy absorption of dynamically-loaded corrugated sandwich beams were discussed, and effects of initial impact energy and impact angle on impact response of specimens were also explored. The results indicate that there are three initial failure modes of corrugated sandwich beams under drop-weight impact, namely face-sheet yield, face-sheet buckling and core buckling, and both initial failure mode and critical load of sandwich specimens are sensitive to the face-sheet thickness and core thickness. The shear deformation of corrugated core and gradually loading load-displacement response were observed for the case of forward impact, while the compression deformation of corrugated core and load-displacement response with a larger initial peak were found for the case of reverse impact. Regardless of forward impact or reverse impact, the increase of initial impact energy will lead to the increase of maximum displacement response and structural resistance of sandwich beams. The increase of impact angle leads to the larger values of peak load, deformation resistance and energy absorption efficiency of specimens for the impact angle less than 60 degrees, while the dynamic response of specimens is not sensitive to the increased impact angle within 75 to 90 degrees.

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abst. 1412
Poster

Fabrication, Characterization, and Evaluation of Electrospun Nanocomposite Fibrous Mats as Interlayer Reinforcements for Fiber Composites

Loizou, K. (), Advanced Materials Design and Manufacturing, Nicosia, Cyprus
Savva, I. (), Advanced Materials Design and Manufacturing, Nicosia, Cyprus
Georgallas, M. (), Advanced Materials Design and Manufacturing, Nicosia, Cyprus
Evangelou, A. (), Advanced Materials Design and Manufacturing, Nicosia, Cyprus
Drakonakis, V. (), Advanced Materials Design and Manufacturing, Nicosia, Cyprus

Fiber reinforced composites (FRPs) find extensive use in various applications due to their intrinsically high specific strength, replacing conventional materials in fields such as sports, transportation, and aerospace. A novel multiscale reinforcement for the interlayer (region between two successive laminas) is suggested via the thermal consolidation of a polymer nanofiber system on both surfaces of dry technical fabrics (carbon glass, aramid), with its enhanced functionality owned to the three different scales incorporated. The material configuration at the lamina level comprises of microfibre-nanofibre-nanoparticle fractal networks, imitating the architecture of natural structures like feathers. The presented work examines the applicability of polymer-based electrospun nanofabrics to be used as interlayer reinforcements for multilayer-FRPs. Three different types of polymers are examined (Polyamide 6 (PA6), polyacrylonitrile (PAN) and Polyvinylidene fluoride (PVDF)) plain or reinforced with Multiwall Carbon Nanotubes (MWCNTs). The effect of electrospinning processing parameters such as applied voltage, collector's distance, winding speed were investigated. Along with processing parameters, the effect of polymer and nano-reinforcement concentrations will be examined. The effect of the above on the morphological characteristics of the resulting nanofabrics, their tensile strength and thermal response are assessed. Resulting nanofabrics were examined in view of their applicability as interlayer reinforcements of CFRPs. Acknowledgments: This work was co-funded by the European Regional Development Fund and the Republic of Cyprus through the Research and Innovation Foundation (Project: INNOVATE/0719/0011).

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abst. 1413
Poster

Enhancing the mechanical properties of carbon fiber reinforced composites by the incorporation of electrospun nanofibers at the interlayer

Georgallas, M. (), Advanced Materials Design and Manufacturing, Nicosia, Cyprus
Savva, I. (), Advanced Materials Design and Manufacturing, Nicosia, Cyprus

Loizou, K. (), Advanced Materials Design and Manufacturing, Nicosia, Cyprus
Evangelou, A. (), Advanced Materials Design and Manufacturing, Nicosia, Cyprus
Drakonakis, V. (), Advanced Materials Design and Manufacturing, Nicosia, Cyprus

The continuous need for materials with higher specific properties has revolutionized material technologies and in particular fiber reinforced polymer composites, which are rapidly becoming the norm for high value applications. The strength of these materials is typically limited by their weaker interlayers due to the tendency for delamination. In this work, interlayer reinforcement is investigated through the incorporation of non-woven, nanoreinforced, nanofibrous mats in between carbon fiber laminas. More precisely, solutions of polyamide 6 (PA6) and Multiwall Carbon tubes (MWCNTs) were electrospun into nanofibrous mats with different thicknesses and areal density characteristics. Ultrasonic welding was then used to consolidate the nanofibrous mats onto unidirectional carbon fiber textiles, which were then processed into multilayer composites using vacuum assisted impregnation. In addition to the areal density variations, multilayer composites were also produced using different configurations consisting of double and single nanofibrous interlayers. Flexural and fracture toughness (Mode I) testing were conducted on a uniaxial testing machine. The results indicated that the presence of nanoreinforced nanofabrics can effectively increase the fracture toughness of the composite materials in the order of 50% without compromising the weight. The enhancement is attributed to the hierarchical structure of the nanoreinforced nanofibers that are integrated at the interlayer region, creating additional load transfer mechanisms. Acknowledgements: This work was co-funded by the European Regional Development Fund and the Republic of Cyprus through the Research and Innovation Foundation (Project: INNOVATE/0719/0011).

Composite structures in civil engineering

abst. 1015
Virtual Room 1
Tuesday
July 19
12h10

Numerical study of DTU 10MW reference Wind Turbine under Earthquake

Huang, Sam (samhuang@mail.nsysu.edu.tw), National Sun Yat-sen University, Taiwan

In this study, a shell-based full finite element model for Technical University of Denmark (DTU) 10MW reference Wind Turbine is built to study the dynamic responses of the blades, nacelle, and tower under earthquake. A close investigation on the original blade input file of DTU 10MW reference Wind Turbine reveals that the natural vibration frequency fails to pass rigid body test. That is, natural frequency must be a fixed value when the finite element model is rotated under arbitrary rigid body rotation. This is due to inappropriate assigned orientation of the blade elements in composites blades. As a result, the natural vibration frequencies reported in DTU's report and the natural vibration frequencies obtained in this study differ significantly. Then, the built shell-based finite element model of DTU 10MW reference Wind Turbine is subject to artificially generated earthquake converted from codes of European Union earthquake response spectrum. The simulation results show that the foundation has a significant impact on the responses of 10MW reference wind turbine. That is, the 10M reference wind turbine suffers less stress in the flexible foundation than in the more rigid foundation . The results also show that current layups of composite blade, tower of DTU 10MW reference Wind Turbine fail under the seismic loadings, that larger value of forces and moments between the airfoil and the web structure, which could potentially lead to the failure of bonded joints between the airfoil and the web structures, and that neglecting the gravity could underestimate the dynamic responses of wind turbines under seismic loadings.

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abst. 1021
Repository

Shaking table test study on seismic performance of UHPC rectangular hollow bridge pier

Ye Mengya (2573619772@qq.com), Fuzhou University, China
Guo Zhan (guozhan115@126.com), Fuzhou University, China
Chen Canwen (771588228@qq.com), Fuzhou University, China
Chen Yu (kinkingingin@163.com), Fuzhou University, China

To study the seismic failure mode and dynamic response characteristics of ultra-high performance concrete (UHPC) rectangular hollow bridge pier under dynamic loads, the El Centro wave, Taft wave, and Northridge wave were selected as seismic excitation for the shaking table test. The responses such as natural frequency, damping ratio, acceleration-time and displacement-time curves were investigated[U+FF0C]and the results were compared with the finite element simulation results. At the same time, 8 finite element models (FEMs) of UHPC rectangular hollow bridge pier were established to explore the influence of longitudinal reinforcement ratio and stirrup ratio on the seismic performance of bridge piers. The results indicated that with the increase of peak ground acceleration (PGA), the damping ratio, acceleration, displacement and UHPC strain of the specimen increased, while the natural frequency and the dynamic amplification factor of the pier decreased gradually due to the accumulation of damage. The increase of longitudinal reinforcement ratio improves the ductility, and the increase of stirrup ratio enhances the constraint effect of core UHPC and ductility to a great extent, which leads to different acceleration, displacement and equivalent plastic strain response of bridge piers. On the whole, after the input of the seismic wave, stiffness degradation appeared in the UHPC rectangular hollow bridge piers, the ultimate bearing capacity was not deteriorated, and the overall seismic performance is superior. In areas with low seismic fortification intensity, the reinforcement ratio of UHPC rectangular hollow bridge piers can be appropriately reduced.

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abst. 1028
Repository

Intelligent recognition for crack and leakage defects of tunnel structures based on deep learning

Hao Yang (H.Yang@ntu.edu.cn), Nantong University, China
Xiangyang Xu (x.y.xu@suda.edu.cn), Soochow University, China

Traditional manual visual inspection of subway shield tunnel cracks and leakage defects is currently unsatisfactory because it cannot distinguish defects from certain disturbances. Based on deep learning, this paper proposes a new image recognition algorithm for semantic segmentation of cracks and leakage defects in subway shield tunnels. This method has great advantages in recognition results, reasoning time and error rate which can be widely adopted to identify defects quickly and accurately in the health monitoring and maintenance of tunnel structures, such as cracks, leaks, and other defects inspection.

Hysteretic behavior of recycled aggregate concrete with ferronickel slag-filled steel tubular columns

abst. 1032 **Repository**

Luo Caisong (0716jpu@163.com), College of Civil Engineering, Fuzhou University, China
Wang Fengxuan (wangfengxuantumu@163.com), College of Civil Engineering, Fujian University of Technology, China
Guo Zhan (guozhan115@126.com), College of Civil Engineering, Fuzhou University, China
Qi Ai (342598520@qq.com), College of Civil Engineering, Fuzhou University, China
Chen Yu (kinkingingin@163.com), College of Civil Engineering, Fuzhou University, China

To study the hysteretic behavior of recycled aggregate concrete with ferronickel slag -filled steel tubular (RAC-FNSFST) columns, the quasi-static loading was implemented on nine specimens with different replacement rates (RCAs), axial load levels, length-diameter ratios, and diameter-thickness ratios. The hysteretic curves, skeleton curves, deformability, energy dissipation capacity, and stiffness degeneration were studied after the loading and failure mechanisms were observed, followed by the construction of FE models for parameter analysis. It is demonstrated that the hysteretic loop curve is full, and the hysteretic performance was not dramatically affected by the replacement rate of RCA. As the axial load level increases, the ultimate strength at the descending stage degrades quickly, stiffness degeneration accelerates, and hysteretic energy dissipation increases. Stiffness degeneration and hysteresis energy dissipation are enhanced as the length-diameter ratio increases. However, when the diameter-thickness ratio decreases, the hysteretic energy dissipation increases and stiffness degeneration accelerates. In addition, a suitable FE model was established and compared with the experimental results, and then a wide range of parameter studies were carried out as a supplement to the experimental study. It is shown that the ultimate strength and ductility of specimens are intimately correlated with the RAC strength, yield strength of steel tube, slenderness ratio, axial load level, and steel ratio.

Compressive Behavior and a New Design-Oriented Stress-Strain Model for FRP-Confined Ultra-High Performance Concrete (UHPC) in Circular Columns

abst. 1037 **Repository**

Jun-Jie ZENG (jjzeng@gdut.edu.cn), Guangdong University of Technology, China
Jinjing Liao (jinjingl@student.unimelb.edu.au), Guangdong University of Technology, China

Ultra-high performance concrete (UHPC) usually exhibits a weak ductility under axial compression. However, the ductility can be enhanced by implementing confining devices such as fiber-reinforced polymer (FRP) wraps. In order to gain in-depth understandings on the compressive behavior of FRP-confined UHPC, axial compression tests on 52 FRP-confined and 12 unconfined UHPC cylinders were carried out in this study. The failure modes, stress-strain behaviors, confinement efficiency, and the influences of crucial variables (steel fiber contents, specimen sizes, FRP fiber types, and FRP thickness) on the compressive behavior of FRP-confined UHPC were investigated and discussed. Results show that the increase in steel fiber content could increase the first peak stress and its corresponding strain, hoop strain efficiency, avoid the abrupt stress reduction after the first peak stress, as well as alleviating the effect of specimen sizes. Addition of steel fibers also alters the actual confinement ratio threshold for sufficient confinement. Comparisons suggest that FRP confinement fiber types have limited influence on the normalized stress-strain behavior of specimens with similar level of actual confinement ratio. Additionally, a large amount of compressive test data collected from five previous experimental studies

involving 117 FRP-confined UHPC cylinders was used for the model development. The assessment results reveal that both versions of the developed design-oriented model have the capability of accurately estimating the characteristic stresses and strains at characteristic points. In addition, it demonstrates that the full stress-strain curves predicted by the developed model agree reasonably well with most of the test results, especially for the slopes of the last linear portions.

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abst. 1045
Room B032
Tuesday
July 19
16h50

Research on Early-age Behaviors of Timber-Concrete Composite Connector

XIN, Zhanwen (zhanwen.xin.1@ulaval.ca), Laval University, Canada
SORELLI, Luca (luca.sorelli@gci.ulaval.ca), Laval University, Canada
EMAMI, Hossein (hossein.emami.1@ulaval.ca), Laval University, Canada
LECOURS, Simon (simon.lecours.1@ulaval.ca), Laval University, Canada
NGUYEN, Truong Thanh (truong-thanh.nguyen.1@ulaval.ca), Laval University, Canada

Timber-concrete composite (TCC) structures are emerging in the last decades as an option for structural optimization in terms of structural stiffness and strength, lightness, slenderness, acoustic and vibrational behavior. It combines several advantages of concrete and of timber. Connector is an essential part in TCC structure to ensure the structural effectiveness, for example, to provide ductility, to prevent uplifting between the two materials and to increase stiffness and strength. With the hardening of concrete, the structural behaviors of TCC connector changes along with time. This paper focuses on the changes of behaviors of TCC connector and its relationship with concrete performance at early age, from 3 days to 90 days. The studied connector in this research is notch with reinforced screws, which combines the Cross-Laminated Timber (CLT) slab and an economical and ecological (eco2) slab of Ultra-High-Performance Concrete (UHPC) newly developed at Laval University. The shear behaviors of the connector were tested by push-out tests at 3, 7, 14, 28 and 90 days after the casting of concrete. In addition, the properties of concrete were tested at the same days by standard concrete test of compressive strength (Fc) and of elastic modulus (Ec) for comparison. The connectors at different ages were compared with regard to maximum shear strength (Vmax), stiffness (Ks) and ductility (Ds). The result showed that the Vmax and Ks of connector strongly depend on the Fc and Ec of concrete respectively. Finally, structural responses of a UHPC-CLT floors at different early ages were numerically estimated with the shear-slip law from the experiment by a FEM program well validated for the design of TCC structure, in order to provide the changes of structural properties in construction stage.

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abst. 1051
Room B032
Tuesday
July 19
16h10

Experimental verification of a well-defined inflatable structures numerical simulation model

Abdelmaseeh, Amir (amir.azer@eng.asu.edu.eg), Ain Shams University, Egypt
Elsabbagh Adel (aelsabbagh@eng.asu.edu.eg), Ain Shams University, Egypt
Elbanhawy Amr (amr.elbanhawy@eng.asu.edu.eg), Ain Shams University, Egypt

Inflatable structures are known by being light weighted, easy to be transported easy to be manufactured, and deployed therefore; they are integrated with in many applications in aerospace engineering, civil engineering and lately the wind energy applications. Where the challenge now is to fabricate a complex shaped inflatable structure that keeps its geometry or even form into a well-defined predicted shape as well as its deformation and behavior against loads. In this paper, an overview on the simulation of the inflatable beam behavior subjected to different loading types will be covered, in addition to practical verification of this model using previously manufactured inflatable beam. The main objective of the model is to predict the geometrical behavior of the different pressurized models then investigate the behavior of those inflatable models under different loading conditions. Manufactured inflatable parts using PVC composite sheets are used to verify the results of this numerical model

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Experimental investigation of the flexural response of CFST members Incorporated with DCLs

abst. 1099
Virtual Room 1
Tuesday
July 19
12h30

Khalaf, Salem (b00074986@aus.edu), American University of Sharjah, United Arab Emirates
Abed, Farid (fabed@aus.edu), American University of Sharjah, United Arab Emirates

Concrete Filled Steel Tubes (CFSTs) have been in use for some time due to the positive effect of confinement that increases the strength of the member. Significant number of studies tested CFST using different types of concrete. However, most of these studies focused mainly on CFST under compression. Furthermore, the production of normal concrete produces different types of waste that has many impacts on the environment, mainly solid waste generation from demolishing sites. Therefore, this paper focuses on testing the flexural strength of CFST beams that incorporate Demolished Concrete Lumps (DCLs), which will be isolated in the middle. Seven rectangular and 16 circular CFST specimens were casted and tested under four-point bending test using a Universal Testing Machine (UTM). The main parameters included in the proposed experimental program were the inner area where DCLs will occupy, size of the DCLs used, and shape of the cross section. The load versus displacement curves were extracted from the experimental tests and the specimens were compared using the results of flexural capacity, ductility, stiffness, and failure modes. By the end of this experimental study, it is observed that all CFST specimens failed in a ductile manner. All rectangular CFST specimens exhibited local outward buckling failure near the point loads applied. However, circular CFST specimens did not fail by local buckling or brittle failure. Circular CFST specimens failed due to the crushing of the concrete in the compression zone. Furthermore, it was concluded that the DCL size and inner area have very insignificant effect on the flexural capacity, ductility, and stiffness of the CFST beam specimens. However, leaving the inner area empty without DCL infill significantly decreased the confinement effect, especially in the rectangular specimens, and thus reducing the flexural capacity, and ultimately the ductility.

Effect of anchorage condition on prestressed NSM FRP system

abst. 1120
Repository

Cho, Sanghyeon (0107sanghyun@khu.ac.kr), Kyung Hee University, Republic of Korea
Chung, Wonseok (wschung@khu.ac.kr), Kyung Hee University, Republic of Korea
Lee, Heeyoung (heeyoung0908@chosun.ac.kr), Kyung Hee University, Republic of Korea

A prestressed near-surface mounted fiber-reinforced polymer (NSM FRP) system was investigated to improve the structural performance of deteriorated concrete structures. This system was hard to form a flat groove for the installation of the anchorage device. For this reason, epoxy is injected into defects on the groove to ensure flatness. In this study, the effect of anchorage condition on this system was analyzed depending on the flat groove and the ensured groove. The anchorage device was installed on a test unit with a length of 0.9 m. The parameters in the longitudinal tension test were set as the groove condition (flat groove, ensured groove) and the anchor type (mechanical anchor, chemical anchor). As a result, the ultimate load on the ensured groove (254 kN) is similar to the ultimate load on the flat groove (251 kN). The prestressed NSM FRP system on ensured groove has excellent structural performance. The experimental results are compared with those of finite element analysis, and the material properties are investigated through a parametric study.

Flexural performance of steel fiber-reinforced concrete-filled stainless steel tubular trusses

abst. 1153
Repository

Kong, Wenyuan (wenyuankong@163.com), Fuzhou University, China
Zhou, Wenbo (zwb505335173@163.com), , China
Zhu, Yao (), Fuzhou University, China
Zhang, Xiaoyong (), Fuzhou University, China
Chen, Yu (), Fuzhou University, China

The stainless steel tubular truss is one of the schemes to deal with the corrosion problem of tubular truss, and mechanical properties of tubular truss can be improved by filling concrete. To study the influence of the filling position of steel fiber reinforced concrete (SFRC) on the flexural performance of stainless steel tubular truss, four-point loading test was carried out with four specimens. The specimens consist of three stainless steel tubular trusses filled with SFRC in the top chord, bottom chord and both chords respectively, and a hollow section stainless steel tubular truss as the control group. According to the test results, the failure modes and load-deflection curves of the specimens are analyzed. By comparing the ultimate bearing capacity and ductility coefficient of specimens, it is found that filling SFRC in top chord can greatly improve the bearing capacity of specimens, while the ductility and safety margin were reduced by filling both top and bottom chords with SFRC despite the further increased bearing capacity. In addition, based on the analysis of load-strain curves, it is found that filling SFRC on chord member can reduce the strain developed rate of the stainless steel tubular truss.

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abst. 1170
Virtual Room 1
Tuesday
July 19
12h50

Dynamic behavior and vulnerability assessment of base isolated structures

De Angelis, Fabio (fabio.deangelis@unina.it), University of Naples Federico II, Naples, Italy
Cancellara, Donato (donato.cancellara@unina.it), University of Naples Federico II, Naples, Italy

In the present work a base isolation approach is presented for protecting solids and structures with respect to dynamic and seismic loadings. Different base isolation approaches are analyzed and the performance of structural systems is studied with respect to the various presented approaches. A dynamic nonlinear analysis is considered for multi-storey reinforced concrete buildings. The dynamic behavior of the base isolated reinforced concrete buildings is illustrated when the structures are subject to strong dynamic and seismic loadings. The dynamic behavior of the structures is illustrated for the different base isolation approaches considered in the analysis. The dynamic nonlinear analysis is conducted by considering three-dimensional base isolated structures related to reinforced concrete building frames. The dynamic analysis has been performed by adopting recorded accelerograms characterized by bi-directional components of the ground motion compatible with the reference elastic response spectrum. The vulnerability assessment of the structures is determined as a result of the performed nonlinear dynamic analysis. The dynamic behavior of the structures is illustrated and the dynamic nonlinear analysis is discussed by showing a comparative analysis of the different adopted base isolation systems and their effectiveness in the protection of irregular in plan three-dimensional structures subject to strong seismic actions. References: [1] EC2, Eurocode 2: Design of concrete structures, UNI EN 1992-1-1, European Committee for Standardization, CEN/TC 250, (2004). [2] EC8, Eurocode 8: Design of Structures for Earthquake Resistance - Part 1: General rules, seismic actions and rules for buildings, PrEN1998-1, European Committee for Standardization, TC250/SC8, (2003). [3] Cancellara, D., De Angelis, F., Assessment and dynamic nonlinear analysis of different base isolation systems for a multi-storey RC building irregular in plan, COMPUTERS AND STRUCTURES, Vol. 180, pp. 74–88, February (2017). [4] Cancellara, D., De Angelis, F., Nonlinear dynamic analysis for multi-storey RC structures with hybrid base isolation systems in presence of bi-directional ground motions, COMPOSITE STRUCTURES, Vol. 154, pp. 464–492, (2016). [5] Cancellara, D., De Angelis, F., A base isolation system for structures subject to extreme seismic events characterized by anomalous values of intensity and frequency content, COMPOSITE STRUCTURES, Vol. 157, pp. 285–302, (2016).

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abst. 1202
Repository

Numerical analysis, optimization, and multi-criteria design of VIG composite panels

Kowalczyk, Izabela (238124@edu.p.lodz.pl), Department of Structural Mechanics, Lodz University of Technology, Poland
Kozanecki, Damian (238125@edu.p.lodz.pl), Department of Structural Mechanics, Lodz University of Technology, Poland
Krasoń, Sylwia (238126@edu.p.lodz.pl), Department of Structural Mechanics, Lodz University of Technology, Poland

Rabenda, Martyna (martyna.rabenda@p.lodz.pl), Department of Concrete Structures, Lodz University of Technology, Poland
Domagalski, Łukasz (lukasz.domagalski@p.lodz.pl), Department of Structural Mechanics, Lodz University of Technology, Poland
Wirowski, Artur (artur.wirowski@p.lodz.pl), Department of Structural Mechanics, Lodz University of Technology, Poland

The subject of this study are vacuum insulated glass (VIG) panels. They consist of two glass panes with an evacuated space between them. Application of the vacuum in the glazing decisively improves their thermal properties. Although, the deflection of the glass panes towards the centre of the structure caused by atmospheric pressure is the mechanical problem that occurs in this type of structure. The space between glass sheets filled with evenly distributed metal micro-support pillars is the solution for this problem. Most previous studies focus on pillars placement, amount, or shape in terms of panes thermal (Park, Oh, and Lee 2019) or mechanical properties e.g., strength of vacuum glass (Kim, Kim, and Jeon 2018). However, due to the increasing number of VIG panels applications in places exposed to external vibrations, such as refrigerated vehicles or in exhibition places, other design criteria for VIG panels are also required. Not only resistance to resonance at certain frequencies of forcing vibrations should be considered, but also aesthetic reasons. The paper presents the results of designing VIG panels, considering the mentioned parameters. In this study the Abaqus/CAE software was used. A large number of numerical models (Kowalczyk, Kozanecki, Krasoń, Rabenda 2022) were created, using Python scripts, then submitted to a complex multi-criteria analysis. This is the first paper to present the use of fractal analysis to automatically assess the aesthetics of the obtained solutions (Coleman 2009). The theoretical solutions could be effortlessly implemented in the industrial production of new VIG plates. It is significant due to increasingly wider applications, requiring appropriate dynamic and aesthetic properties.
References: [1] Park J, Oh M, Lee C. Thermal performance optimization and experimental evaluation of vacuum-glazed windows manufactured via the in-vacuum method. Energies. 2019;12(19). [2] Kim J, Kim Y, Jeon ES. Screen printing for support-pillar placement for vacuum glazing and the effects of pillar spacing on strength properties. Journal of Mechanical Science and Technology. 2018;32(12):5653–7. [3] Kowalczyk I., Kozanecki D., Krasoń S., Rabenda M., Computational modelling of VIG composite panels using FEM – static and dynamic analysis, Materials 2022 (in the course of publication). [4] Coleman R., Fractal Analysis of Stealthy Pathfinding Aesthetics, International Journal of Computer Games Technology 2009(1) DOI:10.1155/2009/670459. ACKNOWLEDGEMENTS: The contribution is founded by Polish Minister of Education and Science under contract no. SKN/SP/496315/2021. This research was supported in part by PL-Grid Infrastructure.

The artificial intelligence methods in non-destructive testing of dynamic properties of VIG-type composite panels

abst. 1203
Repository

Kozanecki, Damian (238125@edu.p.lodz.pl), Department of Structural Mechanics, Lodz University of Technology, Poland
Kowalczyk, Izabela (238124@edu.p.lodz.pl), Department of Structural Mechanics, Lodz University of Technology, Poland
Krasoń, Sylwia (238126@edu.p.lodz.pl), Department of Structural Mechanics, Lodz University of Technology, Poland
Rabenda, Martyna (martyna.rabenda@p.lodz.pl), Department of Concrete Structures, Lodz University of Technology, Poland
Domagalski, Łukasz (lukasz.domagalski@p.lodz.pl), Department of Structural Mechanics, Lodz University of Technology, Poland
Lefik, Marek (marek.lefik@p.lodz.pl), Department of Concrete Structures, Lodz University of Technology, Poland
Wirowski, Artur (artur.wirowski@p.lodz.pl), Department of Structural Mechanics, Lodz University of Technology, Poland

The VIG (Vacuum Insulated Glazing) units, i.e. composite glazing in which the space between glass panes is filled with vacuum, is one of the most advanced technologies. Vacuum glazing consists of two

or more glass panes hermetically sealed together around the edge with a vacuum gap between the panes. The system of the support pillars is placed between glass panes to prevent them from collapsing and contacting under atmospheric pressure (Bao, 2014). Due to the vacuum inside the inter-pane space, the VIG panels thermal properties are higher compared with standard glazing. They are successfully used in modern window and door solutions, curtain walls and skylights. The most key elements of the construction of VIG plates are the support pillars, which, due to their small size, transfer very high stresses (Zheng, Li, Liu, 2011). Therefore, an important issue is the analysis of their mechanical properties, such as, Young's modulus and their variability over a long period of time. It is worth noting that even a slight deterioration of these properties cause, that all structure will lost of such valuable thermal properties of the plate. It is due to very small dimensions of the support pillars and the small distances between the glass plates. Artificial intelligence (AI) methods are undergoing tremendous development these days. Among the many different techniques included in AI, neural networks (NN) and the extreme gradient boosting (XGB) algorithms deserve special attention. They allow for very advanced regression analysis in the case of problems where there are no direct data on the relationships between individual variables. Both methods require an initial stage of training on a fairly large set of data, and then "well trained" can be used in real-world cases for the regression analysis of the input data. In this study, to train selected methods of artificial intelligence, numerical data developed in the VIG plate modelling process using Abaqus program (Kowalczyk, Kozanecki, Krasoń, Rabenda, 2022) were used. The test method proposed in this article is based on the VIG plate subjected to forced vibrations of specific frequencies and then reading the dynamic response of the composite plate (Miller, Ziemiański, 2020). Parameters such as vibration frequency, phase shift, internal damping, etc. are analyzed. Such collected and pre-developed experimental data are transferred to the inputs of a properly trained neural network (NN) or the extreme gradient boosting (XGB) algorithm. Then, in the response, the mechanical parameters of the support pillars hidden inside the analyzed VIG plate were received. The results obtained in the study were analyzed and compared to data given in the literature.. In the future, the proposed research methods can be used to analyze the mechanical properties of other types of composite panels. References: [1] Bao M. Structural and functional integrity of energy-efficient glazing units. Ph.D. Thesis, The University of Birmingham, 2014, p. 39. [2] Kowalczyk I., Kozanecki D., Krasoń S., Rabenda M., Computational modelling of VIG composite panels using FEM – static and dynamic analysis, Materials 2022 (in the course of publication). [3] Miller B, Ziemiański L., Optimization of dynamic behavior of thin-walled laminated cylindrical shells by genetic algorithms and deep neural networks supported by modal shape identification. Advances in Engineering Software, 2020, 147, 102830. [4] Zheng W, Li R, Liu J. Study on stress and deformation of support pillar of vacuum flat glazing. Inner Mongolia, China, 2011 Second International Conference on Mechanic Automation and Control Engineering, 2011, p.2609-2612. ACKNOWLEDGEMENTS: The contribution is founded by Polish Minister of Education and Science under contract no. SKN/SP/496315/2021. This research was supported in part by PL-Grid Infrastructure.

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abst. 1336
Virtual Room 1
Tuesday
July 19
13h10

Experimental study for the rehabilitation of pressure drinking water pipes using Glass Fiber Reinforced Polymer

Gras Travesset, Ferran (ferrangrast@iqs.url.edu), Aigües de Barcelona, IQS School of engineering Universitat Ramón Llull, Spain
Pérez, Marco Antonio (marcoantonio.perez@iqs.url.edu), IQS School of engineering Universitat Ramón Llull, Spain
Torras, Antoni Andreu (aandreu@aiguesdebarcelona.cat), Aigües de Barcelona, Spain

Composite materials have encouraged the emergence of new products and revolutionized specific sectors. In civil engineering, they have allowed the development of new techniques that have multiple advantages over the traditional techniques used. For example, it is the case of the Cured-in-Place Pipe (CIPP) technique, which allows rehabilitating a damaged pipe employing a composite, thus avoiding having to proceed to its replacement. It is a trenchless technology technique based on creating a new pipe within the existing one taking advantage of the host pipe. For this purpose, a soft liner of a material composed mainly of layers of reinforcing glass fiber is immersed into an epoxy resin matrix, and a polymer coating is inserted into the damaged pipe. Then, the liner expands to fit the host pipe. After an ultraviolet curing process, the composite is solidified, forming the new pipe. It is a technique that has become popular in recent years to rehabilitate wastewater pipes by gravity or very low pressure. On the other hand, in drinking water pipes, the composite is subject to considerable pressure, which must be considered, among other factors, for the design of the liner. In addition, the interaction between the two materials will determine the mechanical properties of the composite. For this reason, the fiber must be immersed in the resin matrix preventing the appearance of bubbles (gases) inside as it would cause areas with defects. The CIPP technique has attracted worldwide interest in recent decades due to its economic, social, and environmental advantages. However, it is a technique that uses a composite material and has a complex installation process and therefore requires demanding quality control. However, the circular geometry of the samples obtained from an installed liner makes it difficult to conduct tests to assess the mechanical properties in the hoop's direction and thus verify that the installed liner meets the minimum mechanical requirements. On the other hand, there are regulations for designing the liners based on theoretical approaches and data obtained from laboratory tests. However, the emergence of problems in projects for the rehabilitation of drinking water pipes reveals that a thorough investigation is still needed to establish a relationship between the properties of the constituent materials, laboratory tests of the composite, and the actual behavior of the rehabilitated pipe. This paper analyzes the mechanical behavior of the composite in each of the three phases that the authors of this paper have considered appropriate to differentiate: microscale, mesoscale, and macroscale. In this way, the aim is to obtain a correlation between the mechanical behavior of the constituent materials, the samples tested in the laboratory after rehabilitation, and the natural performance of the composite on site. In this work, new quality control systems have also been developed that complement the existing ones and allow to obtain the mechanical properties of the composite in the circumferential direction simulating the final working conditions of the liner.

Assessment of the slip impact on the deflection of steel-concrete composite beams in the light of experimental tests

abst. 1352
Room B032
Tuesday
July 19
15h50

Kisała Dawid (kisala.dawid@gmail.com), Faculty of Civil Engineering, Cracow University of Technology, Poland
Ostrowski Krzysztof Adam (krzysztof.ostrowski.1@pk.edu.pl), Faculty of Civil Engineering, Cracow University of Technology, Poland
Furtak Kazimierz (kfurtak@pk.edu.pl), Faculty of Civil Engineering, Cracow University of Technology, Poland

The introduction of a new construction concept is connected with the necessity to solve problems specific for a given type of elements. In the case of composite elements of the steel plate-concrete type, the issue is to determine the influence of the slip effect in the assembly surface on their load-bearing capacity and deflections as well as cracking under load. The main gap in the existing solutions to the slip effect problem and its impact on deflections, is the lack of a comprehensive approach, including theoretical solutions and experimental verification. This approach was presented in this study. Experimental tests were carried out on six beams with a length of 5200 mm and a support span of 5000 mm. Mechanical, electrofusion, inductive and optical instruments were used to measure deformations and displacements. Based on the research results, it can be stated that the research results and theoretical analysis are in good agreement. If the slipeffect is not taken into account, the deflection values are reduced by up to 25%. The increase in deflections caused by the slip effect was revealed at all connection levels and at all levels of load. The slip and its influence on the deflections of the beams depends on: the class of concrete, the steel construction class of the sheet and its cross-section, as well as the diameter and spacing of the connectors.

Push-out tests of welded bolt shear connectors

abst. 1353
Room B032
Tuesday
July 19
16h30

Perez, Marines (mperezr@unal.edu.co), Universidad Nacional de Colombia, Colombia
Bermudez, Carlos A. (cabermudezm@unal.edu.co), Universidad Nacional de Colombia, Colombia
Perea, Tiziano (tperea@azc.uam.mx), Universidad Autónoma Metropolitana, México

Steel headed stud shear connectors are typically used in composite construction due to their reliability with regards to high strength and ease of installation. However, due to logistic issues related to the installation process, particularly with the need for special high voltage equipment, in some low-rise and mid-rise construction projects in Latin American countries the standard steel headed stud anchors are replaced with welded bolts. That is, conventional hexagon head bolts with fillet weld all around of shank. This paper presents an experimental program consisting of push-out tests of welded bolt shear connectors. Twenty-three push-out tests were conducted to evaluate the load-slip behavior, the ultimate strength, and the effect of effective embedded depth to bolt diameter ratio (hef/d). Two failure modes were identified: concrete pry-out failure and bolt failure. The concrete pry-out failure occurred with hef/d$\leq$4.0. The load-slip curves have similar behavior as headed studs, but the ultimate strength doesn't reach values of prediction.

Composites in Innovative Applications (chaired by L Solazzi)

Torsional properties of GFRP-timber hybrid beams

abst. 1039
Room B032
Tuesday
July 19
15h10

DARWICH Hassan (hassan.darwich@univ-lyon1.fr), Claude Bernard University Lyon 1, France
GRAZIDE Cécile (cecile.grazide@univ-lyon1.fr), Claude Bernard University Lyon 1, France
JURKIEWIEZ Bruno (bruno.jurkiewiez@univ-lyon1.fr), Claude Bernard University Lyon 1, France

This paper investigates the torsional behavior of innovative GFRP-timber hybrid beams, as the usual failure in bending of these beams occurs by lateral buckling, resulting from combination of torsion and horizontal displacement. Timber elements and GFRP profiles were first tested in torsion. The connection between the timber elements and the GFRP profiles was a bolting connection. Several configurations of hybrid beams were studied. The experimental results showed that the contribution of wood increased significantly the torsional stiffness of GFRP beam in each configuration. The influence of the connector's density was also determined. A finite element analysis was used to simulate the torsional behavior of hybrid beams. Numerical results were in good agreement with measurements. A parametric study confirmed the influence of the connector on the torsional behavior.

Characterization of shape memory wire-polymer composites from additive manufacturing

abst. 1060
Room B032
Tuesday
July 19
15h30

Eyer, Philipp (philipp.eyer@mrm.uni-augsburg.de), Augsburg University, Institute of Materials Resource Management, Germany
Trauth, Anna (anna.trauth@mrm.uni-augsburg.de), Augsburg University, Institute of Materials Resource Management, Germany
Weidenmann, Kay André (kay.weidenmann@mrm.uni-augsburg.de), Augsburg University, Institute of Materials Resource Management, Germany

Actuators based on shape memory wires embedded into polymer matrices using additive manufacturing offer a wide range of shapes and wire integration appropriate to external loads is realisable. Prestrained NiTi wires and a polymer matrix are co-deposited simultaneously using an ARBURG plastic freeformer. Actuation of the shape memory alloy is possible using conductive heating. Actuator function is mainly influenced by the thermal and mechanical properties of the compound as well as the interfacial strength between wire and polymer. In the study at hand, the mechanical and thermomechanical properties of the compound are investigated performing quasistatic tests at different temperatures. Furthermore, cyclic tests are conducted to investigate the long-term function of the actuator. The results highlight the promising potential of this composite material.

STUDY ON THE INFLUENCE OF COLLABORATIVE SHELL COMPOSITE STRUCTURES ON THE CRASHWORTHINESS OF AN ELECTRIC MICROCAR

abst. 1081
Virtual Room 2
Tuesday
July 19
13h10

Acanfora, Valerio (valerio.acanfora@unicampania.it), Università degli Studi della Campania "Luigi Vanvitelli" - Dipartimento di Ingegneria, Italia
Riccio, Aniello (aniello.riccio@unicampania.it), Università degli Studi della Campania "Luigi Vanvitelli" - Dipartimento di Ingegneria, Italia

Frame structure is the principal structural component for vehicles. With the aim of providing lightweight solutions with improved structural capabilities, in this paper, an innovative frame concept is proposed. The first innovative aspect of the proposed frame concept relies on the modularity. The addition of effective junctions between frame components was achieved thanks to the Additive Manufacturing technology. Indeed, differently from standard frame structures manufactured by welding separate tubes, the innovative frame concept, proposed in this activity, has a modular structure designed to be connected by additive manufactured joints and meant to be easily accessible for maintenance

operations and interchangeability of components. Moreover, the second innovative aspect relies in the integration of collaborative shell composite structures able to improve the overall torsional stiffness of the whole frame. The effectiveness of the proposed structural concept has been assessed by simulating the crashworthiness behaviour of an electric microcar equipped with the investigated frame, by means of numerical simulations conducted according to the American homologation standards (FMVSS 208). By performing numerical impact simulations against a rigid and deformable barrier, the mass, the energy efficiency and the torsional stiffness between microcar configurations, respectively, with steel tubes and composite collaborative shell structures, have been compared. The comparison against these two microcar configurations demonstrated that the integration of the collaborating shell composite panels can lead to a total weight saving of about 25% and the simultaneous increase of the impact energy absorbing capability and torsional stiffness of the microcar.

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abst. 1175
Repository

Multifunctional heating film of silver nanoparticles as susceptor for induction welding of thermoplastic composite joints

Dae-Sung Lee (lllsss0007@gnu.ac.kr), Gyeongsang National University, Republic of Korea
Jae-Hyung Jung (jjh3992@gnu.ac.kr), Gyeongsang National University, Republic of Korea
Hyeon-Seok Choe (chs15@gnu.ac.kr), Gyeongsang National University, Republic of Korea
Young-Woo Nam (ywnam@gnu.ac.kr), Gyeongsang National University, Republic of Korea

In this paper, multifunctional heating film of silver nanoparticles and poly-ether-ketone-ketone as a susceptor was developed and tested for induction welding of unidirectional carbon fiber/poly-ether-ketone-ketone (CF/PEKK) thermoplastic composites. The Ag/PEKK films were fabricated with different weight ratios of Ag (40, 50, 60, and 70 wt.%) by dispersion, sintering, and hot press forming. The useful induction heating behavior of the 70 wt.% Ag leads to the faster heating rates of Ag/PEKK film (13.4 [U+2103]/sec) than standard stainless steel mesh under the same welding conditions, carried out at 1.48 kW at a frequency of 250 kHz. The finite element modeling (FEM) of the heat distribution was analyzed based on the generator power, coil coupling distance, coil moving speed, frequency, compaction force, and coil geometry while maintaining the optimal coil speed. The temperature behavior calculated using the simulation model exhibited 87.1% agreement with experimental results. A microscopic inspection, scanning electron microscopy (SEM), and non-destructive test (NDT) were conducted to check the morphology characteristics of the welded joints. To check the mechanical performance of the induction welded specimens, interlaminar shear strength (ILSS) and single lap shear strength (SLSS) were carried out. The results of the highest ILSS and SLSS were obtained at 70 wt.% Ag/PEKK film by 27.91 MPa and 7.97 MPa, respectively. Based on these results, the multifunctional heating film of the joint improves energy efficiency and mechanical performance in welding thermoplastic composites.

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abst. 1181
Repository

Feasibility study of an innovative industrial vehicle transmission adopting aluminium and titanium alloy and composite materials instead of classical structural steel.

Solazzi, Luigi (luigi.solazzi@unibs.it), Dipartimento di Ingegneria Meccanica e Industriale, Università di Brescia, Italy
Bertoli, Davide (d.bertoli011@studenti.unibs.it), Dipartimento di Ingegneria Meccanica e Industriale, Università di Brescia, Italy
Ghidini, Lorenzo (l.ghidini007@studenti.unibs.it), Dipartimento di Ingegneria Meccanica e Industriale, Università di Brescia, Italy

The objective of this research is the study of a transmission for a commercial vehicle by developing alternative solutions adopting different types of innovative materials, including composite materials. In particular, the transmission object of this study is mounted on a Eurocargo vehicle with an engine power of 320 HP. The elements that make up the transmission are a torque converter connected to the engine, an eight-speed automatic transmission, a first transmission shaft, an electromagnetic retarder,

a second shaft and finally the rear axle with its differential. The connection between the transmission shafts and the other elements is made by means of a series of flanges and universal joints to allow for variations in the alignment and distance between the driven and conducted components. In detail, the transmission in the case study is realized through the connection of two different shafts. The first shaft, directly connected to the gearbox, is called ZW shaft, while the second shaft is named MIS shaft, which is in turn divided into two smaller shafts. The first part of the study includes the development of a lumped parameter model that allows the determination of the first dynamic characteristics of the system, such as eigenfrequencies and principal modes of vibration. Validation of the model was then achieved by comparison with results obtained from the supplier of one of the components. The redesign with innovative materials primarily focused on the transmission shafts while the gearbox and couplings were assumed to remain the same. First of all, it is fundamental that the transmission shafts are suitably sized, in order to withstand the stresses imposed and, at the same time, contain the weight, so as to reduce the inertia involved and avoid early breakage. From an initial sizing of the shafts currently mounted on the vehicle, parameters were obtained which were subsequently adopted for the development of the new transmission. Moreover, great attention must be paid to the environment in which the shaft works, in order to foresee possible aspects linked to chemical or mechanical damage. In particular, two important design choices were made, which strongly influenced the results obtained: 1. The static safety coefficient on torsion and the first natural frequencies of vibration for the new shafts must be greater than or equal to the one already in use. 2. The internal diameter of the shaft must not be modified so that all "new" shafts can be splined and used with the couplings already in use. One of the most important subjects of current research is the reduction of vehicle weight, which helps improve vehicle performance and reduce fuel consumption as well as increase overall efficiency. Typically, standard transmissions are made of steel, because they require less maintenance and offer the best driving comfort for everyday use. From an engineering point of view, transmission shafts are components whose weight is not indifferent, for performance purposes, especially in motorsport. A step towards weight reduction is therefore the orientation towards materials other than steel, such as aluminium alloys, titanium alloys and composite materials. Following the redesign with different materials, the total mass is calculated by changing the weight of the tubes while keeping the weight of the other components unchanged. From a first analysis, it is possible to see how the tubes of the transmission shafts alone can have a very strong influence on the total weight of the transmissions, even reaching a weight saving of 30% by redesigning them with the right materials. It clearly emerges that the implementation of composite materials leads to a significant reduction in weight with the same static, fatigue and dynamic behaviour; in particular, the transmission made in steel goes from about 120 kg to about 100 kg using fiberglass composite materials, and to a value of about 80 kg with carbon fiber composite materials.

Implementation of electrode integration for carbon composite bipolar plate for VRFB

abst. 1257
Virtual Room 2
Tuesday
July 19
12h10

Kaur, Amanpreet (amankhamano@gmail.com), Jeonbuk National University, Republic of Korea
Lim, Jun Woo (jul170@gmail.com), Jeonbuk National University, Republic of Korea

The bipolar plate is the key component of the vanadium redox flow battery (VRFB) as it provides the electrical path to electrolyte and supporting structure of the cell in the VRFB stack. The main drawback in the VRFB is multiple core components which causes the interfacial contact resistance (ICR) between the electrode and bipolar plate in the cell stack. In this study, the new concept of electrode integration with bipolar plate is adopted to overcome the drawback of the ICR. The electrode integrated bipolar plate assembly has fabricated from a single carbon felt to eliminate the ICR between the bipolar plate and the electrode. Soluble thermoplastic resin is used for the electrode portion of the carbon felt and the bipolar plate is fabricated with epoxy resin. The soft layer method is adopted while fabrication of the bipolar plate to expose the carbon fiber on the surface. After the bipolar plate fabrication step, the soluble resin is removed to regain the electrode portion of the assembly. The experimental result reveal that the area specific resistance (ASR) of the bipolar plate with electrode reduced significantly. The performances of the electrode integrated bipolar plate assembly are measured with charge/discharge test and compared with those of the conventional bipolar plate.

abst. 1258
Virtual Room 2
Tuesday
July 19
12h30

Development of graphene oxide carbon felt composite electrode for vanadium redox flow battery

Kaur, Amanpreet (amankhamano@gmail.com), Jeonbuk National University, Republic of Korea
Lim, Jun Woo (jul170@jbnu.ac.kr), Jeonbuk National University, Republic of Korea

The energy efficiency of the vanadium redox flow battery is largely depending on the electrode as the electrochemical reaction of vanadium couples occurs on the surface of the electrode. Therefore, carbonaceous material must be subjected to several treatments or synthesizing the new composites of electrodes to improve the performance of the VRFB. In this study, a carbon felt composite electrode is developed by functionalization of sulfonic groups on the surface of the carbon felt. Afterwards, physical, and chemical properties of the electrode are analyzed. The results demonstrate that introduction of the sulfonic species in the graphene oxide enhance the electrochemical activity of the electrode towards positive redox couple. Moreover, the composite electrode exhibits the enhancement in the performance than that of the bare carbon felt electrode. The wettability of the electrode is improved due to the presence of the sulfonic acid groups in the reduced graphene oxide. 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. These results reveal that modification of the graphene oxide by sulfonic species on the surface of the carbon fibers is promising alternative for the high-performance electrode for the VRFB.

abst. 1328
Virtual Room 2
Tuesday
July 19
12h50

Innovative RC permanent form and support system to minimize concrete casting works

Lee, Jeongun (dns1823@yonsei.ac.kr), Yonsei University, South Korea
Park, Ji Woon (jwp1021@yonsei.ac.kr), Yonsei University, South Korea
Lim, Yun Mook (yunmook@yonsei.ac.kr), Yonsei University, South Korea

Concrete is one of the most popular construction materials in the current market because of its price and easy to handle. It is really economical materials compared with the other construction material such steel which is other materials mostly used in the construction market. However, still it has several disadvantages in construction sites where concrete is used. The first one is producing huge amount of waste coming from form works made from wooden materials. Producing the amount of waste by concrete forms should be added to the amount of the total cost for concrete casting works. For this reason, currently reusable concrete form works are introduced into concrete construction market, but still zero waste is little far to achieve. The second one is time consuming to assemble and disassemble the form works before and after the concrete casting work. Also, the ordinary concrete form works are needed support system to keep the form in the place and supporting until sufficient strength of concrete is developed. Including all these detail concrete casting works, the advantages of concrete for cost and efficiency can be reduced in some cases. So, in this study, innovative RC permanent form and the support system are introduced to reduce waste and time to assemble and disassemble form works with supporting system. The innovative RC form works contributed by two parts, permanent form and the supporting system. The permanent forms those are made by cementitious composite with thin plate pattern using 3D mesh textiles for reinforcement. Here, the permanent forms can be handled (cutting, drilling, nailing, and etc.) as like a wooden plate which is used as ordinary concrete form works. Also, these permanent forms applied to the structure which has only assembled rebar with supporting permanent form using air tube from the outside of the RC structure. The pressure of the air tube should be matched with the pressure which can be applied from fresh concrete to the wall made by permanent form. The displacements were measured during the fresh concrete casting to the pilot test RC field casting structure. The safety of the construction method is evaluated by comparing the final displacements with the design standard. In this study, the concrete casting works of the RC structures was minimized using permanent forms and air tubes. So, the working days for new technology might take less than original construction days. Details will be explained in the full paper.

Numerical Modelling of Mould Compensation for Symmetrical Flat Laminate Composite Manufactured through Autoclave Process

abst. 1091
Repository

LERDWONGPAISAN Arnon (lerdwong@insa-toulouse.fr), Institut National des Sciences Appliquées de Toulouse, France
CASTANIE Bruno (castanie@insa-toulouse.fr), Institut National des Sciences Appliquées de Toulouse, France
OLIVIER Philippe (philippe.olivier@iut-tlse3.fr), Université Toulouse-III-Paul-Sabatier, France

Composite laminate structure generally encounter process-induced distortion during autoclave curing. Therefore, some undesired shapes are generated, especially in thin laminate which has low stiffness. This work mainly focuses on tool/part interaction effect and a study on the influence of stacking sequence and release agent to the out-of-plane deflection of symmetrical flat laminate between cross-ply [0° 1 /90° 1] s and angle-ply [45° 1 /-45° 1] s laminates which were autoclave-cured on 2024 aluminium flat mould was completed. The effect of stacking sequence is different : cross-ply laminate exhibit very small out-of-plane deflection while angle-ply laminate provides more than 7 times in maximum magnitude of deformation compared to cross-ply laminate. The existing interfaces employed between mould and laminate such as the use of Freekote, releasing film and peel-ply is unable to eliminate the tool/part interaction, therefore a compensation of mould should be considered. In the literatures, many researchers frequently emphasis on the compensation for curve or angle shape part. In this study, the compensation for flat shape is investigated. We firstly focus on the angle-ply laminate which has a huge deformation in diagonal direction. The mould is redesigned regarding to the shape and magnitude of deformation and again the curing simulation is computed using FEM (ABAQUS) integrated with thermomechanical model. Finally, the manufacturing of mould shape is performed in order to run the experiment in autoclave. The experimental result will be examined to support or improve the numerical modelling.

Numerical investigation of the springback behaviour and residual stresses of a hybrid profile produced by the roll forming process

abst. 1348
Room B035
Thursday
July 21
11h30

Ryll, Tobias (tobias.ryll@tu-dresden.de), Technische Universität Dresden, Institute of Lightweight Engineering and Polymer Technology (ILK), Holbeinstr. 3, 01307 Dresden, Germany
Kuhtz, Moritz (Kuhtz, Moritz), Technische Universität Dresden, Institute of Lightweight Engineering and Polymer Technology (ILK), Holbeinstr. 3, 01307 Dresden, Germany
Nguyen, Minh (minh.nguyen@tu-dresden.de), Technische Universität Dresden, Institute of Lightweight Engineering and Polymer Technology (ILK), Holbeinstr. 3, 01307 Dresden, Germany
Filippatos, Angelos (angelos.filippatos@tu-dresden.de), Technische Universität Dresden, Institute of Lightweight Engineering and Polymer Technology (ILK), Holbeinstr. 3, 01307 Dresden; Technische Universität Dresden, Dresden Center for Intelligent Materials (DCIM), 01067 Dresden, Germany
Gude, Maik (maik.gude@tu-dresden.de), Technische Universität Dresden, Institute of Lightweight Engineering and Polymer Technology (ILK), Holbeinstr. 3, 01307 Dresden, Germany

Hybrid materials made of light metal and fibre-reinforced plastics are used more commonly in the mobile and transport industry due to their good mechanical properties and high lightweight potential compared to the individual material components [1]. A good example for the use are hybrid profiles out of metal sheets and glass fibre-reinforced thermoplastics (GFRTP). The adjustable mechanical properties such as stiffness, eigenfrequencies and good crash properties [2] are only some of the advantages of these profiles. Mere metal profiles are produced for example with the well-established roll forming process. Both the process and the influence of various process parameters such as friction and geometric dimensions are sufficiently well understood [3-6]. In contrast, the manufacturing process of hybrid light metal profiles combined with a composite like GFRTP tapes are still relatively unknown and the influence of the process parameters on the resulting structural properties of the profile still has to be assessed such as residual stresses and springback effects. Therefore, a two-step simulation

approach is introduced in the study presented here, which models both the thermoforming process of the hybrid profiles and the subsequent free deformation after the manufacturing process. In particular, the orthotropic thermal material properties are taken into account by means of a 3D LS-DYNA solid model. Here, the implemented Johnson Cook material model for light metals and a thermal orthotropic composite material are calibrated with basic experimental tests. The process model is validated based on experimental data on the rolling process using the occurring forming forces. In the first step the roll forming process is simulated, which results in a state with residual stresses. During the second step, the final geometry is calculated due to the computation of the release of most of the stresses after the profiles are retrieved from the roll forming machinery. In addition, the geometric dimensions predicted by the simulation model are compared with the real structures which are measured with the help of a three-dimensional measuring system ATOS from the company Gesellschaft für optische Messtechnik mbH. The foundation for a better understanding of the combined roll forming process of hybrid profiles is set, so that this technology can be further applied in the industry. Keywords: process simulation, roll forming, sheet metal forming, hybrid material, gfrp. Key findings: Calibration of material models for light metals and composites with experimental data; Comparison of numerical and experimental roll forming process data regarding profile geometry after roll forming; Prediction of the resultant mechanical properties of the hybrid profile. References: [1] D. Weck, M. Q. Pham, M. Gude, C. Cherif, B. et al. Coupled process and structure analysis of metal-FRP-hybrid structures, Hybrid Materials and Structures 2018,(2018) 18.-19.04.2018, Bremen, Germany. [2] M. Kuhtz, N. Buschner,T. Henseler T, et al. An experimental study on the bending response of multi-layered fibre-metal-laminates. Journal of Composite Materials. (2019);53(18):2579-2591. [3] T. Traub, C. Müller, P. Groche, The perspective of sensor integration and automated decision making in roll forming. AIP Conference Proceedings. (2019). [4] E. Sáenz de Argandoña, J. Larranaga, A. Legarda, L. Galdos, Roll Forming Set-Up Influence in the Forming Forces and Profile Quality. Key Engineering Materials. (2012), 504-506, pp.1249-1254. [5] L. Galdos, U. Ulibarri, I, Gil, R. Ortubay, E. Sáenz de Argandoña, (2014). Friction Coefficient Identification in Roll Forming Processes. Key Engineering Materials, 611–612, pp.425–435. [6] K. Tsang, W. Ion, P. Blackwell, M. English, (2017). Validation of a finite element model of the cold roll forming process on the basis of 3D geometric accuracy. Procedia Engineering. 207.

Data science for composite materials and structures (chaired by N Fantuzzi, H Hu, J Yang, W Huang, L Dong, Z Wu, M Montemurro, F Chinesta, L Chamoin, E Cueto

Data-Model-Driven Hybrid Computational Framework for Bi-stability Analysis

abst. 1075
Virtual Room 1
Thursday
July 21
09h40

Kuang, Zengtao (kuangzengtao@whu.edu.cn), Wuhan University, China
Huang, Qun (huang.qun@whu.edu.cn), Wuhan University, China
Li, Ping (li.ping@whu.edu.cn), Wuhan University, China
Yang, Jie (jie_yang@whu.edu.cn), Wuhan University, China
Hu, Heng (huheng@whu.edu.cn), Wuhan University, China

The distance-minimizing Data-Driven method, proposed by Kirchdoerfer and Ortiz[1], is a new computing paradigm that transforms solving boundary-value problems into solving optimization problems and replaces a constitutive model with discrete material data. Compared to the conventional "model-driven" computing paradigm, the data-driven method has the advantage of eliminating the error and uncertainty in material modeling. However, it may fall into the trap of obtaining the local extremum but not the global one[2] for anlaysis of the bi-stability behavior where non-convex optimization appears. Towards this end, we propose a novel hybrid computational framework for bi-stability analysis by combining the "model-driven" and "data-driven" algorithms. The model-driven algorithm based on the finite element method is firstly performed to obtain preliminary solutions corresponding to various loading level, in which, the consitutive model can be roughly established with material data set. Then, taking these solutions as initial guess, the data-driven algorithm is conducted to find the best solutions in the material data set that are closest to satisfying the equilibrium. Since the initial guess is close to the optimal solutions, the latters can be found with high probability under the current local search scheme. The advantages of both the two algorithms can be gathered, where the robustness is ensured and the uncertainty of material model is eliminated. Since the initial iterations under each loading stage have already been obtained in "model-driven" part, each calculation step in "data-driven" part are independent of each other and can be carried out in parallel, thus significantly improving the efficiency. This work can provide an efficient and robust tool for analysis and design of advanced materials. Key Words: data-driven; model-driven; bi-stability. REFERENCES: [1] Kirchdoerfer T, Ortiz M, 2016. Data-driven computational mechanics. Computer Methods in Applied Mechanics and Engineering 304, 81-101. [2] Lee J, Leyffer S, 2021. Mixed integer nonlinear programming. Springer Science Business Media 154.

Structural-Genome-Driven method for composite plates

abst. 1163
Virtual Room 1
Thursday
July 21
10h00

Yan Wei (yanwei@whu.edu.cn), Wuhan University, Wuhan, PR China
Huang Wei (w.huang@whu.edu.cn), Wuhan University, Wuhan, PR China
Huang Qun (huang.qun@whu.edu.cn), Wuhan University, Wuhan, PR China
Yang Jie (jie_yang@whu.edu.cn), Wuhan University, Wuhan, PR China
Hu Heng (huheng@whu.edu.cn), Wuhan University, Wuhan, PR China

Composite plates are widely used in various industry fields, such as aerospace, automotive. The microscopic architecture plays an important role in defining the mechanical behavior of composite structures. In order to obtain a more accurate macroscopic constitutive relationship of composite plate, the conventional multiscale simulation methods require considerable computing effort and suffers from computational limitations in the length and time scales it can address. In the data era, data-driven multiscale methods provide possibilities for solving the problems. To combine the strengths of both methods and to obtain a multiscale model that efficiently and accurately captures mechanical behavior, we develop an efficient data-driven multiscale method for composite plates, namely Structural-Genome-Driven (SGD) method. Firstly, the generalized strain and stress are adopted to construct the penalty function of data-driven framework of plate. Then, the multi-level finite element method (FE2) is applied to collect the multiscale structural genome data for the database construction of the composite plate. Numerous offline microscopic calculations are performed within Representative Volume Elements (RVEs) using computational homogenization. Finally, the structural genome database is used to drive the online data-driven computing, whose results are compared with those obtained via conventional approaches to verify the accuracy and the efficiency. Since the conventional simulation process is decoupled into the offline data preparation and the online computing, in which the structural elements are employed for the simulations, the efficiency of the proposed data-driven approach is highly improved compared to the conventional one.

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abst. 1221 **Repository**

Using Machine Learning in Composite Design: the Case of a Torsion Spring for Light Vehicles

Fragassa, Cristiano (cristiano.fragassa@unibo.it), Department of Industrial Engineering, University of Bologna, Italia
Pavlovic, Ana (ana.pavlovic@unibo.it), Department of Industrial Engineering, University of Bologna, Italy
Lukovic, Marko (marko-design@hotmail.com), Faculty of Applied Arts, University of Arts in Belgrade, Serbia
Minak, Giangiacomo (giangiacomo.minak@unibo.it), Department of Industrial Engineering, University of Bologna, Italy

Composite materials offer several advantages, including high versatility in design: it is enough, for example, to modify a stratification to obtain quite different properties. However, this opportunity is likely to be of little use if it is not supported by an adequate design optimization technique. For this purpose, finite element software is often used, enhanced by specific tools for composites and automatic optimization. Ansys Workbench, for instance, even allows you to automatically choose the best arrangement of the fibers (e.g., as directions). But all this also means that anyone who needs to optimize a composite component would have a lot to learn, including the need to equip themselves with advanced calculation codes. It was therefore decided to evaluate an alternative approach here, based on expert systems and machine learning (ML). For this purpose, we decided to focus on a specific component, very interesting for its complexity: a composite spring. This spring is defined (if rectangular, e.g.) by 5 geometric parameters: width and height of the section, diameter and pitch, overall length. From these parameters it is possible to obtain its volume and, knowing the (average) density of the material, its mass. On the other hand, it is not possible to derive the stiffness which is a function not only of the materials used, but also of the stratification (e.g., layer thickness, fiber orientation, etc.). The same dependence also applies to other important aspects, such as stresses, deformations and compliance with failure conditions. What can an Artificial Intelligence (AI) algorithm do once it is properly trained? The short answer is that AI can predict, inside a margin of error, one parameter when all the others are known. It therefore allows you to quickly evaluate and compare different design hypotheses ('what would be the value of this parameter if the others assumed the values of ...'). Even a parametric simulator can do this, of course. However, by an ML algorithm you can work differently: 1. no longer through structural calculations, used only at the beginning to train the algorithm, but for 'similarity' through a 'pattern recognition' approach; 2. with a better accuracy in controlling predictions since to a greater ability to supervise ML 'classifiers'. The use of expert systems in the design of composites is just at the beginning and it is not possible to be sure about their convenience but, considering what is happening in other technological areas, it seems plausible. Our initial attempt included to the use of an expert system (from Orange Data Mining) which, 'educated' by less than 100 simulations, attributable to 4 continuous parameters, discretized through 12x26x19x15 values for 88,000 possible combinations, were able to identify targets design with an accuracy greater than 94% in the case of 'category' indication (eg best stratification between different proposals) and 88% in the case of 'numerical values' (eg dimensions). Actually, our spring is characterized by no less than 8 design parameters for which it is necessary to proceed through a stratification of decisions. In this the expert algorithm does not need data as much as information: it is of little use, in fact, to add data if they do not bring new patterns with them. For instance, from our tests it emerged that adding a parameter linked to one already present showed a negligible improvement in the accuracy of the predictions (<1%). Instead, information that would seem only consequential to the design choices, can intervene by helping predictions. For instance, in case of the maximum principal stress, it does not use to represent a real design parameter, but only an aspect to be verified. However, this element makes the algorithm more accurate (+ 8%) offering new recognition schemes to the expert algorithm. At this point, anyone who needed to design a similar composite spring would not need any particular knowledge, nor structural calculation programs, but only the link to the expert system. Acknowledgments: this research was funded by the Italian Ministry of Foreign Affairs and International Collaboration within the 'Two Seats for a Solar Car' project and promoted inside the Central European Initiative as part of the 'Composite for All' and 'ATC.EVO' technology transfer actions.

Prediction of temperature-dependent polyphenylsulfone tensile properties through a machine learning approach

abst. 1238
Repository

Fragassa, Cristiano (cristiano.fragassa@unibo.it), Department of Industrial Engineering, University of Bologna, Italia
Wentz, André Viegas (andre.wentz@senairs.org.br), SENAI Institute of Innovation in Polymer Engineering, Brazil
Lukovic, Marko (marko-design@hotmail.com), Faculty of Applied Arts, Industrial Design Department, University of Arts in Belgrade, Serbia
Cabreira, Vinicius (vinicius.cabreira@senairs.org.br), SENAI Institute of Innovation in Polymer Engineering, Brazil
de Camargo, Vannucchi Felipe (felipe.camargo@senairs.org.br), SENAI Institute of Innovation in Polymer Engineering, Brazil

Machine Learning (ML) can be considered as part of the broader concept of Artificial Intelligence (AI) but probably highlights one of its most interesting aspects: the possibility that machines 'learn' from data. This concept, first expressed (by Alan Turing) at the dawn of the discipline, is fundamental for the large development AI is having today. The ability of ML to learn from data reconfiguring AI allows to offer useful answers in incredibly wide application areas. Moreover, a ML approach is almost affordable for everyone nowadays: simple, fast, and powerful tools are now available allowing to perform a data analysis with results that, although not always optimized, can still provide valid indications. This is the case here reported where ML algorithms, embedded in the Orange data mining platform, are used to analyze data from tensile tests on polyphenylsulfone (PPSU). It is a type of high-performance polymer usually consisting of aromatic rings linked by sulfone (SO2) groups, often reinforced by glass or carbon fibers to produce reinforced composites. PPSU offers excellent characteristics as high operating temperature (to 180°C), good chemical compatibility, high rigidity over a wide range of temperatures, very high impact strength, good dimensional stability and electrical insulation. These characteristics make PPSU a very interesting target of investigation. Specifically, in the present study, tensile tests were carried out at 5 different temperatures (from -40 to + 70 ° C) making possible to measure engineering stresses and strains at yield and breaking points respect to 48 samples. The equivalent true stresses and strains were also numerically evaluated together with the elastic and resilience moduli. This dataset was used as basis for applying the most common ML classifiers as neural network, K-nearest neighbors, logistic regression, random forest and so on. Simplistically, it can be said that a ML classifier works by trying to recognize patterns in the data. Unfortunately, it is hard to predict which classifier work better respect to a dataset never considered before. Then, a so-called cross-validation was done as first. The procedure extracts a little group of data from the dataset before the training and use them for testing. The procedure is repeated several times averaging the results. Depending on specific aspects and parameters (including the need to exclude the quantities related together by formulas), the accuracy changes, but its typical value is around 92-96%. This means, to put it simply, that the ML system is able to correctly predict one unknown parameter (e.g., test temperature, breaking stress...). For instance, it is very accurate (>90%) in identifying at which temperature a test was done knowing all the experimental measures but can also estimate the (yield or breaking) stress when the related strain is known or vice versa. It occurs through the recognition of patterns and not through other techniques (as extrapolation). The accuracy drops when more than one parameter is unknown, but rarely falls below 75% in situations of real interest. This is the case when the ML is expected to estimate both stress and strain at the breaking point by knowing the values at the yield point, or vice versa. Outcomes are

very interesting especially when it is considered the experimental measurements as characterized by an intrinsic variability. For instance, considering the breaking stress at 23 °C, even if this test condition permits to have the largest consistency of samples (22 out of 54), the standard deviation is 5.6 respect to an average value of 69.6 (i.e. 8%). Finally, the ML applicability respect to extreme predictions is still open. Specifically, it would be really interesting to predict the material properties respect to a specific temperature by knowing the same properties at other testing temperatures. It is the situation of four unknown values (i.e., stresses and strains in yield and breaking points) against a single known value (i.e., the testing temperature). ML classifiers are not able to recognize appropriate patterns at the moment while latest attempts are made including new data from other experiments (such as impact tests).

Delamination, damage and fracture

Influence of crack location and crack number on the responses of 3D representative unit cell of unidirectional composites

abst. 1007
Virtual Room 2
Thursday
July 21
11h30

Huang, Sam (samhuang@mail.nsysu.edu.tw), National Sun Yat-sen University, Taiwan

In this study, numerical study on crack location and crack number on the responses of representative unit cell of unidirectional composites under tension is conducted by extended finite element method (XFEM). The composites studied here are single-crack composites, two-crack composites, and three-crack composites. Each of the composites is under tension in the x direction, in the y direction, and in the z direction. Basing on simulation results, one can draw conclusion that the averaged strength decreases as the embedded crack number increases when composites are under tension. One interesting finding is that a crack could be a dominant crack but becomes inactive when other different cracks are in presence under the same loads. The responses of representative unit cell of composites depend upon crack location and the applied loading direction. The results from these simulations can also explain why there is discrepancy of strength prediction from the composites manufactured under the same conditions. The simulation method presented here in this study can be used to model degree of defects (by modelling the number of cracks) and stochastic characteristics of ultimate strength (by modelling distribution of crack strength)

How to obtain similar responses from CFRP laminates subjected to low-velocity impact fatigue and fatigue indentation loading

abst. 1062
Virtual Room 2
Thursday
July 21
12h30

Huo, Lubin (L.Huo@tudelft.nl), Delft University of Technology, Netherlands
Alderliesten, René (R.C.Alderliesten@tudelft.nl), Delft University of Technology, Netherlands

Fatigue of composite laminates caused by repeated transverse impact loading has been studied in the past few decades[1-3]. Composite material systems under transverse impact fatigue loading with different incident energies will have different fatigue life (i.e. the total number of impact cycles till degradation of the composite mechanical properties). In general, for high velocity impact, the material system could be perforated within few impacts, while for low-velocity impact, it may require thousands of impacts to perforate the specimen. Obviously, semi-automatic motorized drop-weight impact devices (i.e. manual operation is unavoidable for each impact) are not suitable for the study of low-velocity impact fatigue. Relevant studies [4-7] have shown that, with comparable boundary and loading conditions, quasi-static indentation and low-velocity impact can yield similar damage characteristics for the same material system. In contrast with low-velocity impact, quasi-static indentation has the advantages that force-deflection curve can be directly recorded instead of numerically integrating force-time curve. Furthermore, the indentation locations are more consistent, and damage initiation and propagation can be observed more easily. Therefore, it would be significant if quasi-static indentation could be applied repeatedly (fatigue indentation) loading to reproduce low-velocity impact fatigue loading. To that aim, the transverse fatigue loading responses of CFRP composite laminates were compared, tested either in impact fatigue loading or in repeated indentation loading. The laminates consisted of 150 $\times$ 300 $\times$ 2.5 mm panels made by hand-lay-up using unidirectional carbon/epoxy prepreg M30SC/DT120 [8, 9] supplied by Delta-Tech S. p. a., with a layup sequence [45, 0, -45, 90]2s. In both cases, the panels were subjected to 225 transverse load cycles (i.e. low-velocity impacts or quasi-static indentations), and these loads were applied to the panels by a 30 mm diameter hemispherical steel impactor or indenter. The specimens were under the same clamp boundary condition and two similarity principles were used to generate more similar loading conditions. The first one is called force quasi-static indentation (FQSI), it applies the 3 mm/min quasi-static indentations to the same maximum force as obtained from drop-weight impacts with 8.4 J incident energy. The second one is referred to as an energy quasi-static indentation (EQSI), for which 6.5 J quasi-static indentations with the same rate are applied. This 6.5 J originated from preliminary tests showing that 6.5 J quasi-static indentation and 8.4 J low-velocity impact yield similar peak forces, because part of the energy is dissipated by vibration and loud noises during low-velocity impact, which don't occur in quasi-static indentation. The responses were evaluated based on force-displacement curves that were divided into loading and unloading stages, and based on the morphologies of the cross-section damages which were obtained through KEYENCE® laser microscopy and subsequently AutoCAD® software package to obtain the damage profiles. The comparison of force-displacement curves suggests that quasi-static indentation fatigue loading have similar loading behavior as repeated low-velocity impacts, but that the EQSI principle fits better than FQSI principle. However, neither FQSI or EQSI could induce similar behavior to low-velocity impact during the unloading stage. This may be the result of the dynamic response of low-velocity impact, which is not present during the quasi-static indentations. The damage patterns of these three damage specimens all have a pine tree shape which indicate that the specimens under low-velocity impact fatigue loading and quasi-static indentation fatigue loading have similar macro damage mechanisms, although FQSI seems to be closer to low-velocity impact loading than EQSI in terms of damage amount. This study does not yet answer the question whether quasi-static indentations can be used to study impact fatigue properties of CFRP composite laminates, it does demonstrate the concept how to compare both loading conditions. Although quasi-static indentation never yields the exact same damage pattern and response, the current results seem to imply that comparison should be based on FQSI rather than EQSI. In further research, the thickness and configuration of the specimen, the boundary condition, shape and size of the impactor/indenter etc. are all factors that will be considered. References: 1. Wyrick, D.A. and D.F. Adams, Residual strength of a carbon/epoxy composite material subjected to repeated impact. Journal of Composite Materials, 1987. 22: p. 749-765. 2. Belingardi, G., M. Cavatorta, and D. Salvatore Paolino, Repeated impact response of hand lay-up and vacuum infusion thick glass reinforced laminates. International Journal of Impact Engineering, 2008. 35(7): p. 609-619. 3. Maria Pia Cavatorta and D.S. Paolino, Damage variables in impact testing of composite laminates, in Composite Materials Reasearch Progress, L.P. Durand, Editor. 2008, Nova Science Publishers. p. 237-256. 4. Bull, D.J., S.M. Spearing, and I. Sinclair, Investigation of the response to low velocity impact and quasi-static indentation loading of particle-toughened carbon-fibre composite materials. 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abst. 1184
Room B035
Thursday
July 21
15h30

Uncoupled cohesive laws including large scale bridging

Joki, Reidar Kvale (rkj@joki-engineering.no), JOKI Engineering AS, Norway
Grytten, Frode (Frode.Grytten@sintef.no), SINTEF Industry, Norway
Jørgensen, Jens Kjær (Jens.K.Jorgensen@sintef.no), SINTEF Manufacturing, Norway
Sørensen, Bent F. (bsqr@dtu.dk), DTU, Department of Wind Energy, Denmark

Cohesive zone modelling with cohesive elements is a convenient and commonly used tool for investigating delamination in glass fibre reinforced polymer (GRP) laminates. The behaviour of the cohesive elements is governed by a cohesive law relating tractions to opening displacements. Large scale bridging (LSB) and how this phenomenon is included in cohesive laws is the topic of this paper. The presence of LSB can affect the opening mode of the crack tip. Mode II opening of the crack tip is usually reported do dissipate more fracture energy than a mode I opening. A crack tip mode shift towards mode II should therefore increase the fracture resistance. Any mode shift promoted by LSB should therefore be of interest and the governing factors should be understood. To investigate how the crack tip is affected by the presence of LSB a parameter study has been carried out. The study includes four series of simulations on moment loaded double cantilever beam specimens where one of the beams is loaded and the other is unloaded. This moment configuration will promote a mixed-mode delamination. In each of the simulation series one of four key parameters has been investigated. In all simulations the Mode I law has been kept constant while the specified parameters have been variated for the Mode II law. The specified parameters include cohesive stiffness, critical cohesive traction, critical opening, and fracture

resistance (area under the cohesive law). An uncoupled cohesive law implemented in LS-DYNA has been used in this study. For each series the opening displacement components (normal and tangential to the fracture interface) of the initial crack tip and a steady state crack tip were compared. Here steady state refers to a state where the crack front propagates without any increase in the applied moment. Steady stated delamination is thus assumed to have a self-similar evolution. The phase angle of the steady state crack tip opening mode was also recorded for all simulations. The phase angle was determined from the ratio of the opening displacement components when critical cohesive tractions was reached. It was observed that the evolution of the opening displacement components differed from the initial crack tip to that of a crack tip initiated during steady state delamination. The steady state crack tip phase angle was plotted against the evaluated parameters. It was evident that the critical cohesive traction was the most dominating parameter for determining whether the crack tip would shift towards mode I or mode II. The phase angle always shifted towards the mode with the lowest critical traction.

On the influence of non-woven carbon veils with different binders on mode-I interlaminar fracture toughness of carbon fibre/epoxy composite laminates

abst. 1191
Virtual Room 2
Thursday
July 21
12h50

Wang, Sheng (sheng.wang-3@postgrad.manchester.ac.uk), Department of Mechanical, Aerospace and Civil Engineering, The University of Manchester, UK
Katnam, Kali Babu (kali-babu.katnam@manchester.ac.uk), Department of Mechanical, Aerospace and Civil Engineering, The University of Manchester, UK
Zou, Zhenmin (Zhenmin.Zou@manchester.ac.uk), Department of Mechanical, Aerospace and Civil Engineering, The University of Manchester, UK
Potluri, Prasad (prasad.potluri@manchester.ac.uk), Department of Materials, The University of Manchester, UK

The objective of this research is to investigate the effect of non-woven carbon veils with different binders on the interlaminar fracture toughness under mode-I condition. The non-woven carbon veils with the same areal weight (i.e. 10 gsm) of four different binders including polyvinyl alcohol (PVOH), Polyester (PET), cross-linked PET (xPET), and cross-linked styrene-acrylic (xSA) were chosen as the interleaf for the carbon fibre/epoxy laminates manufactured by vacuum resin assisted infusion and out-of-autoclave curing. Double Cantilever Beam (DCB) tests were used to obtain the mode-I fracture energies and R-curves. Fractography was carried out to characterize the toughening mechanisms. The results demonstrated that the binders influenced the toughening performance of the non-woven carbon veils. Although all the toughed laminates exhibited relatively flat R-curves, the carbon veil with PET binder gave the best toughening performance with an increase of 52% and 56% for fracture initiation and propagation energies, while the carbon veil with PVOH had the poorest performance with a decrease of 18% and 17% for fracture initiation and propagation energies compared to those of the baseline.

Influence of the restitution coefficient value on damage of composite shields protecting the chassis of a rail vehicle.

abst. 1237
Room B035
Thursday
July 21
15h50

Juzuń Mateusz (mateusz.juzun@gmail.com), DB Cargo Polska SA, Poland
Pawlak Mariusz (mariusz.pawlak@polsl.pl), Silesian University of Technology, Poland

To protect the undercarriage of a railway vehicle moving at high speeds, rolling stock manufacturers use covers made of polymer composites. During operations, damage to these guards is often observed due to railway ballast hitting them. Verification of the course of the impact and the extent of damage caused to these shields has drawn attention to the potential effect of the structural damping of the material on the impact resistance of these shields. This property is expressed by the coefficient of restitution, which determines the amount of energy absorbed by the material during the impact, and its direct influence on the simulation results is rarely a separate research subject. In this paper, an attempt was made to verify the influence of this coefficient on the compliance of railway ballast impact simulation results with the results of bench tests. Two test stands were built for this purpose: to measure the

coefficient of restitution of the composite samples and to verify the impact resistance of shields. This allowed a comparative analysis of the results with the model developed for numerical analysis in the LS Dyna environment. The principle of the restitution coefficient tester is based on the ISO 10545-5 standard and its operation is based on measuring the time elapsed between two consecutive impacts of a steel ball on the surface of the tested specimen. The experimental tests carried out led to the determination of the coefficient for the composite material adopted. This material was a laminate of flax fibres and epoxy resin with a core of 2 different types of materials, i.e., XPS and EPS, and the coefficient values obtained were 0.74 and 0.69 respectively. Knowing these values allowed us to relate the extent of damage caused to the value of the restitution coefficient. To simulate the impact of the railway ballast on the casing, a second test bench was prepared, which allowed the impact to be reproduced. A discretised model was then prepared for numerical analysis of this phenomenon and to allow verification of other materials without the need for bench testing. The first results obtained in the simulations, despite using the correct material form and design of the specimen, differed significantly from those obtained on the test bench. Therefore, another model was prepared for numerical tests reproducing the phenomenon of steel ball rebound, to verify the coefficient of restitution for the adopted material model. A different value of the coefficient was found, which made it necessary to manually adjust the parameter to bring the value of the coefficient of restitution close to that of the experimental tests. The influence of several methods available in LS-Dyna was checked. Once the expected value was achieved, the significance of the changes introduced on the extent of damage observed in the original railway ballast impact simulation was verified. The observed significant effect on the results confirmed the validity of the assumption and the result of the simulations was significantly closer to the real specimens verified on the impact test rig. The whole study was related to two models differing in the way the lamina layers were represented, which were formed by T-SHELL or SOLID elements. In addition, in the case of the model based on solid elements (SOLID), the influence of the sensitivity of the model to the size of the finite element was verified. Common models for numerical analysis do not focus on the consideration of the restitution factor in impact simulations. The analysis of the numerical model prepared for the railway ballast impact simulation showed differences between the coefficient of restitution assumed in the model by LS-Dyna and the results of the samples determined by bench testing. Manual fine-tuning of the model has the effect of increasing the compliance of the impact simulation results with respect to the default values chosen by the environment.

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abst. 1259
Room B035
Thursday
July 21
16h10

Spallation of thermal barrier coatings for gas turbine applications

Hay, Harry (h.hay@lboro.ac.uk), Loughborough University, United Kingdom
Wang, Simon (s.wang@lboro.ac.uk), Loughborough University, United Kingdom
Harvey, Christopher (c.m.harvey@lboro.ac.uk), Loughborough University, United Kingdom

Blisters of alumina oxide films formed on the surface of Fe-Cr-Al alloy substrates at 1200 degrees 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 that occur due to the effects of thermal expansion coefficient mismatch and creep during high temperature operation and cooling. An analytical framework is presented alongside the finite element model to further validate the theory.

Advanced finite element analysis of composite plates with two delamination fronts

abst. 1275
Room B035
Thursday
July 21
16h30

Hauck, Bence (bence.hauck@mm.bme.hu), Department of Applied Mechanics, Budapest University of Technology and Economics, Hungary
Szekrényes, András (szeki@mm.bme.hu), Department of Applied Mechanics, Budapest University of Technology and Economics, Hungary

The existing semi-analytical modelling methods of plates are severely restricted, especially in the case of delaminated composite plates. The basic problem is that boundary conditions cannot be defined arbitrarily. Furthermore, analytical methods are not able to handle delaminations that have two or more fronts. Finite element discretization allows for applying any kind of boundary conditions and many configurations of delamination. The most obvious way is creating special composite plate elements. For the analysis of delaminated plates, one needs at least three different types of plate elements: an intact, a transition and a delaminated one. Firstly, a plate theory has to be chosen for establishing an element. In this study, the first-order shear deformation theory (FSDT) is used, which assigns the number of displacement components at a node. In addition to displacement, strain and stress fields, fracture mechanical analysis is also important and necessary. We are concerning delaminations that have two perpendicular fronts to each other, therefore the focus must be on their corner. In the sense of fracture mechanics, the energy release rate needs to be calculated along the delamination fronts. A convenient way is computing the path-independent J-integral around every point of delamination fronts. This can be carried out as a numerical Gauss integration. J-integral has to be computed in two directions at the corner of delamination and its fracture modes have to be separated. This model is implemented in a Python programming environment, in which geometrical dimensions, material properties and the location of delamination along thickness may be varied easily. It leads to a robust and fast analysis tool for delaminated composite plates with rectangular shaped delaminations. The accuracy of the model can be enhanced by applying higher-order plate theories, however, it increases the CPU time and memory usage significantly. Elements should be checked by applying them to classical problems, which have semi-analytical solutions. But the most difficult task is the verification of the model that includes rectangular delamination. Results can be compared with another finite element model that is built by solid elements only, but it is cumbersome if several configurations are subjected to comparison. On the other hand, miscellaneous numeric methods can be used like differential quadratures.

Damage Detection and localization in FRP plates by lamb wave considering material anisotropy

abst. 1278
Repository

Xu, Ying (cexyx@hotmail.com), Harbin Institute of Technology, Shenzhen, China

Ultrasonic Lamb wave method is commonly applied in detecting the damage of plate structure. However, the anisotropy material property of FRP (fibre reinforced plastics) has a great effect on the accuracy of damage localization based on lamb wave method. To solve this problem, a time probability density method is proposed, which is developed from traditional ellipse method and considers the anisotropy property of FRP material. By taking account of the group velocity variation of A0 mode waves with different propagation directions, this method calculates the travel time of the reflected wave with any damage on FRP plate, and the time flight diagram can then be obtained. By establishing the mapping relationship between the time of flight and the travel time of the actual damage reflected wave, a time probability density map can be obtained to characterize the probability of the existence of the fracture area. The result from numerical analysis and the experimental study shows that the damage localization error of this method can be reduced by more than 70% compared to that of the traditional ellipse method. This paper demonstrates the feasibility and accuracy of this method for the damage localization of anisotropic FRP plates.

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abst. 1287
Virtual Room 2
Thursday
July 21
11h50

Interactive characteristics of delamination damage growth of composite laminates under various sequential static and cyclic loading

Li, Shuxin (lishuxin@whut.edu.cn), Wuhan University of Technology, Foshan Xianhu Laboratory, P.R. China
Duan, Qingfeng (lishuxin@whut.edu.cn), Wuhan University of Technology, P.R. China
Hu, Haixiao (18771025278@162.com), Wuhan University of Technology, P.R. China
Cao, Dongfong (caodongf@163.com), Wuhan University of Technology, P.R. China

Damage tolerance assessment for composite structures, such as the FAR 25 and CS-25 airworthiness regulations, are required to consider the interactions of load events occurring in-service with variable amplitude cyclic loading and static overload events. The interactive characteristics of delamination damage growth of composite laminates are investigated in this paper with experimental testing and analysis as well as numerical simulations. Experiments are carried out with monotonic loading and two different types of multilevel sequential cyclic loading and step monotonic loading which either induce delamination damage growth due to overload or no damage growth. Significant differences in delamination damage growth behavior had been observed from the experimental results. Damage increment at a given load cycle strongly depends on the current load cycle and the damage induced in preceding load events. The analysis indicated that the interactive characteristics is attributed to both the differences in terms of the damage zone ahead the delamination crack tip and the effects of fiber bridging behind the delamination crack tip. Further experiments are carried out to assess the fiber bridging effects and then the damage zone effects under different loading conditions. Modified constitutive equations with the cohesive zone model are subsequently developed to enable numerical simulations of the interactive characteristics of delamination damage growth observed from the experiments under various sequential static and cyclic loading.

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abst. 1288
Virtual Room 2
Thursday
July 21
13h10

Application of The Effective Crack Length Method to Model Delamination of Unidirectional Composite Laminates Under Mode II Shear Loadings

Liu, Heng (Hannah) (Heng.Liu@nrc-cnrc.gc.ca), National Research Council Canada, Canada
Qi, Gang (gang.qi@nrc-cnrc.gc.ca), National Research Council Canada, Canada
Li, Chun (Lucy) (Lucy.Li@nrc-cnrc.gc.ca), National Research Council Canada, Canada

Damage modelling of composite material delamination is an intense field of research to understand the complex composite failure behaviour and predict the residual strength of damaged structures. One of the widely employed methods to simulate delamination is the cohesive zone modelling (CZM) technique. To successfully utilize this approach, accurate characterization of the interlaminar fracture toughness is crucial, while the composite delamination is dominated by Mode I and Mode II fracture in most cases. Numerous studies have been conducted on composite materials delamination under Mode I loadings using double cantilever beam (DCB) tests. Accordingly, the ASTM standard testing procedure and data reduction scheme to obtain Mode I fracture toughness (GIc) have been well established and widely accepted. However, it is still challenging to characterize the composite Mode II delamination resistance due to the susceptibility problems inherent to the existing testing methods and the lack of robust data reduction schemes to accurately identify the initial crack tip and monitor the crack growth. This study attempts to find a reliable solution to obtain the Mode II fracture toughness (GIIc) and an effective modelling strategy to simulate Mode II delamination in laminated composites. First, we reviewed the existing testing set-ups and surveyed the data reduction schemes conventionally used to obtain GIIc. The advantages and drawbacks of the three most used test methods, and particularly the standard end-notched flexure (ENF) test (ASTM D7905/D7905M) and the end-loaded split (ELS) test (ISO 15114:2014) were examined. Second, the advantages of several effective-crack-length-based data reduction schemes against the classical data reduction schemes were empirically studied with the ENF tests conducted on G40-800/5276-1 carbon-fibre reinforced composite laminate coupons. Although many studies have studied the accuracy of the effective-crack-length-based approaches from different aspects, there is a lack of direct comparison between the numerical results and experimental data. Our modelling study demonstrates that the classical data reduction schemes underestimated

GIIc while the equivalent-crack-based data reduction schemes provided a more accurate value. Finite element (FE) modelling of the ENF tests using the CZM technique was carried out and comprehensive parametric studies were conducted to achieve an efficient and robust strategy for delamination modelling of composite laminates under Mode II shear loadings.

Impact damage of CFRP with preload

abst. 1295
Room B035
Thursday
July 21
16h50

Barca Iga (iga.barca@wat.edu.pl), Military University of Technology, Poland
Rośkowicz Marek (marek.roskowicz@wat.edu.pl), Military University of Technology, Poland
Komorek Andrzej (a.komorek@law.mil.pl), Polish Air Force University, Poland
Przybyłek Paweł (p.przybylek@law.mil.pl), Polish Air Force University, Poland

The article presents the results of impact test of a composite material with preload. Before impact, material specimens were preloaded in four-point bending conditions. On the basics of tests with the use of the computer tomography, it has been proved that damage distribution in CFRP depends on internal loads in the material – tensile or compression stresses.

Influence of distributed out-of-plane waviness defects on the mechanical behavior of CFRP laminates.

abst. 1367
Repository

Calvo Orozco, José Vicente (jocalvoo@ing.uc3m.es), Department of Mechanical Engineering, Universidad Carlos III de Madrid, Spain
Feito Sánchez, Norberto (norfeisa@upvnet.upv.es), Institute of Mechanical and Biomechanical Engineering-I2MB, Department of Mechanical Engineering and Materials, Universitat Politècnica de València, Spain
Miguélez Garrido, María Henar (mhmiguel@ing.uc3m.es), Department of Mechanical Engineering, Universidad Carlos III de Madrid, Spain
Giner Maravilla, Eugenio (eginerm@mcm.upv.es), Institute of Mechanical and Biomechanical Engineering-I2MB, Department of Mechanical Engineering and Materials, Universitat Politècnica de València, Spain

One of the most common defects encountered when manufacturing laminates such as Carbon Fiber Reinforced Polymers (CFRP) is out-of-plane fiber waviness. This defect significantly affects the mechanical behavior of the laminate, affecting its stiffness, strength, and fatigue properties, and reducing the load capacity of the material. Therefore, it is important to understand the impact of fiber waviness on the performance of composite laminates. In this work, different out-of-plane waves have been introduced in a controlled manner throughout a CFRP laminate and at different thickness heights. Laminates with this kind of wrinkling have been found to have an 18% lower tensile load strength, and non-destructive techniques such as Digital Image Correlation (DIC) allow to locate these defects. Furthermore, numerical simulations were conducted and show a good agreement with experimental results.

A multi-scale damage model based on SCA method for unidirectional CFRP laminate

abst. 1368
Virtual Room 2
Thursday
July 21
12h10

Cong Guo (guocong114@sjtu.edu.cn), State Key Laboratory of Mechanical System and Vibration, Shanghai Jiao Tong University; Shanghai Key Laboratory of Digital Manufacture for Thin-walled Structures, Shanghai Jiao Tong University, China
Shengda Jiang (JiangShengda@sjtu.edu.cn), State Key Laboratory of Mechanical System and Vibration, Shanghai Jiao Tong University; Shanghai Key Laboratory of Digital Manufacture for Thin-walled Structures, Shanghai Jiao Tong University, China
Ji He (benbenhj@sjtu.edu.cn), State Key Laboratory of Mechanical System and Vibration, Shanghai Jiao Tong University; Shanghai Key Laboratory of Digital Manufacture for Thin-walled Structures, Shanghai Jiao Tong University, China

The self-consistent clustering analysis (SCA) method is an accurate and efficient algorithm for the multi-scale concurrent simulation of heterogeneous materials. However, the multi-scale damage model containing strain softening behavior in the SCA method still needs to be improved in terms of efficiency and feasibility. In the paper, a multi-scale damage model based on SCA method for unidirectional CFRP laminate is proposed, and the evolution of the damage variable is derived from the relationship of the energy. In the macroscale, the characteristic length of the element is introduced into the microscale damage model based on the dissipated strain energy density to reduce mesh dependency, while in the microscale, an anisotropic stress degradation principle is adopted to account for the different damage characteristics in different directions, and the damage variable evolution and stress degradation process are decoupled to avoid the strain concentration effect. The mesh dependency of the damage model is verified by a simple tensile test. Finally, the damage model is applied on the concurrent simulation of a V-notch specimen to analyze its damage evolution process under shear loading condition.

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abst. 1398
Room B035
Thursday
July 21
17h10

Effects of the various aluminum surface modifications on the interfacial metal-composite adhesion of fiber metal laminates

Drozdziel-Jurkiewicz, Magda (m.drozdziel@pollub.pl), Department of Materials Engineering, Faculty of Mechanical Engineering, Lublin University of Technology, Poland
Jakubczak, Patryk (p.jakubczak@pollub.pl), Department of Materials Engineering, Faculty of Mechanical Engineering, Lublin University of Technology, Poland
Bienias, Jaroslaw (j.bienias@pollub.pl), Department of Materials Engineering, Faculty of Mechanical Engineering, Lublin University of Technology, Pland

In Fibre Metal Laminates (FMLs), a very important issue remains the metal-composite interface. It plays a crucial role in the stress transfer between the metal and the composite layers. The study assesses the issues of metal surface treatment in fibre-metal laminates to obtain high adhesion at the metal-composite interface. Laminates were based on the aluminum alloy Al2024-T3 and carbon-fibre/epoxy. The metal surface modifications were carried out by mechanical, chemical, electrochemical, and plasma treatment, as well as the use of sol-gel coatings. The surface analysis was conducted based on the surface geometric, its morphology, and determination of physicochemical properties such as surface free energy as well as its components. It was noted that the applied surface treatments influence the obtaining a specific surface structure with a characteristic topography, morphology, and physicochemical properties. It seems that electrochemical methods are still the most effective in enhancing the expected adhesion, in particular chromic acid anodizing. The adhesion was assessed using shear adhesion strength testing (single lap-joint). The analysis was performed based on the shear adhesion strengths, force-displacement curves, cohesive failure values, and fracture analysis using scanning electron microscopy. A suitable technique may be the use of chemical treatment, especially P2 etching of alumnium. The obtained results showed that P2 etching and chromic acid anodizing increase the adhesion at the metal-composite interface in fibre metal laminates. It is due to the advantageous combination of surface structure and morphology. Simultaneously, a positive effect of the use of sol-gel coatings for the adhesion was noted. The synergistic interaction of these layers in combination with the sol-gel coating makes it possible to receive high adhesion due to the combination of mechanical and chemical adhesion. Acknowledgments: 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. 1399
Room B035
Thursday
July 21
15h10

In-situ SEM investigation on the damage behavior of an interpenetrating metal ceramic composite

Schukraft, Joél (joel.schukraft@mrm.uni-augsburg.de), Institute of Materials Resource Management, Augsburg University, Germany
Morbitzer, Philipp (philipp.morbitzer@student.uni-augsburg.de), Institute of Materials Resource Management, Augsburg University, Germany

Siegmund, Frederik (frederik.siegmund@mrm.uni-augsburg.de), Institute of Materials Resource Management, Augsburg University, Germany
Lohr, Christoph (christoph.lohr@mrm.uni-augsburg.de), Institute of Materials Resource Management, Augsburg University, Germany
Weidenmann, Kay A. (kay.weidenmann@mrm.uni-augsburg.de), Institute of Materials Resource Management, Augsburg University, Germany

In nowadays engineering success regarding to reduction of greenhouse gases and environmentally compatible implementations in mobility and transportation, light-weight materials for structural application play a key role. Improved mechanical properties, as well as wear resistance of a composite, combined of light-weight metals and ceramics 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. Based on an alumina ceramic preform, an interpenetrating metal ceramic composite is produced via gas-pressure infiltration with a cast aluminum alloy (AlSi10Mg). The elastic-plastic properties of this novel composite, as well as the damage behavior are tested in tensile testing experiments. To investigate the microstructure at the sample surface during the experiment, an in-situ scanning electron microscopy tensile testing setup. Focus during the investigation is on the yield strength, the corresponding microstructural damage at that point and the damage evaluation process. Following the in-situ experiments, the fracture surfaces are investigated to clarify the crack path through the sample - the phases and the phase boundary. To support the evaluation, the SEM-images are read into a digital image correlation software to determine the local strain on the surface and correlate it with the microstructural investigation.

Design and application of composite structures

abst. 1004
Repository

Aero-structural design, fabrication, and analysis of composite wind turbine blades for grid interactive hybrid renewable energy system

D, Muniraj (muniraj@sastra.ac.in), SASTRA Deemed to be University, India
VM, Sreehari (sreehari_vm@mech.sastra.edu), SASTRA Deemed to be University, India
AP, Haran (), Park College of Engineering and Technology, India
S, Govindaraj (), Park College of Engineering and Technology, India

The design, fabrication, and analysis of composite wind turbine blades for hybrid renewable energy system is presented in this work. The aim of this work is to present a methodology to produce power continuously for residential applications and distribute the excess power to grid through wind-solar hybrid renewable energy system. Aero-structural design and analysis of 1 kW small wind turbine blade was performed with an objective function of extracting maximum power and withstand extreme wind condition. The optimum blade structural configuration having low rotational inertia was determined through iteration without compromising the structural integrity. Fiber-glass/epoxy composite blade was manufactured using vacuum assisted resin transfer moulding method. Composite blade was modelled in software also and initial experimental result was correlated with the result from finite element method to validate the numerical model. Deformation, strain and stress of composite blade were evaluated initially for extreme wind condition experimentally and numerically. The experimental results are in good agreement with the numerical predictions. It was noted from the structural analysis that the designed composite blade is confirmed to withstand all possible load cases and was away from the resonance condition. Continuous power distributing control system was developed by integrating two small wind turbine system of 1 kW capacity each and 1 kW solar system with local energy storage. The designed wind solar hybrid system meets the design objective and reduces the grid dependency.

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abst. 1052
Virtual Room 1
Thursday
July 21
11h30

DESIGN AND CHARACTERIZATION OF GRAPHENE RUBBER COMPOSITES TO ACHIEVE ZERO THERMAL EXPANSION

Yan, Han (h-yan21@mails.tsinghua.edu.cn), Applied Mechanics Laboratory, Department of Engineering Mechanics, Tsinghua University, China
Yao, Xuefeng (yxf@mail.tsinghua.edu.cn), Applied Mechanics Laboratory, Department of Engineering Mechanics, Tsinghua University, China

Graphene rubber composites, exhibiting excellent electrical, thermal conductivity and the characteristic of super elasticity, become ideal materials for smart sealing and flexible sensors, and has significant application prospects and scientific value. When temperature changes severely, the mismatch of the thermal expansion coefficient may cause uncontrolled thermal expansion of the sealing interface and cause the interface to separate, which in turn leads to the failure of the sealing structure and even irreversible damage. However, the present researches lack clear methods for the zero-expansion design of graphene rubber composites, and there is an urgent need to investigate the zero-expansion design method of graphene rubber composite microstructure. The purpose of this article is to propose a zero-expansion microstructure design method for graphene-rubber composite, base on mechanical microstructure design, and therefore to achieve controllable thermal deformation of rubber materials. In this paper, the zero-expansion microstructure design method of graphene rubber is proposed, and the influence of the microstructure and material components on the mechanical properties and thermal expansion coefficient of the material is revealed. The establishment of a zero-expansion thermo-mechanical coupling model for graphene rubber composites is significant for process control, performance evaluation and intelligent sealing of graphene rubber composites. The main contents are as follows: First, considering the negative thermal expansion characteristics of graphene and the difference in thermal expansion coefficients between graphene and rubber, the geometric models of negative expansion structures in two-dimensional and three-dimensional situations are established respectively, and the material properties of graphene and rubber are given in different regions, and the properties of graphene and rubber are calculated. Based on the deformation and thermal expansion coefficient under temperature change, the concave structure is further introduced to explore the coordinated control method of the thermal

deformation characteristics of the structure and the thermal expansion coefficient, elastic modulus and Poisson's ratio. Secondly, two-dimensional and three-dimensional graphene rubber negative expansion finite element models are established, and corresponding material subroutines are used to simulate the mechanical response of negative expansion structures under uniaxial tension, compression rebound, and temperature changes. The equivalent elastic modulus, Poisson's ratio and thermal expansion coefficient, combined with theoretical derivation are calculated. Then the quantitative relationships between the mechanical properties of the material, such as thermal expansion and compression rebound, and the properties of the components and the geometric parameters of the structure are investigated. Finally, to determine the optimal combining parameters, zero expansion of the overall structure is taken as the design goal, and the compression resilience of the material, the difficulty of preparation are comprehensively considered to optimize the geometric parameters and material ratio of the graphene rubber porous negative expansion structure., so as to obtain a porous structure design model with controllable thermal expansion and good resilience characteristics.

Design, analysis, manufacture and testing of the spacecraft mirror antenna with the composite high precision and size-stable solid surface reflector

abst. 1106
Virtual Room 1
Thursday
July 21
11h50

Morozov, Evgeny (e.morozov@adfa.edu.au), The University New South Wales at the Australian Defence Force Academy, Canberra, Australia
Lopatin, Alexander (lopatin@krasmail.ru), Federal Research Center for Information and Computational Technologies, Krasnoyarsk, Russia
Taygin, Vitaly (lopatinalexander@gmail.com), Reshetnev Siberian State University of Science and Technology, Krasnoyarsk, Russia

Axisymmetric mirror antennas with a composite solid surface reflector are integral parts of modern spacecraft. These antennas have a high coefficient of the radio signal amplification and a broad frequency band. The design of such an antenna should satisfy various requirements determined by its purpose and operational conditions. The main requirement is a high precision of the shape of the reflector surface. Deviations from the parabolic shape of reflector lead to the reduction in the amplification coefficient of radio signal. Also, the antenna must be lightweight and compact. The antenna structure must withstand vibration and acoustic loads exerted by the space launcher in the process of the orbit injection. The thermal dimensional stability of the antenna's structural elements during its movement in the orbit is another important design requirement. Currently, there is a high demand in the increase of speed of the information transmission by spacecraft communication systems. Such an increase is related to the use of high-frequency ranges of radio signals. These developments of space communication systems initiate the quest for new designs of axisymmetric mirror antennas. In this paper, an original new design of the spacecraft mirror antenna with the composite high precision and size-stable solid surface reflector is proposed and investigated. The antenna design consists of the reflective, supporting, and joining shells; antenna feed; support of the antenna feed; base; counter reflector and its support. The three antenna shells are made of carbon fibre reinforced polymer and joined together creating a closed structure with substantial stiffness. The parabolic reflector of the antenna has the aperture diameter of 0.8m and the focal distance of 0.23m. The solution of the design problem was based on the results of parametric finite-element modal analysis. In this analysis, the effects of geometric characteristics of the reflector shells on the fundamental frequency of the structure have been investigated. As a result, the combination of geometric parameters ensuring that the first natural frequency of the structure was not less than 150 Hz was found. In addition, the strength verification of this design was performed. Using the results of the design analysis, a physical prototype of the spacecraft mirror antenna with the composite solid surface reflector was fabricated. An appropriate manufacturing technology and tooling were developed for the antenna components. To confirm the operational capability of the antenna prototype, radiation, vibration, and thermal tests were carried out. The radiation tests were performed in an anechoic chamber the walls of which were covered with radiation absorbent material. The diagram of directivity of the antenna obtained from these tests confirmed its capability. The dynamic loading exerted on the spacecraft during its injection into orbit was replicated in the vibration tests. The antenna was placed on the vibration table and subjected to random and sinusoidal vibrations. The frequency of sinusoidal vibrations ranged from 5 to 100 Hz with

the vibration acceleration varying up to 20g. In the random vibration tests, the antenna was subjected to mechanical loads with the frequency of application varying from 20 to 2000 Hz and power spectral density ranging from 0.8 to 0.4 g2/Hz. The thermal testing was carried out in the environmental vacuum chamber with the temperature varying from -140 to +140 . The results of tests performed confirmed the structure operational capability, resilience, and ability to withstand external loads. It is demonstrated that the design of the mirror antenna with the composite high precision and size-stable solid surface reflector developed in this work is lightweight and have all the necessary parameters to be able to generate high directivity radiation in the high-frequency ranges employed in the modern systems of space communication.

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abst. 1117
Repository

Design and form-finding of composite freeform structures

Moskaleva, Anastasiia (Anastasiia.Moskaleva@skoltech.ru), Skolkovo Institute of Science and Technology, Russia
Sergey Gusev (S.Gusev@skoltech.ru), Skolkovo Institute of Science and Technology, Russia
Safonov, Alexander (A.Safonov@skoltech.ru), Skolkovo Institute of Science and Technology, Russia
Enrique Hernandez-Montes (emontes@ugr.es), University of Granada, Spain

Fiber reinforced polymers are used in double-curved freeform structures; however, the whole variety of methods and materials are not involved, and some of them are undeservedly neglected. In particular, composite materials are rarely applied in freeform structures, designed with form-finding methods. Their application is limited to research and experimental projects, and is not yet common in construction practice. The work presented in this article demonstrates that a combination of form-finding methods such as force density method and topological mapping with advanced composite materials can help to overcome limitations in design and construction of complex geometry structures. Article describes the process of form-finding, finite element analysis, manufacturing and mechanical testing of composite shell structure. The structure is a square in plan double-curved shell with four supports. The material of the structure is carbon fiber reinforced polymer. The methods used for form finding are force density method and topological mapping. These methods allow to obtain effective shape of structure with very small bending moments under the own weight. The use of composite materials in such structures allows to increase load-bearing capacity to withstand loads exceeding their own weight. The non-linear FE analysis of the designed structure was carried out in the ABAQUS FEA software suite. To confirm the numerical analysis results, a prototype shell was made and mechanical tests were performed. Composite materials help to overcome the limitations of design and construction of freeform structures due to its light weight and possibility to combine load-bearing and insulating properties. The technology of vacuum infusion allows to make double-curved complex structures with considerably high precision. This research project proves that these design methods and manufacturing technology together have a high potential in freeform architecture.

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abst. 1180
Repository

FE simulation of distortion of CFRP part formed by the stamping process

Ryu, Jaechang (jcr0416@pusan.ac.kr), Pusan National University, South Korea
Shin, Dohoon (dohshin@koreanair.com), Korean Air Lines, South Korea
Lee, Chanjoo (cjlee80@kitech.re.kr), Korea Institute of Industrial Technology, South Korea
Kim, Mingi (kkkkk@pusan.ac.kr), Pusan National University, South Korea
Ko, Daecheol (dcko@pusan.ac.kr), Nano Mechatronics engineering, Pusan National University, South Korea

Recently, the lightweight materials have been studied due to environment regulation and improvement of fuel efficiency. Carbon fiber reinforced plastic(CFRP), one of the representative lightweight material, has been applied to produce component for aerospace industry. Additionally, the demand of CFRP material has been increased in the automotive industry to reduce weight of the vehicle. The distortion, such as warpage and spring-in, is a crucial challenge in manufacturing CFRP component. This phenomenon that is happen during the cooling process of the formed CFRP part often presents

dissatisfaction of dimensional accuracy. The satisfaction of tolerance is very important and essential considering following assembly process. Therefore, prediction of the distortion is required to reduce cost for modification of the tool in a cost driven manufacturing industry. Not only the prediction technology, selection of the manufacturing process is also crucially important considering mass production. In other words, the prediction technology of distortion occurred in formed CFRP component and manufacturing method for mass production will play an important role in application of CFRP material to automotive industry. This paper presented the prediction method of the distortion occurred in manufactured CFRP part using the stamping process. The finite element method of whole forming process, such as transfer process of CFRP blank, the gravity analysis, stamping process, is conducted to obtain the temperature distribution of CFRP part. Consecutively, the FE simulation of cooling process is performed to predict the distortion of formed CFRP part using nodal temperature data of all plies obtained with forming simulation. Finally, a comparison between the results of the experiment and FE simulation shows the possibility of applying CFRP materials to actual industry. Acknowledgement: This study was supported by National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2019R1A5A6099595), the National Research Foundation of Korea (NRF) grant funded by the Korea government (MOE) (NRF-2021R1I1A3A04037420), and Technology Innovation Program (No. 20007444) funded by the Ministry of Trade, Industry Energy (MOTIE).

Systematic approach for designing composite blades of a tidal turbine based on both its theoretical beam model and FE shell model

abst. 1220
Room B035
Wednesday
July 20
15h30

Lee,JaeYong (fcswhat@naver.com), Korea aerospace university, Republic of Korea
Lee,Hakgu (hakgulee@kau.ac.kr), Korea aerospace university, Republic of Korea

The composite blades of a tidal turbine are crucial components that extract renewable energy from tidal currents. Although both a tidal turbine and a wind turbine have the same operational mechanism, their operational circumstance and loading conditions are quite different. A systematic approach that can deal with these differences should be developed to design composite blades for a tidal turbine. This study focused on how to design the composite blades systemtically based on theoretical beam model and FE shell model. When operating a tidal or wind turbine, its main loads are two types of bending moment distribution along its blades, called flap-wise bending moments and edge-wise bending moments. For a tidal turbine blade unlike a wind turbine blade, flap-wise bending moments due to lift force become much larger than edge-wise bending moments because buoyancy reduces dramatically edge-wise bending moments. Thus, a spar box beam sturcture that has to withstand flap-wise moments governs whole design of a tidal composite blade. If it is possible to correlate the blade's FE shell model with a theoretical beam model able to handle the spar box beam structure, the tidal composite blade can be designed effiently. The correlation factors devised in this study match the sectional properties between the two models such as each section's moment of inertia, neutral plane location, and geometrical difference. The beam model in this study had almost the same results as the FE shell model did. First, the thickness distribution of UD laminates in the spar cap was decided based on the beam model. Till the final design, the sectional moment of inertia at each section should be kept because the calculated spar box beam governs whole design. Then, the thickness distribution of 2AX[+45/-45] laminates in the shear webs was detemined by static analysis under the flap-wise loading, and the thickness distribution of foam core in the surface shell was determined by buckling analysis under the flap-wise loading. After that, the thickness distribution of 2AX[+45/-45] laminates in the surface shell was calculated by static analysis under the same loading. According to the sequence above, overall lamination plan near an optimal design was obtained systematically. The most critical part of whole desing was the shear webs just bellow the pressure side spar cap affected by the flap-wise bending stress. Consequently, the approach in this study can reduce computational load dramatically by eliminating a lot of iterative analysis using a huge FE shell model in the conventional approach.

Wear Performance of Thermoplastic Polymers Reinforced with Glass Fibres at Variable Fibre Volume Fractions

abst. 1274
Room B035
Wednesday
July 20
15h50

Zaghloul, Moustafa Mahmoud Yousry (Moustafa.Mahmoud@uq.edu.au), School of Mechanical and Mining Engineering, The University of Queensland, Brisbane, Australia., Australia
Steel, Karen (), School of Chemical Engineering, The University of Queensland, Brisbane, Australia, Australia
Veidt, Martin (), School of Mechanical and Mining Engineering, The University of Queensland, Brisbane, Australia., Australia
Heitzmann, Michael T. (), School of Mechanical and Mining Engineering, The University of Queensland, Brisbane, Australia., Australia

High wear rates and frictional coefficient have always been the primary reasons for limiting the service life of critical elements such as pumps, couplings, bushings, bearings and gears. The premature and erratic failures are costing the industries extensive amounts of money every year. Additionally, under severe service conditions, the wear resistance requirements are higher, which greatly hinders the application of neat thermoplastics in different sectors. Hence, it is vital to enhance the tribological characteristics of thermoplastics, due to the emerging trend in replacing the traditional metallic materials with light-weight polymeric composites. The mechanical and tribological properties of Polyamide 6, PolyKetone, Thermoplastic Polyurethane, Polyadmide 12, glass fibre reinforced (GFR) Polyadmide 6 and glass fibre reinforced (GFR) PolyKetone Composites were investigated. Pin specimens with Polyamide 6 reinforced with (25%, 33% 50%) by volume of fibres were fabricated by injection moulding process. The specimens were tested for tensile, compression, hardness, and wear under dry sliding condition using a pin-on-disc configuration. The effect of the varying glass fibre content was studied at a constant sliding distance and room temperature. Furthermore, the samples were scanned using a micro-computed tomography (micro-CT) and the worn out samples were analysed using field emission scanning electron microscopy. The experimental results showed that Polyamide 6 was the highest resistant polymer to wear. Additionally, the fibre volume fraction was found to be inversely proportional to the wear resistance of the prepared composites. This research will enable the industry partners to supply cutting edge technology to the global oil and gas industry that not only reduces well operation cost but also enhances well resilience.

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abst. 1286
Virtual Room 1
Thursday
July 21
12h10

Energy absorption characteristics of composite channel section structure under quasi-static compression loading

Lv Rui (lvrui@hnu.edu.cn), College of Mechanical and Vehicle Engineering, Hunan University, China
Ren Yiru (renyiru@hnu.edu.cn), College of Mechanical and Vehicle Engineering, Hunan University, China

To improve the energy-absorbing capacity of the composite channel section structure, the mechanical response of the T700/2510 carbon fiber/epoxy channel section structure under axial quasi-static crushing loading is studied. A nonlinear failure model based on a stiffness degradation method is created that considers multiple failure modes of fiber and matrix damage at the macroscopic scale. The maximum stress failure criterion and the exponential evolution law are used to predict the initial failure and damage evolution of the intra-layer, respectively, and the inter-layer failure is based on the traction-separation constitutive model. The failure mechanism and energy absorption mechanism of the composite channel section structure are revealed by studying the influence of geometric size and stacking sequence on the failure modes and energy absorption characteristics. Different trigger types are designed, and the research shows that reasonable triggering types can improve the failure mode of the structure and improve the energy absorption of the structure. The method of local reinforcement is used to enhance the crushing response of the structure, and the research shows that the thickness, number, position, and stacking sequence of reinforcement are important factors affecting its energy absorption characteristics.

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abst. 1291
Virtual Room 1
Thursday
July 21
12h30

Proposal and Effectiveness of Compression-free Braces Using Partially Fibered CFRP

Hamasaki Mizuki (Hamasaki.mizuki.ay@tut.jp), Department of Architect and Civil Engineering, Toyohashi University of Technology, Japan
Tsogbayar Tsendjav (tsogbayar.tsendjav.dg@tut.jp), Department of Architect and Civil Engineering, Toyohashi University of Technology, Japan
Yamamoto Rino (yamamoto.rino.ya@tut.jp), Department of Architect and Civil Engineering, Toyohashi University of Technology, Japan
Matsumoto Yukihiro (y-matsum@ace.tut.ac.jp), Associate Professor, Department of Architect and Civil Engineering, Toyohashi University of Technology, Dr.Eng., Japan
Taguchi Takashi (t-taguchi@yahagi.co.jp), Engineering Center, YAHAGI CONSTRUCTION CO., LTD., Dr.Eng., Japan
Shimizu Keisuke (k-shimizu@yahagi.co.jp), Engineering Center, YAHAGI CONSTRUCTION CO., LTD, Japan
Komiya Iwao (i-komiya@fukui-fibertech.co.jp), FUKUI FIBERTECH Co., LTD., Dr.Eng., Japan
Nakajima koji (k-nakajima@fukui-fibertech.co.jp), FUKUI FIBERTECH Co., LTD., Japan

Turnbuckle braces have been widely used for the seismic resistant member of steel structures. Because it is a very slender member, its compressive resistance capacity is not considered in the structural design, but it buckles easily by the compressive force and the buckling deformation leads to the damage of finishing material, local plastic strain concentration, and plastic fatigue failure. Based on the background, the authors have developed a compression-free brace that can be easily jointed to existing steel turnbuckle braces, focusing on the use of lightweight, high-strength CFRP as a brace material and by jointing CFRP rod to the existing steel turnbuckle braces through a pipe style turnbuckle body (Japan industrial standards). The proposed compression-free brace uses the partially fibered CFRP (PFCFRP) rods to absorb compressive deformation, so that only tensile forces apply on the brace and out-of-plane deformation due to buckling are significantly reduced. In addition, the combined use of steel turnbuckle braces can be expected to absorb seismic energy by the plastic deformation of steel. PFCFRP rods are only fiberized in the middle position and un-fiberized position, CFRP rods at both ends, are used for the joint. They were molded by pultrusion because of their excellent cost-effectiveness, superior mechanical performance, and stability. In addition, the partially fibered sections were created without resin injection. PFCFRP rods were connected to the braces using pipe style turnbuckle body. The fixing method of the PFCFRP rod and the pipe type turnbuckle body is to widen the end of the PFCFRP rod to drive a wedge and insert it into the turnbuckle body. Then fill it with steel balls and epoxy resin to resist pulling out. Furthermore, we adopt the pipe type turnbuckle body to connect the steel structure like a sleeve joint to provide easy and useful assembly. Two different tests were carried out to confirm the effectiveness of the compression-free braces. Firstly, testing of materials used in compression-free braces was conducted. The results of the tests were compared with the strength of steel turnbuckle braces to clarify the scope of the application of compression-free braces. Next, cyclic loading tests were carried out on a full-scale steel structural frame incorporating the proposed braces. The results show that the proposed compression-free braces have similar historical behavior to existing steel turnbuckle braces. Because the PFCFRP rod absorbs the compressive axial deformation, the out-of-plane deformation can be significantly reduced. Based on these results, it was demonstrated that the proposed compression-free braces using PFCFRP can provide a safe and applicable seismic bracing system.

Compressive properties of polyurethane foam-filled Al/CFRP sandwich structures: quasi-static and dynamic experiments

abst. 1302
Virtual Room 1
Thursday
July 21
12h50

Yang, Chengxing (Chengxing_Yang_Hn@163.com), Central South University, China
Chen, Zhifang (csu_czf@163.com), Taicang Transportation Bureau, China
Yao, Shuguang (ysgxzx@csu.edu.cn), Central South University, China

Composite structures combine the advantages of multiple materials, which can improve the structural mechanical properties. This paper aims to combine the high strength of carbon fibre-reinforced plastic (CFRP), the excellent ductility of aluminium alloy (Al), and the good compressibility of polyurethane (PU) foam. Quasi-static compression and low-velocity impact tests were conducted on thin-walled tubes made of single materials and composite sandwich structures made of multi-materials, namely Al-PU-Al,

Al-PU-CFRP, CFRP-PU-Al, and CFRP-PU-CFRP. The structural deformation behaviour and mechanical properties were analysed and compared under different loadings. The results showed that the CFRP thin-walled tube exhibited a progressive damage and failure mode, and the resultant force changed smoothly. The CFRP tube possessed a larger mean crushing force and specific energy absorption than the corresponding aluminium tube. Composite structures exhibited more stable deformation mode and higher energy absorption, compared with the sum of linear superposition (SLS) of individual components, due to the interaction effects among components. Among the designed four combinations, CFRP-PU-CFRP exhibited an ideal energy absorption under both quasi-static compression and dynamic impact. The SEA of CFRP-PU-CFRP was 120.7% higher than that of Al-PU-Al under quasi-static compression. In addition, CFRP-PU-CFRP did not show an initial peak crushing force under the axial low-velocity impact, but gradually rose and fluctuated during the compression process.

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abst. 1327
Room B035
Wednesday
July 20
16h10

Design and Manufacturing of Composite 3D-printed Architected Material for Low Frequency Broadband Vibration Control

Muhammad (Dr.Muhammad@tcd.ie), Trinity College Dublin, Ireland
Kennedy, John (jkenned5@tcd.ie), Trinity College Dublin, Ireland

Architected materials have seen tremendous amount of research interest in controlling elastic wave propagation with potential applications in vibration and noise control. Such synthetic structures are also refereed to as phononic crystals and acoustic metamaterials that utilise bandgap engineering to manipulate wave propagation in certain frequency regions. Such bandgaps are formed either by the Bragg scattering effect, a local resonance mechanism or by their mutual coupling. Here in this study, we propose a new class of architected material, so called composite elastic metastructure that takes advantage of the system periodicity and composition to generate a low frequency ultrawide bandgap. The metastructure manipulates the Bragg scattering effect together with local resonance modes of the structure to open the bandgap. The width and frequency range of the bandgap can be controlled by altering the position of the beam struts supporting the composite block. The opening bounding edge of the bandgap is supported by a compressive resonant mode where the complete unit cell structure is in motion. As a result, this resonant mode is situated in the relatively low frequency region. While, at the closing bounding edge, the resonant motion is localized in the beams. Thus, the beam flexure rigidity is a defining parameter that closes the bandgap. By manipulating the geometric parameters and position of the supporting beam strut, the bandwidth of bandgap can be controlled. The numerical findings are validated by performing experiment tests on the manufactured prototype, utilising additive manufacturing. The prototype is investigated through vibration testing and results are compared with numerical findings. Overall, excellent agreement is observed between both results. Our findings and metamaterial design strategy will have a broad range of applications including vibration and noise control and shock absorption.

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abst. 1329
Room B035
Wednesday
July 20
16h30

Design approach for automated transverse leaf spring composite structures in a suspension system

Gruenheid, Thomas (thomas.gruenheid@dlr.de), German Aerospace Center (DLR), Germany
Deisser, Oliver (oliver.deisser@dlr.de), German Aerospace Center (DLR), Germany
Sturm, Ralf (ralf.sturm@dlr.de), German Aerospace Center (DLR), Germany

Developing sustainable products using high persistent and durable materials is challenging. Associated processes to mature innovations in industrial development are often inflexible due to safety reasons and economic requirements. A possible approach to solve these challenges can be found in digitalized development processes. By using optimization techniques for automated evaluation, a high number of structural concepts can be created. The introduced optimization approach focuses on a virtual process chain for the automated design of glass fiber reinforced transverse leaf springs. Composite materials have the potential to reduce weight by functional integration and improved fatigue performance.

As reference suspension system an innovative McPherson-like front suspension system is used. The control arms, coil springs and stabilizer bar are substituted by a composite leaf spring with the main goal to integrate wheel controlling functionalities into the structure. Parameters for wheel control are shape, fiber orientations and laminate lay-up. Designing composite transverse leaf springs with wheel controlling functionalities is extremely challenging due to obtained high number of design parameters. Large deflections due to wheel travel by preserving longitudinal and lateral stiffness and strength also complicate the identification of solutions in the design space. Therefore automation in modelling and evaluation is essential for using the required optimization algorithms. Meta-model-based, evolutionary or gradient optimization methods can be used to identify solutions in the obtained complex design space. The process chain connects CAD, finite element and multi body simulation software within the developed process chain. To ensure elastic behavior and durability, the Puck criterion is applied as an optimization constraint. The first results show that the investigated optimization approaches have high potential for finding appropriate composite structures with wheel controlling functionalities.

Sustainable optimal design of FRP composite structures

abst. 1358
Room B035
Wednesday
July 20
16h50

António, Carlos Conceição (cantonio@fe.up.pt), Faculty of Engineering, University of Porto, Portugal

The sustainable concept, as described in document "Our Common Future" (World Commission on Environment and Development, 1987) is defined as follows: Sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations. Sustainable development "... meets the needs of the present without compromising the ability of future generations to meet their own needs". The recent increases in structural material prices is further evidence that global consumption will raise both awareness and need to design for the efficient and rational use of materials. From a structural engineering point of view the biggest impact can be made by focusing on optimizing the structural systems to reduce the material requirements of a project supported by sustainability concepts. One approach for decreasing costs in lightweight structures using FRP composite materials is to adopt a hybrid construction where expensive and high-stiffness materials are used together with inexpensive and low-stiffness material. The optimization problem of topology associated with material distribution and stacking sequence design of hybrid composites is very complex when sizing variables, as ply angle and layer thickness are simultaneously considered. Furthermore, since the balance between weight/sustainable cost and stiffness is important in hybrid laminates construction the use of multi-objective design procedures are necessary. Multi-objective Memetic Algorithm (MOMA) searching Pareto-optimal front is proposed. MOMA applies multiple learning procedures exploring the synergy of different cultural transmission rules. The approach is based on multiple populations, species conservation, migration, self-adaptive, local search, controlled mutation, age control and features-based allele's statistics (Conceição António 2014). The search for each population in the hierarchical optimization algorithm proceeds for the same objective functions and constraints. However, the number of design variables used at each generation is lower than the number of variables of the original optimization problem. This "natural" decomposition of the original problem is associated with the nature of the variables in the design of the hybrid composite structures: the ply thickness and the cross section beam variables are associated with the structural weight, the ply orientation is associated with the anisotropy, the stacking sequence at the laminate level and the material distribution on the structure are associated with discrete material possibilities. The trade-off between minimum weight/sustainable costs and minimum strain energy, depending on given stress, displacement and buckling constraints imposed on composite structures, is searched. The global Pareto-optimal front is built at age structured population (VP) using the concept of Pareto dominance (Conceição António 2013). Self-adaptive rules are incorporated in Pareto front design based on genetic search. The search method adopts an elitist strategy storing non-dominated solutions found during the evolutionary process in an age-structured population. Results show that MOMA is promising in multi-objective optimization of FRP composite hybrid structures based on sustainability concepts.
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2013, 48, p. 73-94. Conceição António C. "A memetic algorithm based on multiple learning procedures for global optimal design of composite structure", Memetic Computing, 2014, 6, p. 113-131.

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abst. 1387
Room B035
Wednesday
July 20
15h10

EXPERIMENTAL STUDIES ON THE MECHANICAL PROPERTIES OF UNIDIRECTIONAL GLASS/CARBON/EPOXY COMPOSITES

Agrawal, Mayank (2019rme0002@iitjammu.ac.in), INDIAN INSTITUTE OF TECHNOLOGY, JAMMU, India
Raghavalu Thirumalai, Durai Pranhakaran (durai.prabhakaran@iitjammu.ac.in), INDIAN INSTITUTE OF TECHNOLOGY, JAMMU, India
Mahajan, Puneet (puneet.mahajan@am.iitd.ac.in), INDIAN INSTITUTE OF TECHNOLOGY, DELHI, India

Hybrid composites are gaining popularity and are used in many structural applications. The advantage of hybrid composites is mixing two different quality fibres (low elongation and high elongation, cheap and costly, natural and synthetic) to get a cost-efficient product that possesses good mechanical properties. By introducing high elongation fibres, the failure strains can be increased. This article aims to evaluate the sequencing and hybridization effect of glass and carbon fibre composites keeping the volume fraction constant. Glass fibre composites have a massive application in wind turbine blades. Here it is an attempt to provide a hybrid composite alternative with less weight and better mechanical performance. The four types of glass/carbon/epoxy composites are studied i.e. [0G]8, [0C]8, [[0C]2/[0G]2]S and [[0G]2/[0C]2]S. Experiments are focused to characterize the hybrids for tensile and flexural properties. These preliminary experiments are used further to develop the hybrids which can perform better in static tests will be considered further for the fatigue analysis.

Durability and Ageing of Composite Materials and Structures (chaired by M. Gigliotti, F. Ascione)

Durability of glass fiber and glass fiber-reinforced polymer (GFRP) bars in simulated seawater

abst. 1003
Repository

Lu,Zhongyu (luzy@gdut.edu.cn), School of Civil and Transportation Engineering, Guangdong University of Technology., China
Xie,Jianhe (jhxie@gdut.edu.cn), School of Civil and Transportation Engineering, Guangdong University of Technology., China
Li,shixin (1534583475@qq.com), School of Civil and Transportation Engineering, Guangdong University of Technology., China
Tan,Yongqiang (2111909108@mail2.gdut.edu.cn), School of Civil and Transportation Engineering, Guangdong University of Technology., China

This study focused on the durability of glass fiber and glass fiber-reinforced polymer (GFRP) bars used for reinforcing seawater sea-sand concrete (SSC) structures in ocean engineering. An experimental study was conducted to investigate the durability of glass fiber and GFRP bars immersed in simulated seawater environment. The immersion temperatures were set at room temperature (25 °C), 40, and 60 °C, and the specimens immersed in 60 °C distilled water was used for comparison. Monofilament tensile properties were investigated on glass fiber. A series of tensile, horizontal shear, and water absorption and diffusion tests of GFRP bars were performed. The residual properties of the specimens after immersion to a 180-day immersion were analyzed. These findings indicate that the degradation in tensile strength of the monofilament generally increased as the immersion time increased, and 60 °C seawater showed the most degradation (decreased by 60% after 90-day immersion), and the brittleness of the glass fiber is increased due to the decomposition of sizing agent. The tensile strength retention of GFRP (67%) was higher than that of glass fiber due to the protective of resin matrix, and 60 °C distilled water showed the most degradation (retention 64%) because the chloride ion in seawater was benefit to the resistance of moisture absorption. Interlaminar shear strength also showed the same trend. The water absorption of GFRP results were accordance the mechanical test results, and the specimens immersed in 60 [U+2103] distilled water showed the maximum water absorption. The mechanical test results of GFRP after moisture desorption is higher than that of the specimens after moisture absorption, the results indicated that some of the degradation was reversible.

Durability of BFRP bar in seawater environment: Coupling effects of SSGC wrapping and prestressing

abst. 1065
Repository

Xie, Jianhe (jhxie@gdut.edu.cn), School of Civil and Transportation Engineering, Guangdong University of Technology, Guangzhou, 510006, Guangdong, China
Tan, Yongqiang (2111909108@mail2.gdut.edu.cn), School of Civil and Transportation Engineering, Guangdong University of Technology, Guangzhou, 510006, Guangdong, China
Lu, Zhongyu (luzy@gdut.edu.cn), School of Civil and Transportation Engineering, Guangdong University of Technology, Guangzhou, 510006, Guangdong, China
Li, Shixing (2112009140@mail2.gdut.edu.cn), School of Civil and Transportation Engineering, Guangdong University of Technology, Guangzhou, 510006, Guangdong, China
Li, Jianglin (2111609085@mail2.gdut.edu.cn), School of Civil and Transportation Engineering, Guangdong University of Technology, Guangzhou, 510006, Guangdong, China
Huang, Liang (2111709010@mail2.gdut.edu.cn), School of Civil and Transportation Engineering, Guangdong University of Technology, Guangzhou, 510006, Guangdong, China

In order to expand the space for socioeconomic development, more and more coastal and marine infrastructures (e.g. ports, bridges and offshore wind farms) are being built in coastal countries. The major challenges for the development of these infrastructures with conventional reinforced concrete include the shortage of freshwater and river-sand for making concrete, and steel corrosion caused by chloride ion. In addition, growing concerns over the greenhouse emissions of the Portland cement and

conventional concrete industry have led to a high level of interest in the development of geopolymeric construction materials. To address these challenges, a new type of concrete structure is developed: seawater sea-sand geopolymeric concrete (SSGC) structure reinforced with basalt fibre-reinforced polymer (BFRP) bar (i.e. BFRP-SSGC structure). The advantages of this type of structure include: (1) using seawater and sea-sand to alleviate the depletion of freshwater and river sand resources; (2) BFRP is an environment-friendly material with low cost, and good resistance to chloride ion; (3) geopolymer is also an environment-friendly material alternative to Portland cement. For the safe and economic use of BFRP bars to reinforce SSGC, the long-term performance of BFRP bars under der service environment needs to be properly understood, especially under seawater environment. This study aims to investigate the durability of BFRP bar immersed in seawater, focusing on the coupling effects of SSGC wrapping and prestressing load. A series of tensile tests of immersed bare and SSGC-wrapped BFRP bars were conducted. The various tested parameters included the following: (1) wrapping thickness (0 and 32mm) ; (2) prestress level (0 and 20% of the ultimate tensile strength of BFRP)[U+FF1B](3) alkali content (M+) of SSGC (4% and 6%); (4) immersion time (0 and 120 days); (5) conditioning temperature (at room temperature (RT, 26 °C), 40°C, and 60°C). The results showed that both the SSGC wrapping and the prestress caused negative influence on the long-term properties of BFRP bar, and the increase of immersion temperature could further reduce its tensile strength. The alkali dosage of SSGC had insignificant effect on the durability of BFRP bar, which was evidenced by that the tensile strength retention decreased range from 74.7% to 73.1% as the alkali dosage of SSGC decreased from 6% to 4% for the specimens immersed in seawater after 120-day at RT). In addition, the real-time monitoring result of prestress loss of BFRP bars embedded in SSGC immersed in seawater environment showed that the prestress loss occurred mainly during the first 7-day, and tended to be stable for approximately two weeks thereafter; immersion temperature exhibited little effect on the prestress loss. After 120-day, the residual prestresses were 14.6%, 14.9% and 13.9% for the 20% initial prestress level at RT, 40°C and 60°C, respectively. Keywords: BFRP bar; Sea-sand, Seawater; Geopolymer; Prestress; Durability; Marine environment

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abst. 1073
Room B035
Thursday
July 21
10h20

Hygrothermal durability of full scale beam-to-column adhesive joints: experimental results and modelling

Ascione, Francesco (fascione@unisa.it), University of Salerno, Italy
Granata, Luigi (lgranata@unisa.it), University of Salerno, Italy

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 of different parameters such as: temperature and hygro-thermal and outdoor ageing as well as moisture [2]. The authors are fully convinced that in order to connect each other the pultruded profiles the best technique is the adhesive one even if, in order to preserve their integrity avoiding the classical brittle failure, it is necessary to limit the stress distribution to the linear elastic stage [3]. Within this scope, a wide experimental study was recently developed in order to study the global mechanical behaviour of a beam-to-column adhesive connection with particular regard to the influence of the hygro-thermal aging. The connection is composed of a hollow profile acting as column and a built-up beam realized by two U-profiles. The adhesive region is limited by the overlapping area between the column and the beam. The load condition was a vertical force applied at the free end of the beam. The strain/stress distribution inside the adhesive layers allows to govern the strength and the stiffness of the beam-to-column connection in function of the mode II of fracture energy only [4]. Two commercial cold curing epoxy resins were adopted. Consequently, 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 both the mode II fracture energy of the two abovementioned resins and the strength and stiffness of the full scale connection. 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 [5], lower than the classical one, corresponding to elastic fracture energy only. Experimental results, in term of the failure load, were also used to set an ad hoc mechanical model characterized by a closed form solution. References: [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] Sousa JM, Correia JR, Cabral-Fonseca S. Durability of an epoxy adhesive used in civil structural applications. Constr Build Mater 2018; 161: 618–633. [3] Ascione F, Granata L, Guadagno L, Naddeo C. Hygrothermal durability of epoxy adhesives used in civil structural applications. Composite Structures 2021; 265, 113591. [4] Ascione F, Granata L, Carozzi G. Flexural and shear behaviour of adhesive connections for large scale GFRP frames: influence of the bonded area and hygro-thermal aging. Accepted for publication by Composite Structures. [5] Ascione F, Granata L, Lombardi A. The influence of the hygro-thermal aging on the strength and stiffness of adhesives used for civil engineering applications with pultruded profiles: an experimental and numerical investigation. Journal of Adhesion 2021, DOI: 10.1080/00218464.2021.1936507.

Biodegradable Polymeric Composites Based on Pistachio Shell Powder – Synthesis and Characterization

abst. 1105
Repository

Pączkowski, Przemysław (przemyslaw.paczkowski@mail.umcs.pl), Department of Polymer Chemistry, Institute of Chemical Sciences, Faculty of Chemistry, Maria Curie-Sklodowska University in Lublin, Poland
Gawdzik, Barbara (barbara.gawdzik@mail.umcs.pl), Department of Polymer Chemistry, Institute of Chemical Sciences, Faculty of Chemistry, Maria Curie-Sklodowska University in Lublin, Poland

The growing environmental concerns and the search for more versatile polymer-based materials have led to increasing interest in the use of polymer composites with natural, organic biodegradable and renewable fillers. The use of reinforcements is associated with high hopes for the design of new sustainable polymer materials with the desired properties. Therefore, numerous studies are carried out on the production of biodegradable polymer composite materials, especially due to their unique physical and mechanical properties, comparable to pure polymer matrices. A further degree of environmental friendliness is achieved when also the polymer matrix is biodegradable and comes from renewable sources. This work presents the results of research on the unsaturated polyester resin and vinyl ester resin composites containing the common natural biofiller – pistachio shell powder. Degradation study was conducted in the presence of solar radiation (accelerated aging chamber), solvents of different nature (immersion test), microwaves (microwave reactor) and under the influence of high temperature.

On the effect of environmental actions on the bond capacity of FRP concrete joints

abst. 1126
Repository

Calabrese Angelo (angelosavio.calabrese@polimi.it), Politecnico di Milano, Italy
Colombi Pierluigi (pierluigi.colombi@polimi.it), Politecnico di Milano, Italy
D'Antino Tommaso (tommaso.dantino@polimi.it), Politecnico di Milano, Italy

FRP composites is nowdays currently used as external reinforcement of concrete structures. In particular, both FRP strips and FRP sheets have been adopted to improve the performance of RC columns, beams, and slabs. In the literature, a large number of studies investigates the mechanical and bond properties of FRP composites. On the other hand, the durability of externally bonded FRP systems is strongly affected both by the ageing of the constituent materials and by the degradation of the bond capacity of the interface between FRP and concrete. The so-called environmental conversion factors are usually adopted in design standards and guidelines in order to evaluate the reduced bond capacity of FRP systems for different exposure conditions. Unfortunately, in some cases, these conversion factors are often overestimated since calibrated on a limited amount of experimental data. In this work, different kinds of environmental actions are taken into account (freeze-thaw cycles, exposure to saline and alkaline solutions, effect of temperature cycles and continuous immersion in water). Outcomes

from experimental campaigns performed by the authors and data from the literature are collected to create an extended database. The most frequently observed failure mode was the cohesive failure within the concrete substrate or the adhesive failure at the adhesive/concrete interface. 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, the same is done for conditioned specimens and the environmental conversion factors are finally 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 increases the concrete strength, the bond capacity may slightly increase. In other cases, the adhesive failure mode leads to a significant decrease of the bond capacity. 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, a model from the literature is used to separate the effect of mechanical interlocking from the chemical bond.

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abst. 1152
Room B035
Thursday
July 21
09h40

A novel test for characterising the effects of thermo-oxidation ageing on damage onset in bonded joints for aeronautical applications

Masson, Julie (julie.masson@ensma.fr), Institut Pprime, CNRS - ISAE-ENSMA - Université de Poitiers, Département Physique et Mécanique des Matériaux, Futuroscope Chasseneuil, France
Gigliotti, Marco (marco.gigliotti@ensma.fr), Institut Pprime, CNRS - ISAE-ENSMA - Université de Poitiers, Département Physique et Mécanique des Matériaux, Futuroscope Chasseneuil, France
Grandidier, Jean-Claude (jean-claude.grandidier@ensma.fr), Institut Pprime, CNRS - ISAE-ENSMA - Université de Poitiers, Département Physique et Mécanique des Matériaux, Futuroscope Chasseneuil, France
Delozanne, Justine (justine.delozanne@safrangroup.com), Safran Composites, a technology platform of Safran Tech, Itteville, France
Dagorn, Noelig (noelig.dagorn@safrangroup.com), Safran Composites, a technology platform of Safran Tech, Itteville, France

Adhesively bonded assemblies are more and more employed to join structural parts in the aerospace industry since they are lightweight and more suited than classical assemblies are. However, compared to bolts or rivets, these solutions are much more sensitive to the environment, especially at temperatures that can be sufficiently high to promote thermo-oxidation phenomena. With the increase in temperature of the future engines to improve their performance, this type of ageing is even more concerning and must be studied. Thermo-oxidation is a particular type of ageing characterised by oxygen diffusion-reaction: since no oxygen saturation does occur in the joint, the degradation induced by thermo-oxidation is heterogeneous and confined in the oxidized layers close to the external edges exposed to the environment. The characterisation of its effects on the bonded joints mechanical behaviour is consequently complex since the classical existing tests are designed to minimize the edges effects and to render the stress state as uniform as possible. The information obtained with such tests is highly impacted by the virgin part of the adhesive with no focus on the mechanical gradients in the oxidized zones. It is therefore needed to design a test for thermo-oxidation aged bonded assemblies and associate a numerical tool to estimate the gradient and the level of stresses. This model taking into account the thermo-oxidation effects on the adhesive has been developed [1] and used to design a specific test. The experimental setup includes an environment-controlled chamber set up on the testing machine, allowing to reproduce couplings between mechanics and thermo-oxidation, a long-distance microscope captures the crack initiation in the oxidized layer of a bonded assembly tested in 3-point bending. The evolution of the crack initiation time is a function of the oxidation time. The crack initiation time under a constant load in oxygen pressure and temperature-controlled environment is followed. The results of the tests are analysed with the numerical model assessing the thermo-oxidation associated gradients to understand and characterise the couplings. It is indispensable to predict the crack initiation depending on oxygen pressure, temperature, time and mechanical load. Acknowledgment: Agence Nationale de la Recherche et de la Technologie (ANRT) is thanked for having granted this study (Cifre N[U+25E6] 2019-1702).

Computations have been performed on the supercomputer facilities of the Mesocentre de calcul SPIN Poitou Charentes. [1] J. Masson, M. Gigliotti, J.-C. Grandidier, J. Delozanne, W. Albouy, et N. Dagorn, « Numerical method to assess the stress state and gradients induced by thermo-oxidation in adhesively bonded joints for aircraft engine applications », Int. J. Adhes. Adhes., vol. 113, no 103063, 2022.

Experimental investigation on the hygroscopic ageing of carbon fiber reinforced vinylester resin composites

abst. 1161
Repository

Zhang Yuheng (yuhengzhang@whut.edu.cn), Wuhan University of Technology, China
Ding Anxin (axding@whut.edu.cn), Wuhan University of Technology, China

The hygroscopic behavior of vinylester resin and carbon fiber reinforced vinylester resin composites are examined here, including moisture absorption behavior and corresponding degradation of mechanical properties. The fabricated resin and composites specimens were immersed into deionized water and artificial seawater with temperature of 70°C, and then water uptakes were weighed at specified time intervals in combination with observation of surface morphology using SEM and identification of variation of functional groups using FTIR spectroscopy to clarify the process and mechanism of moisture absorption. Meanwhile, the change in tensile strength and modulus, compressive strength and modulus for resin and CFRP specimens as well as in-plane strength and modulus and interlaminar shear strength for CFRP specimens with 2016 hours' immersion duration are tested periodically.

An Experimental Validated Model of Environmental Aging Accelerated Damage under Tension-tension Fatigue in Composites

abst. 1178
Repository

Li, Zhiye (zli88@stanford.edu), Stanford University, United States
Michael Lepech (mlepech@stanford.edu), Stanford University,

Glass Fiber-reinforced polymer composites (GFRPs) are made by combining polymer with reinforcement glass fiber yarns to produce lightweight yet strong materials. This study is to build a Multiphysics and Multiscale model to predict the synergistic effect of environmental exposure to fatigue-damage of the composite. Based on the authors' previous UV/ moisture exposure experiment-computational study, this extended study couples environmental aging induced material weakening to continuum fatigue-damage model. The extended research developed a fatigue-damage model at the structural length scale, using diffusion coefficient tensor and stiffness tensor homogenized from a plain-woven RVE at mesoscale length scale. The experimental validated computational model shows that environmental exposure causes material degradation, which leads to a mild change of damage variable field and considerable change of fatigue parameter after 1000 hours of accelerated cyclical UV/moisture exposure. The synthetic effects of these two changes reduce structural stability. The most significant effect is observed by measuring bending moments after the tension-tension fatigue test. After 100,000 cycles, the bending moment of cyclic UV/moisture degraded samples decreased up to 40 percent compared to undegraded samples. This model can be incorporated into many commercial finite element codes for a sustainability study of composite structures/systems. In future work, the models developed in this study will be combined with life cycle assessment (LCA) tools to better support sustainability focused design of new material, thus reducing costs and environmental impacts of the built environment.

Effect of Thermal Cycling on Damage Onset in Three-Dimensional (3D) Woven Organic Matrix Composites for Aero-Engines Applications by in-situ X-Ray μ-Computed Tomography

abst. 1222
Room B035
Thursday
July 21
10h00

Gigliotti, Marco (marco.gigliotti@ensma.fr), Département Physique et Mécanique des Matériaux, Institut Pprime CNRS, ISAE-ENSMA, Université de Poitiers, France, France

Orenes Balaciart, Salvador (orenes-balaciart.salvador@ensma.fr), Département Physique et Mécanique des Matériaux, Institut Pprime CNRS, ISAE-ENSMA, Université de Poitiers, France, France
Pannier, Yannick (yannick.pannier@ensma.fr), Département Physique et Mécanique des Matériaux, Institut Pprime CNRS, ISAE-ENSMA, Université de Poitiers, France, France
Mellier, David (david.mellier@ensma.fr), Département Physique et Mécanique des Matériaux, Institut Pprime CNRS, ISAE-ENSMA, Université de Poitiers, France, France
Guigon, Camille (camille.guigon@safrangroup.com), SAFRAN Composites, Conception Development Department, Itteville, France, France

Three-Dimensional (3D) Woven Organic Matrix Composites are increasingly used as elements of structural parts close to aircraft engines and in aero-engine fan blades. These materials are therefore requested to operate in high-performance ranges subjected to mechanical solicitations at different temperatures and exposed to cold/hot thermal cycling. Not much research has been carried out concerning damage onset in such materials. Moreover, there is almost no research concerning the effect of thermal cycling induced ageing and degradation on damage onset of such materials. The present research investigates the effect of thermal ageing degradation on damage onset of off-axis tensile loading in 3D woven carbon/epoxy composite samples at room (20ºC), high (120ºC) and low (-30ºC) temperature. Preliminary thermal cycling between -55°C and 120°C is performed on samples, then in-situ tests are carried out by coupling X-Ray micro-Computed Tomography (µ-CT) and Acoustic Emission (AE). AE is used to detect first damages and for interrupting in-situ tests while μ-CT is used to obtain material 3D volume scan, in order to visualize damage mechanisms. Results show that for each temperature preliminary ageing may have significant effect on damage onset. Acknowledgements: The authors acknowledge SAFRAN Composites for providing the material under study. The research subject falls within the research themes of the French Government program "Investissements d'Avenir" (LABEX INTERACTIFS, reference ANR[U+2010]11[U+2010]LABX[U+2010]0017[U+2010]01, EQUIPEX GAP, reference ANR[U+2010]11[U+2010]EQPX[U+2010]0018).

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abst. 1247
Repository

Hygrothermal ageing and progressive damage modelling of CFRP laminates under quasi-static tensile loading

XU, Jian (xujian19960621@163.com), Dalian University of Technology, China
Hu, Mengting (2097707847@qq.com), Dalian University of Technology, China
SUN, Liangliang (13260514133@163.com), Dalian University of Technology, China
HAN, Xiao (hanxiao@dlut.edu.cn), Dalian University of Technology, China

In order to analyse the failure in composite structures under different ageing extent in hygrothermal environment, this paper proposed a progressive failure analysis modelling method coupled with heat and humidity. In this paper, a unidirectional CFRP is used to manufacture test specimens of basic mechanical properties before and after ageing, to provide model parameters for subsequent numerical modelling. Open-hole CFRP laminates with different ageing degrees were then tested under quasi-static tensile loading, to provide verification for numerical modelling stage. A progressive failure analysis model involving coupled hygrothermal effects is presented for predicting failure of composite structures in hygrothermal environments. The model adopts the Hashin failure criterion to simulate the progressive damage as well as moisture-induced degradation of stiffness and strength parameters. USDFLD subroutine was developed and embedded into Abaqus to perform the failure analysis in CFRP laminate after exposure to hygrothermal environment. Numerical analysis revealed that damage initially occurred around the hole of the laminate, and then gradually spread to the edge of the specimen. Considering the laminate with the same loading displacement before failure, the higher the moisture absorption is, the greater the damage evolves in the laminate. Meanwhile, it can be seen from the load-displacement curve that the higher moisture absorption led to lower failure load of the laminate. Good agreement between numerical and experimental results was achieved in both failure mode and peak load, validating the FE model established.

Thermo-mechanical Viscoelastic Behaviors with Consideration to Physical Aging for CF/EP Laminates: Experiments and Constitutive Modeling

abst. 1297
Repository

Yang jiangyan (yangjiangyan@stu.xjtu.edu.cn), Xi'an Jiaotong University, China
Ma xiaofei (maxf041600@sina.com), Xi'an Institute of Space Radio Technology, China
Wang hui (13519122235@139.com), Xi'an Institute of Space Radio Technology, China
Shang fulin (shangfl@mail.xjtu.edu.cn), Xi'an Jiaotong University, China
Hou demen (dmhoe@mail.xjtu.edu.cn), Xi'an Jiaotong University, China

The characterization of the time-dependent deformation of fiber reinforced polymer laminates is critical when evaluating the reliability of composite structures over long time service life. This work conducts several isothermal tensile creep tests under different temperatures and mechanical load levels for two types of carbon fiber reinforced epoxy composite laminates. The composites deformed in a time-dependent way and exhibited clearly both creep temperature effect and physical aging effect. Their total strains increased within short time period after the tests began, and then decreased with time during most of the loading process. To formulate these kinds of time-dependent deformation behavior, a nonlinear viscoelastic constitutive model of single-integral form with consideration to physical aging effect was proposed. The corresponding incremental and iterative algorithm formulations were presented as well, and they were implemented into a finite element software and verified by comparing the simulation results with the experimental results.

Hygrothermal behaviour of adhesive bonded connections

abst. 1361
Virtual Room 2
Wednesday
July 20
13h10

Maurel-Pantel, Aurelien (maurel@lma.cnrs-mrs.fr), LMA, Aix Marseille University, CNRS, France
Lamberti, Marco (lamberti@lma.cnrs-mrs.fr), LMA, Aix Marseille University, CNRS, France
Lebon, Frederic (lebon@lma.cnrs-mrs.fr), LMA, Aix Marseille University, CNRS, France

The development of floating (offshore) wind turbines on a commercial scale is expected to grow considerably over the next few years after that different countries have recognized them as the best solution for the production of sustainable energy. In order to satisfy the required needs of safety, serviceability, durability and affordability, the actual connections and the secondary structures have to be replaced by a new ones based on the bonding technique. An extensive experimental program have to be undertaken for the feasibility and assessment of adhesive connections for offshore wind installations in the marine environment. In fact, the long-term durability of joints in seawater environments is one of the factors which have limited more widespread application of adhesives for marine offshore structures. In order to guarantee long-term properties and sufficient mechanical strength the characterization of the mechanical performance of adhesive connections has been investigated. Three different adhesives have been tested in static condition with a modified Arcan system after being subjected to controlled temperature and humidity in laboratory ovens.

Dynamics of Composite Materials

abst. 1058
Repository

An investigation of deformation and failure mechanisms of fiber-reinforced composites in layered composite armor

Guo (Guodong.Guo@tamuk.edu), Texas AM University-Kingsville, United States of America

We present a study on the deformation characteristics and failure mechanisms of fiber-reinforced polymer composites used in layered composite armor under ballistic impact. A Kevlar-29/epoxy composite and an ultra-high molecular weight polyethylene (UHMWPE) fiber-reinforced composite backed bilayer ceramic armor were respectively impacted against 7.62 mm APM2 projectiles at several different velocities. The dependence of failure mechanisms on impact velocity was analyzed both experimentally and numerically. Ballistic tests revealed that the Kevlar-29/epoxy composite backed armor displayed a lower perforation velocity than the UHMWPE fiber reinforced composite backed armor. However, under non-perforated impacts, the UHMWPE fiber reinforced composite exhibited a much higher back face deflection (BFD). According to the post-mortem visual and SEM analysis, the failure of the Kevlar-29 fiber was dominated by shear plugging in the front layers and fiber tensile breakage in the rear layers, whereas in the UHMWPE fiber reinforced composite, failure was dominated by shear plugging initiated from the front layers. These results suggest that the UHMWPE panel is more effective in resistant fiber tensile breakage which usually occurs on the back side of the panel. Using the Ls-dyna explicit dynamic finite element (FE) program, the ballistic behavior of a layered armor backed by a hybrid panel with varying mix ratio was studied numerically. The results show that using high resistant fiber in the rear layers can effectively prevent fiber tensile failure and using high shear resistance fiber in the front layers can effectively prevent shear failure. These results are valuable in making the best use of fiber-reinforced composites in advanced armor design.

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abst. 1102
Virtual Room 2
Wednesday
July 20
16h30

Dynamic Instability of Rotating Tapered Composite Shaft Subjected to Time-varying Axial Loading

Najafi, Mohsen (mohsen.najafi@concordia.ca), Concordia University, Canada
Ganesan, Rajamohan (r.ganesan@concordia.ca), Concordia University, Canada

Application of composite shaft under axial load has been extensively studied and reported for various mechanical components such as automotive drive-shaft, cutting tool and helicopter tail rotor. The present study investigates the dynamic behaviour of a rotating tapered composite shaft subjected to time-varying axial loading. Figure 1 shows the system consists of a filament wound hollow tapered composite shaft and two rolling bearings as end supports. In order to model the tapered laminated shaft as a so-called equivalent single layer, the Timoshenko beam theory is adopted, and the laminate is modelled based on Modified Equivalent Modulus Beam Theory, wherein the shear-normal coupling effect of the composite laminate is introduced by modifying the expression for the equivalent longitudinal Young's modulus for each layer. The potential, kinetic energies and work done by axial load of the system are obtained, and accordingly, the equations of motion are determined using Lagrange's equation. Then, second-order differential equations with periodic coefficients of the Mathieu-Hill type are derived by employing the Finite Element Analysis (FEA) with cubic Hermite polynomial shape functions. To verify the model, the rotor-dynamic characteristics of the system, such as natural frequencies and critical speeds of the tapered composite shaft, are determined and compared with results that are reported in the literature. In addition, utilizing Bolotin's method, dynamic stability threshold and steady-state response of the system are obtained. The numerical results show that the tensile load increases and the compressive load decreases the natural frequency and critical speed evidently. Furthermore, the regions of dynamic instability are expanded by increasing the amplitude of both static and fluctuating parts of the axial load.

High strain rate dynamic tensile behavior of chopped glass fiber polypropylene composite at high and low temperatures

abst. 1179
Virtual Room 2
Thursday
July 21
10h40

Se-Min Lee (minhappy96@gmail.com), Department of Mechanical Convergence Engineering, Hanyang University, 222, Wangsimni-ro, Seongdong-gu, Seoul, Republic of Korea, Republic of Korea
Dug-Joong Kim (kdj9207@gmail.com), Department of Mechanical Convergence Engineering, Hanyang University, 222, Wangsimni-ro, Seongdong-gu, Seoul, Republic of Korea, Republic of Korea
In-Soo Han (94hans@hyundai.com), Hyundai Motor Group R D Division, Gyeonggi-do, 18280, Republic of Korea, Republic of Korea
Hak-Sung Kim (kima@hanyang.ac.kr), Institute of Nano Science and Technology, Hanyang University, 222, Wangsimni-ro, Seongdong-gu, Seoul, Republic of Korea, Republic of Korea

The demand for high fuel efficiency and high efficiency has been emerging as important issues in the automobile industry due to global environmental regulations. The fuel efficiency can be increased with weight reduction by applying lightweight materials and plastics. Polypropylene (PP) is one of the most widely used plastics for automotive components. They are promising materials for automobile interior components because of their excellent heat resistance, impact resistance, and formability [1]. PP is also a more economical alternative to expensive plastics of similar strength and durability, which helps driving down the manufacturing cost. Especially, the usage of polypropylene-long glass fiber (PP-LGF) has grown within the automotive industry because of its mechanical superiority and weight-saving potential, particularly when switching from metal solutions. PP-LGF is commonly used for components such as instrument panel carriers, front end modules and door module assemblies. Polypropylene is known to be a material with strong sensitivity to strain rates. [2] In order to develop reliable automotive parts using these materials, it is very important to predict their damage behavior and mechanical properties under high strain rate impact load. In this study, the strain rate dependent tensile properties of PP-LGF and PP was measured under the high strain rate by using the Split Hopkinson Pressure Bar (SHPB). Also, the dynamic properties of PP-LGF and PP were measured under temperature from -35 °C to 85 °C. The SHPB is the most widely used apparatus to characterize dynamic mechanical behavior of materials at high strain rates between 100 s$^{(-1)}$ and 10,000 s$^{(-1)}$ [3]. The SHPB setup consists of the striker, incident bar and transmission bar, made of aluminum. The high strain rate tensile loading was achieved through the incident bar by an axial impact from a striker. It generates tensile pulse to the to the specimen through the incident bar. On the reaching the specimen, a part of the incident pulse is reflected, and the rest is transmitted to the transmission bar. The stress, strain, and strain-rate can be obtained from the records of strain gauges on the incident and transmission bars by using elementary linear elastic wave propagation theory. The strain data obtained through the high-speed camera and Digital Image Correlation (DIC) were compared and verified during the high strain tensile test of the PP-LGF and PP specimen. As a result, it was found that both PP-LGF and PP materials can be seen that the tensile strengths were significantly increased with the strain rates. In addition, the strain verified through DIC showed similar results from the SHPB experiment. The results imply that the strain dependent properties should be considered when designing automotive components. Additionally, the impact simulation of automotive was conducted to verify the measured strain rate dependent mechanical behavior of PP-LGF and PP by using the impact FEM software LS-Dyna. Finally, it was found that the impact response of automotive could be accurately predicted by using the strain rate dependent mechanical behavior compared to those of quasi-static properties. Acknowledgement: This work was supported by Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government (MOTIE)(20202020800360, Innovative Energy Remodeling Total Technologies for the Aging Public Buildings). References: [1] Thomasset, J., et al. "Rheological properties of long glass fiber filled polypropylene." Journal of non-newtonian fluid mechanics 125.1 (2005): 25-34. [2] Bouix, Rémy, Philippe Viot, and Jean-Luc Lataillade. "Polypropylene foam behaviour under dynamic loadings: Strain rate, density and microstructure effects." International journal of impact engineering 36.2 (2009): 329-342. [3] Chen, W. W., Song, B., "Split Hopkinson (Kolsky) bar: design, testing and applications". Springer Science Business Media, 2010.

An analysis of modified CT specimens for the determination of the longitudinal intralaminar fracture toughness in composite laminates using SHPB configuration

abst. 1200
Room B032
Wednesday
July 20
11h30

Cimadevilla Díez, Adrián (acimadev@ing.uc3m.es), Universidad Carlos III, Madrid
Vaz-Romero, Álvaro (avazrome@ing.uc3m.es), Universidad Carlos III, España
Pernas Sánchez, Jesus (jpernas@ing.uc3m.es), Universidad Carlos III, España
ARTERO GUERRERO, Jose Alfonso (jartero@ing.uc3m.es), Universidad Carlos III, España
Maimi, Pere (pere.maimi@udg.edu), Universitat de Girona, España
GONZALEZ JUAN,EMILIO VICENTE (emilio.gonzalez@udg.edu), Universitat de Girona, España

The material characterization of composite materials under dynamic loading has been researched over the last two decades. Composite materials subjected to dynamic conditions exhibit significant strain rate sensitivity. Several experimental methodologies has been proposed to analyse its influence. Taking into account the strain rates ranges representative for an impact event (50-1000s-1), Split Hopkinson Pressure Bars (SHPB) is the preferred experimental method to evaluate the dynamic behaviour [1]. Most of the scientific work has been focused on the determination of the variance of the mechanical properties of the composite material in this range of strain rate loadings, including properties of individual constituents, failure mechanisms and fracture toughness for both intralaminar and interlaminar behaviour. There are only few works concerning fracture toughness analysis. Specifically, the work of Hoffmann et al. [2] shall be mentioned here, where the typical Compact Tension (CT) specimen has been used for characterizing the intralaminar longitudinal fracture toughness of IM7/8552 under tensile loading conditions. After the study, it is reported more than a 50% reduction of the property analysed. Also, the double edge notched tensile (DENT) specimen is commonly used in the SHPB [3]. Conclusions are divergent between both techniques, even for the same material [2,3]. This clearly indicates that the optimal technique to characterize this property under high-rate loading is still a question unresolved. In this work, it has been studied the original configuration of a CT specimen in a SHPB based on the work of Hoffmann et al. [2]. A numerical model has been generated in the commercial FEM code ABAQUS/Explicit. The numerical model has been validated with the results of the referenced paper. The asymmetrical opening of the specimen induces inertial forces that produces a non-unidimensional stress wave propagation in the bars. New design of the specimen has been proposed to reduce the asymmetrical effects of the original CT configuration in the SHPB. The new geometry guarantees a correct property characterization under dynamic loadings since avoids the emergence of inertial effects on the data reduction analysis. This study has been developed within the framework of the European Clean Sky project BEDYN, with reference number 886519. References: [1] H. Koerber and P. P. Camanho, "High strain rate characterisation of unidirectional carbon–epoxy IM7-8552 in longitudinal compression," Composites Part A: Applied Science and Manufacturing, vol. 42, p. 462–470, May 2011. [2] J. Hoffmann, H. Cui and N. Petrinic, "Determination of the strain-energy release rate of a composite laminate under high-rate tensile deformation in fibre direction," Composites Science and Technology, vol. 164, p. 110–119, August 2018. [3] P. Kuhn, G. Catalanotti, J. Xavier, M. Ploeckl and H. Koerber, "Determination of the crack resistance curve for intralaminar fiber tensile failure mode in polymer composites under high rate loading," Composite Structures, vol. 204, p. 276–287, November 2018.

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abst. 1210
Virtual Room 2
Wednesday
July 20
15h50

Multimode dynamic response analysis of curved composite panels under dynamic in-plane loading using a Finite Element based Reduced Order Model

Jansen, Eelco (e.l.jansen@hr.nl), Rotterdam University of Applied Sciences, The Netherlands
Rahman, Tanvir (T.Rahman@dianafea.com), DIANA FEA BV, The Netherlands

The buckling and post-buckling behavior of composite panels under static and dynamic loading is an important topic in the design of thin-walled structures. Flat plates under in-plane compressive loading typically exhibit a stable static post-buckling behavior, while for curved panels, depending on the radius of curvature and the laminate configuration, a snap-through type behavior can occur. An extension of initial post-buckling analysis has been used in earlier work in a Finite Element framework to assess the post-buckling characteristics of structures under dynamic in-plane loading [1,2]. The reduced order dynamic response analysis employed in the present work is based on the approach in [2] and makes use of static buckling modes. For curved panels, the dynamic response behavior may not be represented

sufficiently well by the buckling modes obtained from a static buckling analysis based on a linear pre-buckling state. It was shown, that by including the effect of pre-buckling nonlinearity, the reduced order model approach is capable of representing the dynamic response behavior of a specific curved composite panel reasonably well [3]. In shell buckling analysis, besides considering pre-buckling nonlinearity, it is often necessary to take the interactions between various buckling modes into account. In the present work, a multimode dynamic response analysis will be used to assess the behavior of specific curved composite cylindrical panels in which modal interactions play an important role. The results of the reduced order model analysis are compared with full model Finite Element analysis. REFERENCES: [1] H. Chen and L.N. Virgin. Finite element analysis of post-buckling dynamics in plates - Part I: An asymptotic approach. International Journal of Solids and Structures, Vol. 43, 3983–4007, 2006. [2] E.L. Jansen, T. Rahman, R. Rolfes. Finite Element Integrated Fast Buckling Analysis Tools using a Perturbation Approach. In: Buckling and Postbuckling Structures II: Experimental, Analytical and Numerical Studies, World Scientific, Editors: B. G. Falzon, M. H. Aliabadi, 2018. [3] E.L. Jansen, T. Rahman. Dynamic Buckling Analysis of Composite Cylindrical Panels using a Finite Element Integrated Fast Tool. In: Proceedings of AIAA SCITECH 2022 Forum, January 3-7, 2022, San Diego, CA Virtual, 2022.

The Influence of Conditioning on Dynamic Properties of Polymer Composites

abst. 1404
Virtual Room 2
Wednesday
July 20
16h10

Borowiec, Marek (m.borowiec@pollub.pl), Lublin University of Technology, Poland
Kosicka, Ewelina (e.kosicka@pollub.pl), Lublin University of Technology, Poland
Krzyzak, Aneta (a.krzyzak@law.mil.pl), Military University of Aviation, Poland

The aim of this study is to determine the effect of environmental factors in the form of UV radiation and temperature on the amplitude-frequency behaviour of polymer composites (prepregs) based on a framework of thermosetting epoxy resin reinforced with high-strength R-glass fibres. Two series of composites with different fibre arrangements were prepared. The series had fibres arranged at angles of 30°, 45°, and 60°, at symmetric and asymmetric orientations in relation to the central layer. The composites were subjected to conditioning which simulated a six-month period of use in the spring and summer in the temperate warm transitional climate of Central and Eastern Europe. An UV QUV/SPRAY/RP accelerated aging chamber manufactured by Q - Lab Corporation was used for this purpose, and UV-A 340 lamps were used to simulate daylight. In addition, varying loads caused by sudden temperature changes were simulated using a Shock Event T/60/V2 Weisstechnik thermal shock chamber. Conditioned samples were tested using a TIRAvib 50101 electromagnetic exciter in combination with an LMS Scadias III controller and Test.Lab software. The results of the tests, in the form of amplitude-frequency diagrams in resonance regions, indicated that certain changes occurred as a result of the conditioning, which is a new development in the area of material tests. The results shed light on the effects of environmental conditions on the stiffness charac-teristics of composites, causing dynamic nonlinearities when operating at resonant frequencies.

Experimental Methods

abst. 1035
Virtual Room 1
Thursday
July 21
10h20

Characterization of out-of-plane tensile stress-strain behavior for GFRP composite materials at elevated temperatures

Ziqing Hao (15536989720@163.com), Beijing Institute of Technology, China
Chen, Guangchang (chengc004@avic.com), Avic Helicopter Design and Research Institute of China, China
Ke, Hongjun (kehongjun2012@126.com), Aerospace Research Institute of Special Material and Technology,, China
Deng, Linlin (denglimlin12@163.com), Beijing Institute of Technology, China
Liu, Liu (liuliu@bit.edu.cn), Beijing Institute of Technology, China

Three-dimensional stress-strain constitutive parameters in various environments are essential for understanding the mechanical behavior of thick cross-section composite load-bearing structures. This work aims to expand a short-beam bending test combined with a digital image correlation method to obtain the out-of-plane (interlaminar) stress-strain behavior for polymer-matrix composites at elevated temperatures. A simple and repeatable digital speckle pattern fabrication method was used based on the water transfer printing (WTP) technique to reduce deformation measurement uncertainty induced by the quality of the speckle pattern. The effects of DIC parameters and misalignment of the DIC stereo camera system on the uncertainty of deformation measurement have been studied. The out-of-plane properties, including elastic modulus and tensile strength for a 50-ply thick S6C10/AC318 glass/epoxy unidirectional panel, have been obtained at elevated temperatures for the first time. The experimental results showed that the out-of-plane modulus and tensile strengths were 15.95 GPa and 76 MPa at room temperature. The modulus was nearly unchanged at 50oC and decreased 18% at 80oC. The out-of-plane tensile strength decreased 9% at 50oC and 22% at 80oC, respectively, indicating that the tensile strength degradation is more sensitive to temperature rising than the modulus. The study suggests that the improved short-beam bending test combined with the DIC method can guarantee reproducible results and usability at elevated temperatures.

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abst. 1071
Repository

Effect of Seasoning Conditions on the Mechanical Properties of Modified Adhesive Compositions Based on Bisphenol A Epoxy Resin

Miturska-Barańska, Izabela (i.miturska@pollub.pl), Lublin University of Technology, Faculty of Mechanical Engineering, Department of Production Engineering, Polska

A significant advantage of epoxy compositions as an adhesive is the ability to bond many different materials such as glass, metal, wood, ceramics, polymeric materials. This is possible due to excellent adhesion. In addition, basic adhesive compositions are increasingly undergoing numerous modifications involving the introduction of fillers of both organic and inorganic origin. Due to this, epoxy adhesive compositions are characterised by good mechanical properties and resistance to many environmental factors. The working conditions of epoxy adhesive compositions can have a large effect on their strength, as well as on the strength of adhesive joints made using these compositions. One of the important factors determining the strength and durability of epoxy compounds is the environment of use at elevated temperatures and increased ambient humidity. It is important to check the properties of adhesive compositions in conditions of high humidity and temperature, because epoxy compounds may change their properties in a reversible or irreversible way. The problems analyzed in this work are a continuation of studies on the modification of epoxy adhesive compositions, and concern the influence of the composition seasoning on their mechanical properties. The aim of this paper is to compare the influence of climatic factors on strength properties of epoxy compositions based on solvent-free epoxy resin Epidian 5 and three curing agents: TFF type Mannich, Z-1 amine curing agent and PAC polyamide curing agent. The compositions were modified with three fillers: Montmorillonite NanoBent ZR2, calcium carbonate CaCO3 and activated carbon CWZ-22. Each filler was added in the amount of 5 wt% of the composition. Samples made of the unmodified composition were also tested as reference for comparative purposes. The cured adhesive compositions were seasoned in an Espec SH 661 climate

chamber at 80°C and 95% humidity. The influence of the modification and seasoning process on selected mechanical properties of the compositions - tensile and compressive strengths - was tested. Analysis of the results obtained showed, among other things, that the addition of a filler to the matrix of the adhesive composition does not always improve the properties analyzed, similarly in the case of seasoning. The highest tensile strength was obtained for the composition of epoxy resin Epidian 5, TFF curing agent and calcium carbonate CaCO3. The distribution of results was similar in the case of compressive strength analysis. The obtained results were subjected to statistical analysis, which allowed to precisely determine the effect of modification and seasoning on the strength properties of the composition. For comparison, a fracture surface analysis of epoxy compositions was performed using a scanning electron microscope to evaluate the structure of the cured adhesive.

Numerical and experimental damage process of real L-shaped thin-walled columns under axial shortening

abst. 1079
Virtual Room 1
Thursday
July 21
10h40

Gawryluk, Jaroslaw (j.gawryluk@pollub.pl), Department of Applied Mechanics, Faculty of Mechanical Engineering, Lublin University of Technology, Nadbystrzycka 36, 20-618 Lublin, Poland,, Poland
Teter, Andrzej (a.teter@pollub.pl), Department of Applied Mechanics, Faculty of Mechanical Engineering, Lublin University of Technology, Nadbystrzycka 36, 20-618 Lublin, Poland,, Poland

Angle columns carrying axial compressive loads are main structural elements in many modern structures, therefore the problem of buckling occurring in such structures makes up a vital aspect of engineering calculations. Although buckling does not always result in structural failure, losing structural stability leads to change stiffener of the structure and caused the damage. The higher risk of stability loss is when the more lightweight structure. The main problem in modern structures is their post-buckling behaviour. When the post-buckling equilibrium path is stable, losing stability does not lead to the failure of the structure. However, the structure can continue to operate safely until the limit state. If the limit point is close, the post-buckling equilibrium path becomes unstable and the structure failure. In numerical studies, to determine the limit state, it is necessary to define material damage criteria and describe the process of material degradation. The progressive damage criterion is nowadays one of the most advanced method to solve the problem of composite material damage. The main aim of this study was prepared a numerical model of the real structures under compression and simulations its collapse process. Non-linear simulations were performed by the Newton-Raphson method until ultimate failure of the structure using Abaqus software, where composite material damage was described with a progressive damage model. The numerical model of the structure was obtained using a 3D scanner. The undamaged samples were scanned. Using reverse engineering software, the geometrical model of the real samples was prepared and was imported to the Abaqus program. When the shells model of the real samples was built and numerical studies in the full range of loads were performed. Thin-walled L-structures under consideration in this study were made of laminates comprising reinforcing carbon fibres and an epoxy matrix. The lay-up configuration of the laminate was [60,02,-602,603,-602,03,-602,0,602]T. Thickness of the column was 0.81mm, length 300mm and its width of the flanges was 40mm. The experimental collapse process of thin walled L-columns on a testing machine was performed. The real samples were subjected to uniform axial shortening. The tested columns were loaded with the load from 0 to the maximal load, which allowed one to observe the column behavior until its collapse. Experimental tests were performed at a constant velocity of the cross-bar equal to 1 mm/min. Flexible pads were used to prevent stress concentration where the column contacts with the rigid support plates. During the tests, the angle columns flanges displacement were registered with the contactless Aramis system. The acoustic emission method was used to determine the moment of laminate damage initiation and even the cracking of laminate matrix/fibre or delamination onset. Finally, all obtained results for real L-structures were compared. Experimental and numerical post-buckling equilibrium paths were presented in which the characteristic limit states were compared. 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. 1151
Room B032
Thursday
July 21
16h10

A novel approach for determining the intra-ply energy release rate of composites made of prepreg

Rose, Philip (philip.rose@HAW-Hamburg.de), Hamburg University of Applied Sciences, Germany
Linke, Markus (markus.linke@haw-hamburg.de), Hamburg University of Applied Sciences, Germany
Busquets, David (dbusquets@mcm.upv.es), Polytechnic University of Valencia, Spain

Fibre reinforced plastics have found steadily increasing use in the aviation industry in recent decades. Due to the internal structure of composites composed of reinforcement as well as matrix material, but also due to the layered structure of laminates, matrix cracks and delamination of the individual fibre layers are typical occurring forms of damage in this group of materials. Matrix cracks are associated with the intralaminar and delamination with the interlaminar energy release rate. Since the geometric distance between the regions is in the sub-millimetre range, the crack propagation must be controlled very precisely to achieve a distinction between interlaminar and intralaminar energy release rates. Various authors have already undertaken investigations with the aim of differentiating the energy release rate between the inter-ply and intra-ply region of the laminate [1, 2]. Sato et al. [2] have developed a method which enables this distinction between inter-ply and intra-ply values. However, this method cannot be applied to components made of prepreg semi-finished products, because Sato et al. firstly impregnate the fibre layers only partially and then pull them apart in order to apply the insert that creates the artificial crack in the specimen. Since prepregs are already fully impregnated at delivery, this method is not applicable for prepreg semi-finished products. Czabaj et. al. [1] presented an approach in which the crack primarily propagates through the intralaminar area of the laminate and thus leads to a slightly smeared measurement. In addition, the double cantilever beam (DCB) specimen is used in this work for the determination of the interlaminar energy release rate and the compact tension specimen for the intralaminar energy release rate, which limits the comparability of the determined characteristic values. Based on the approach described in Sato et al. [2], this paper presents a method that distinguishes between interlaminar and intralaminar energy release rates with the DCB specimen and is also applicable to fully impregnated semi-finished products (prepreg). A modified double cantilever beam specimen is developed for this purpose. In addition to the associated manufacturing process, the test procedure is also adapted in such a way that the crack growth takes place in a controlled manner only within one fibre layer (intralaminar) and enables a precise determination of the intralaminar energy release rate. This is demonstrated by the results of an investigation on the material Hexply 8552 / IM7, in which a significant difference in the energy release rates is observed. REFERENCES: [1] M. W. Czabaj, J. G. Ratcliffe, Comparison of intralaminar and interlaminar mode I fracture toughnesses of a unidirectional IM7/8552 carbon/epoxy composite. Composites Science and Technology, Vol. 89, pp. 15–23, 2013. [2] N. Sato, M. Hojo, M. Nishikawa, Novel test method for characterizing accurate intra-laminar fracture toughness in CFRP. Composites Part B, Vol. 65, pp. 89–98, 2014

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abst. 1155
Room B032
Thursday
July 21
17h30

Fatigue characterization of glass fibre/acrylic based infusible thermoplastic composite intended for offshore structural applications: Thermography and Acoustic Emission.

Hejjaji, Akshay (akshay.hejjaji@ul.ie), Bernal Institute, School of Engineering, University of Limerick, Limerick, Ireland, Ireland
Portela, Alexandre (alexandre.portela@ul.ie), Bernal Institute, School of Engineering, University of Limerick, Limerick, Ireland, Ireland
Comer, Anthony (anthony.comer@ul.ie), Bernal Institute, School of Engineering, University of Limerick, Limerick, Ireland, Ireland

The climate change goals have persuaded the energy sector to initiate environment centric actions, emphasising renewable technologies like offshore wind and tidal energy. The harsh and corrosive marine environment poses a challenge in terms of efficiency, maintenance and durability of the steel structures. Composites, especially glass fibre reinforced (GFRP) composites can be a suitable alternative owing to their low cost, high strength to weight ratio and most importantly, corrosion resistance. For now, thermoset plastics dominate the composite structures owing to ease of manufacturing (out of autoclave,

infusion of large structures). However, the properties of thermoset plastics complicate the reparability and recyclability of composite structures during service life and at end of service life respectively. This makes them less favourable as it acts against the environment centric actions for which the use of composites was considered. Hence, in this work, the authors propose the use of acrylic-based infusible thermoplastic- Elium® for manufacturing glass fibre composites. Nevertheless, despite having stated advantages, the industry refrains from the large-scale implementation of composite offshore energy structures due to the lack of understanding of the behaviour of such materials under a variety of loading conditions. Given that these structures must endure several decades of efficient operation, adequate knowledge in terms of fatigue behaviour of materials used is required for the purpose of design and certification. With the aim of filling these research gaps the FIBREGY Horizon 2020 EU funded project was initiated to enable the extensive use of FRP materials in the next generation Offshore Wind and Tidal Power (OWTP) structures. As a part of the FIBREGY Horizon 2020 project, in this research, the behaviour of glass fibre/ acrylic based infusible thermoplastic composite (Elium®) composite under fatigue loading is investigated. GFRP composites with different layups (±45° and Quasi-isotropic) are subjected to tension-tension fatigue tests instrumented with thermography and acoustic-emission transducers. The damage induced by fatigue loading is quantified in terms of heat dissipation (specimen temperature from IR camera) and acoustic energy (AE) released. The fatigue loading induced damage is quantified from the heat and AE energy data and is used to estimate the fatigue limit (to last >106 cycles) using a fast and innovative temperature (damage) stabilisation method. The S-N curve for the new GFRP material is obtained by performing classical tests and is used to confirm the fatigue limit values obtained by the new method. Finally, the post-mortem analysis is performed using X-ray tomography and scanning electron microscopy techniques to understand the damage initiation and progression in the material due to fatigue loading. Keywords: Glass fibre reinforced composites (GFRP), Infusible thermoplastic Fatigue testing, IR Thermography, Tomography, Acoustic emission.

Experimental studies of the thermal contact conductance for bundles of round steel bars

abst. 1165
Repository

Wyczółkowski, Rafał (rwyczolkowski@wip.pcz.pl), Czestochowa University of Technology, Poland
Bagdasaryan, Vazgen (vazgen_bagdasaryan@sggw.edu.pl), Warsaw University of Life Sciences – SGGW, Poland
Tomczyk, Barbara (barbara_tomczyk@sggw.edu.pl), Warsaw University of Life Sciences, Poland

Transport phenomena of heat in porous media have been focus of many investigations. Most studies deal with low-porosity granular media. A specific example of such a medium are steel bars heated during heat treatment in the form of cylindrically shaped bundles. The intensity of heating is determined by the processes of heat transfer which occur in the radial direction of the bundle, in which the considered charge is characterized by the lack of continuity of the solid phase. Therefore, the ability of the bundles to transfer heat is expressed by effective thermal conductivity kef. The value of the kef coefficient, which is necessary to optimize heat treatment processes of bar bundles, can be determined by doing model calculations. As authors have demonstrated based on their own studies, only models which take into account the contact conduction phenomenon are suitable for calculating the effective thermal conductivity of bar bundles. This means that the knowledge on contact conduction between the adjacent bars in the bundle is necessary to model its effective thermal conductivity. Contact conduction is expressed in a quantitative manner with thermal contact conductance hct, the unit of which is W/(m2K). The paper describes experimental investigations concerned with determining the hct coefficient for bundles of round bars made of low-carbon steel. It presents an original research methodology, which is based on the analysis of stationary heat transfer in flat, packed beds of steel bars. The measurements were performed on a laboratory stand which operates on the principle of a guarded hot plate apparatus. Measurements were made for the temperature range 50-600C. The tests were performed for 12 samples with four different bar diameters (10, 20, 30 and 40 mm) and three arrangements of the bars (staggered, in-line, crossed). The thermal contact conductance depends on sample arrangement, bar diameter and temperature and its value is in the range 50-175 W/(m2K).

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abst. 1239
Room B032
Thursday
July 21
17h10

Thermoplastic and Bio-based epoxy infusible resin systems: candidates for offshore renewable energy structural applications

Portela, Alexandre (alexandre.portela@ul.ie), Bernal Institute, School of Engineering, University of Limerick, Limerick, Ireland
Hejjaji, Akshay (akshay.hejjaji@ul.ie), Bernal Institute, School of Engineering, University of Limerick, Limerick, Ireland
Bhatia, Gursahib Singh (gursahib.s.bhatia@ul.ie), Bernal Institute, School of Engineering, University of Limerick, Limerick, Ireland
Comer, Anthony (anthony.comer@ul.ie), Bernal Institute, School of Engineering, University of Limerick, Limerick, Ireland

The climate change goals have persuaded the energy sector to initiate environment centric actions, emphasising renewable technologies like offshore wind and tidal energy. The harsh and corrosive marine environment poses a challenge in terms of efficiency, maintenance and durability of steel structures. Composites, especially glass fibre reinforced polymer (GFRP) composites can be a suitable alternative owing to their low cost, high strength to weight ratio and most importantly, corrosion resistance. Composite manufacturing technology has proven that manufacturing large-scale structures (>15m) is possible to achieve using a bio-based epoxy resin system and most recently a thermoplastic infusible resin. FIBREGY Horizon 2020 EU funded project was initiated to enable the extensive use of FRP materials in the next generation of Offshore Wind and Tidal Power (OWTP) structures. This study is part of a comprehensive down-selection of commercially available resins in terms of their suitability for offshore renewable energy structures, as part of the EU H2020 project FIBREGY. In this work, an extensive comparative study of GFRP composite laminates manufactured with acrylic-based infusible thermoplastic composite (Elium®) and Bio-based epoxy infusible resin system (SR InfuGreen 810) was conducted.

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abst. 1346
Room B032
Thursday
July 21
16h30

Automated Manufacturing and mechanical properties of bio-inspired carbon fiber laminates

Rodríguez-García, Verónica (veronica.rodriguez@eitmanufacturing.eu), EIT-manufacturing and FIDAMC, Spain
Aguado, Leticia (laguado@usal.esl), University of Salamanca, Spain
S.Maamri, V. Martinez (), University of Salamanca, Spain
Lorenzo, Miguel (mlorenzo@usal.es), University of Salamanca, Spain
Guzman de Villoria, Roberto (roberto.guzman@usal.es), University of Salamanca, Spain

By creating "discontinuities" within the composite it is possible to improve toughness, reduce delamination to limited areas and increase the ductile performance of the composite materials, which is known as "pseudo-ductility" , . Among the possible forms of introducing discontinuities in composites, a bioinspired design seems to bring promising results . This is because natural structures present a multi-level hierarchical organization, controlling the orientation of structural elements from the molecular level up to the macroscopic assembly, which provides them with superior mechanical properties. Particularly, in nacre, aragonite forms thin platelets linked together by a continuous protein phase, creating the so called "brick and mortar" structure. One of the main advantages of these structures is that they present crack deflection, as the fracture surface area increases, so does the energy needed to propagate cracks through it. Taking this into account, this study implements a biomimetic design and "brick and mortar" structure in carbon fibre composites. This is achieved by means of making discontinuities and stacking unidirectional prepreg plies (AS4/8552) with an Automated Tape Layer machine. The interlaminar fracture toughness of the bio-inspired CFRP laminates was measured via double cantilever beam (DCB) and three-point bending end-notched flexure (3ENF) tests. The results indicated increments of up to 32% and 92%, respectively, in the interlaminar fracture toughness when compared with that of conventional continuous CFRP samples. In addition, the translaminar fracture toughness of the developed nacre-inspired CFRPs was measured through a compact tension (CT) test, which revealed increments of up to 30%. Finally, different reinforcement mechanisms were

analysed to understand the effect of the 'brick-and-mortar' structure. References: [1] Czél G, Pimenta S, Wisnom M R and Robinson P. Demonstration of pseudo-ductility in unidirectional discontinuous carbon fibre/epoxy prepreg composites (2015). Composites Science and Technology 106 pp 110–119. Doi:10.1016/j.compscitech.2014.10.022. [2] Aligned Discontinuous Fibre Composites: A Short History. Matthew Such, Carwyn Ward and Kevin Potter. Journal of Multifunctional Composites, 3 (2014) 155–168. [3] Reza Mirzaeifar, Leon S. Dimas, Zhao Qin, and Markus J. Buehler. Defect-Tolerant Bioinspired Hierarchical Composites: Simulation and Experiment. ACS Biomater. Sci. Eng. 2015, 1, 5, 295-304. Doi: 10.1021/ab500120f

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Research solution for automatic analysis of drilling fiber-reinforced materials

abst. 1394
Room B032
Thursday
July 21
16h50

Hrechuk, Andrii (andrii.hrechuk@iprod.lth.se), Lund University, Sweden
Hörndahl, Mikael (mikael.horndahl@iprod.lth.se), Lund University, Sweden
Schultheiss, Fredrik (fredrik.schultheiss@iprod.lth.se), Lund University, Sweden

The demand for composite materials in aerospace, automotive, and energy sectors keeps growing, showing the necessity of its development and research. Among many subjects, the drilling takes a special place because of the high demand in holemaking operations to enable joints between parts of composites. Considering the composite machinability, drill tool life, and the quality of drilled holes remain crucial for the industry, thus are researched. The research of composite machinability is challenging because of the non-homogeneity of the composite structure. The plied structure leads to unique and complex defects when drilling, such as damage to the fiber-matrix interface, delamination, and uncut fibers. The research of defect formation requires intensive and repeated experimental drilling tests to provide sufficient statistics to prove the phenomena' behavior. Considering that the tool life of some PCD drills reaches 2000-3000 holes, the research becomes impossible due to high labor intensity. Therefore, this paper shows the research solution for automatic analysis of drilling fiber-reinforced materials. It is a complex of solutions, including robotization, optical measurements, and machining strategies which enables highly intensive research tests in composite drilling by automatization to some extent. The work of the developed solution is exemplified in the CFRP drilling and benchmarked by the analysis performance.

Failure of Composites

abst. 1041
Repository

Multiscale modeling based failure criterion of injection molded SFRP composites considering skin-core-skin layered microstructure and variable parameters

Li, Zeyang (lzy115020910122@sjtu.edu.cn), Shanghai Jiao Tong University, China

Injection molded short fiber reinforced polymer (IMSFRP) composites are superior lightweight materials with great application potential in many industries. One of the most challenging tasks is to predict the failure strength of the material containing complicated fiber distributions. In this study, a parameterized failure criterion of IMSFRP composites is proposed based on multiscale modeling method. In microscale, RVE models with multiple constituents and different fiber orientation distributions are built to predict the failure envelopes of the microstructures. The constitutive model of single layer is proposed to describe micromechanical behaviors of the material. In mesoscale, a skin-core-skin (SCS) model is proposed considering the variation of fiber orientation in the thickness direction, namely layered structure. Three parameters of SCS model are extracted from process simulation and the relationship between the microstructural parameters and macroscale mechanical properties is built based on analysis results and surrogate models. Finally, a parameterized failure criterion with the parameters as independent variables is established which considers the layered structures of the material and is capable to capture the variation of strength at different locations on a practical component. The numerical analysis and bench tests of a liftgate inner verify the effectiveness and accuracy of the failure criterion.

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abst. 1068
Virtual Room 2
Wednesday
July 20
17h10

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

Ammar Ahmed (ahmed.ammar@u-picardie.fr), Université de Picardie Jules Verne, Laboratoire des Technologies Innovantes, France
Leclerc Willy (willy.leclerc@u-picardie.fr), Université de Picardie Jules Verne, Laboratoire des Technologies Innovantes, France
Haddad Hamza (hamza.haddad@u-picardie.fr), Université de Picardie Jules Verne, Laboratoire des Technologies Innovantes, France
Guessasma Mohamed (mohamed.guessasma@u-picardie.fr), Université de Picardie Jules Verne, Laboratoire des Technologies Innovantes, France
Haddar Nader (nader.haddar@enis.tn), Ecole Nationale d'Ingénieurs de Sfax, Laboratoire de génie des matériaux et environnement, Tunisie

The present contribution deals with a 3D Discrete Element Method (DEM) to simulate debonding process in 3D short glass fibre composite materials under hygrothermal conditions. For that purpose, we consider a hybrid lattice-particle approach based on a cohesive beam model. In particular, it proved its ability to simulate thermo-mechanical behaviour and damage of composite materials in previous works. In this paper, emphasis is placed on the interfacial debonding in 3D short fibre composite materials. Especially, we consider the influence of hygrothermal conditions on the debonding process in PA6/GF30. Indeed, experimental observations exhibit that PA6 is hydrophilic so as absorbed water accumulates at the interface fibre/matrix and leads to undesirable debonding effects. For that purpose, a discrete thermo-hydro-mechanical coupling model is developed and applied to simulate the behaviour and the damage of PA6/GF30 under a wide range of hygrothermal conditions. The approach was first developed and validated in the context of a hygrothermal study dedicated to the drying of a magnesium aluminate block through a comparison with the FEM and experimental results from the literature. Then, the model was applied to study hygrothermal transfers occurring during a water absorption process in PA6/GF30. Variations in mass, concentration and concentration gradient were evaluated and compared with the results of numerical simulations obtained by FEM. In addition, the concentration and concentration gradient fields were determined by both methods. Thus, discrete modelling applied to the PA6/GF30 composite showed its potential to handle hygrothermal problems. Finally, the capacity of DEM to model the interfacial debonding within PA6/GF30 induced by hygroscopic swelling during

a water absorption process was also proven. A local hygroscopic swelling model was introduced in the case of a homogeneous PA6 material and subsequently extended to the case of hygroscopic swelling of the PA6/GF30 composite. Von Mises stress and resulting displacement fields were determined and compared to the results obtained from FE simulations. These results showed the ability of the DEM to predict areas where material degradation may occur, including interfacial damage in PA6/GF30 during a hygroscopic ageing process.

Modelling progressive damage development under fatigue of a laminate with a hole

abst. 1076
Room B032
Thursday
July 21
10h40

Maneval, Victor (victor.maneval@ntnu.no), NTNU - Norwegian University of Science and Technology, Norway
Vedvik, Nils Petter (nils.p.vedvik@ntnu.no), NTNU - Norwegian University of Science and Technology, Norway
Echtermeyer, Andreas T. (andreas.echtermeyer@ntnu.no), NTNU - Norwegian University of Science and Technology, Norway

Thanks to their flexibility, inherent corrosion resistance and high fatigue resistance, composite pipes are gaining interest in the conventional oil and gas industry, as well as for CO2 capture (CCUS) and hydrogen (H2) transportation. For safety-critical applications, adopting a damage tolerant approach and an integrity management system are essential. When defects in the laminate are detected during inspection, their criticality must be assessed, to decide which maintenance action is to be taken (no action, repair, or replacement). To optimize the integrity management system and avoid over-conservative expensive maintenance actions, it is necessary to predict the laminate's residual properties and remaining lifetime. Thus, accurate damage growth models under fatigue loads are needed. A progressive FEA degradation model is developed to predict the damage growth in laminates under mechanical cyclic fatigue loads. Both the development of the failure mechanisms and the final failure of the laminate are predicted. The FEA model is implemented in Abaqus. It includes both ply failure mechanisms (matrix cracking or yielding, splits, fiber failure) and laminate failure mechanisms (delamination). Matrix cracking/yielding is predicted using a static strength-based failure criterion. To account for the fatigue degradation, the strengths in the criterion (i.e. the failure envelope) is reduced along the fatigue life according to a matrix dominated S-N curve and a damage accumulation rule. The other in-plane microscopic failure mechanisms (fiber failure) are predicted using the same principle. Laminate failure mechanisms and macroscopic matrix splits (parallel to the load direction) are modeled using cohesive zone models (CZM). The cohesive law is initially defined with the undamaged cohesive material parameters. To account for the damage growth under fatigue, the maximum traction of the cohesive elements is reduced according to the relevant matrix dominated S-N curve. The fatigue simulations are run with a cycle-jump method: damages are calculated for some specified cycles and extrapolated over given cycles span (or cycle jumps). This model only requires material properties but no curve-fitting parameters. In addition to the regular inputs required for the static failure criteria and the cohesive law, S-N curves are required: one for a UD ply and one for the interlaminar shear strength. The main emphasis in this presentation is on explaining the progressive fatigue model. Some initial results of comparing the model to experiments are shown for flat E-glass/Epoxy specimens with a hole. Damage growth and lifetimes are compared.

Experimental Study of Off-Axis composite laminates subjected to dynamic compression: The Open Hole effect

abst. 1188
Room B032
Thursday
July 21
10h00

Rodríguez Sereno, José Manuel (josemanr@ing.uc3m.es), Universidad Carlos III, España
Pernas-Sánchez, Jesús (jpernas@ing.uc3m.es), Universidad Carlos III, España
Artero Guerrero, José Alfonso (jartero@ing.uc3m.es), Universidad Carlos III, España
López-Puente, Jorge (jlpuente@ing.uc3m.es), Universidad Carlos III, España

Composite laminates are extensively used in aircraft industry and engineering applications due to their high ratio between mechanical properties and density. In fact, composites in aircraft industry have achieved 50% in terms of weight. However, when subjected to transversal loads such as those generated by impact, unidirectional laminates present large delamination areas. Woven Fabric laminates, although possessing lower mechanical properties in the fiber direction, they exhibit lower delamination areas and higher fracture toughness and impact tolerance. There is little available information regarding the behavior of plain weave composites at high strain rates. Even that woven composites exhibit an increment of mechanical properties proportional to the loading rate, the research community has not yet agreed to find a solid methodology to describe the impact response. An experimental study has been performed to describe the behavior of a plain woven CFRP composite in longitudinal, transverse and off-axis compression, at three different strain rate levels (1x103 s-1, 150 s-1 and 300 s-1). Digital Image Correlation (DIC) has been used to obtain the true stress-strain response. Moreover, Open Hole Compression tests have been set up at different rate levels to analyze the open hole effect in specimens loaded in longitudinal and off-axis compression. The material system used for this study is a carbon/epoxy preimpregnated AS4-8552-AGP193 plain weave fabric. AGP193-PW represents a perfect balanced woven composite (equal number of fibers in warp and weft direction). To obtain a nominal panel thickness of 4 mm at a given cured ply thickness of 0.2 mm, a layup of [0]20 was chosen. Quasi-static compression tests on woven CFRP specimens were performed by means of an INSTRON 8516 (100KN). The compression load was applied along the longer direction, with a constant velocity of 1.25 mm/min. Since the nominal specimen length is 20mm the quasi-static strain rate is 1x103 s-1. The experiments were recorded by means of a Basler acA2440 Camera with a resolution of 2404x2056 pixel2. The acquisition rate was configured at 5 fps, whit a shutter speed of 1/5,000 s. VIC-2D software was implemented to obtain the strain field. The DIC pattern was performed implementing the Water-Slide Paper Technique in order to ensure repeatability and accuracy in the strain analysis. Intermediate and high-rate compression tests were performed using a Split Hopkinson Pressure Bar System. The striker, incident, and transmitted bars, which are made of steel, have a length of 0.5m, 2.6m and 1.4m respectively, using the same diameter (22mm) to balance the impedance. Different sizes for a circled-section copper pulse shaper were used depending on the fiber orientation to ensure a constant strain rate along the dynamic loading. Strain gauges were connected to a Digital Oscilloscope RTB2004 with a frequency of acquisition of 41.7 MHz. A Photron SA-Z high speed camera was used to record the experiments at both loading rates, using a frequency of acquisition of 200,000 fps, with a shutter speed of 1/800,000 s, being able to record a pixel size of 364x160 pixel2. The high-speed camera pictures were imported to the VIC-2D software to analyze the strain field. As explained in QS Set-Up, the DIC pattern was implemented using the Water-Slide Paper Technique, giving us a better understanding of the strains in the CFRP fragment along the experiment. Quasi-static off-axis experiments allowed us to analyze the material failure envelope. SHPB experiments have given us a better understanding about the strain rate dependency of the woven CFRP, both for mechanical properties and failure envelope. Finally, the open hole compression tests were important to analyze the influence of the stress and strain concentration in dynamic tests.

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abst. 1189
Virtual Room 2
Wednesday
July 20
16h50

Tensile behaviour of two systems of Carbon Reinforced Cementitious Matrix (CFRCM)

Rodríguez-Marcos, María (m.rmarcos@alumnos.upm.es), Departament of Civil Engineering: Construction, ETSICCP, Universidad Politécnica de Madrid (UPM), Spain
Villanueva-Llaurado, Paula (paula.villanueva@upm.es), Departament of Structures and Building physics, ETSAM, Universidad Politécnica de Madrid (UPM), Spain
Fernández-Gómez, Jaime (jaime.fernandez.gomez@upm.es), Departament of Civil Engineering: Construction, ETSICCP, Universidad Politécnica de Madrid (UPM), Spain
López-Rebollo, Jorge (jorge_lopez@usal.es), Departament os Cartographic and Land Engineering, Higher Polytechnic School of Ávila, University of Salamanca, Hornos Caleros, 50, 05003 Ávila, Spain

Fiber Reinforced Cementitious Matrix (FRCM) is a composite material used for retrofitting structures due to its major strength-to-weight ratio. Its main advantages are the high temperature resistance and the ability to be applied on wet substrates in comparison with more widespread use of FRP. The mechanical properties of FRCM are affected by mortar and fabric/textile characteristics, in addition to the strength at the interface which may be responsible for premature sliding phenomena and cohesive failure in the matrix. The main type of fibers used in FRCM are alkaline resistant (AR) glass, carbon, aramid, basalt and synthetic polymer reinforcements such as PBO. Mortars can be lime-based or cementitious with several additions as polymers and fly ash. Prior to application for structural retrofitting, an assessment of the mechanical properties of the FRCM is usually performed by means of tensile tests. Tensile test of these materials typically show a trilinear behaviour. The initial stage is an elastic phase, in which applied load is carried by the uncracked matrix and in which the stiffness of the FRCM system is similar to that of the matrix. After reaching the tensile strength of the mortar, the first cracks appear. The second phase is characterized by progressive cracking; in this phase, the slope of the stress-strain curve decreases and the load is transferred from the matrix to the embedded fibers. The third phase begins when the matrix is fully cracked, new cracks stop appearing and the existing cracks only increase their size. Once the matrix is fully cracked, the load is sustained by textile and the matrix is exclusively responsible for certain load redistribution, so the stiffness and tensile strength are associated with textile properties. This phase can be not present in some configurations of fibers and matrix, due to the slippage. In this research, in order to compare the influence of the mortar on the mechanical properties of a Carbon-FRCM system, two types of specimens with the same carbon fabric are tested. This allows assessment of the dependence of fiber-to-matrix interaction upon the mechanical properties and dosage of the matrix. It should be noted that, when compared to FRP reinforcements, FRCM are highly dependent on the fiber-to-matrix interaction, being premature slippage between the fibers and the matrix the prevailing failure mode. The tensile tests were carried out with a Servosis ME-405/50/5 with a rate of cross-head displacement of 0.5 mm/min. Displacement and strain measurements were obtained with Digital Image Correlation (DIC). This technique allows to obtain the complete deformation field during the test without disturbing the specimen, as it is a non-contact method. Using the DIC method we can properly observe the cracking pattern and the sliding of the fibers in the matrix, which is particularly useful for FRCM to estimate the interaction between textile and matrix and to adequately address the slippage failure mode. At least five samples of each system were tested. Stress-strain curves representing the tensile behaviour of individual composites were compared. Bond strengths and adherence values were evaluated using ACK model. To compare the different systems, composite reinforcing efficiency factors were calculated for the different configurations, with the aim of obtaining the relative benefits of different mortars and grids in the overall performance of the FRCM.

In-situ investigation of the damage behaviour of an interpenetrating metal matrix composite based on metallic glass (Ni60Nb20Ta20)

abst. 1236
Poster

Dittmann, Kerstin (kerstin.dittmann@mrm.uni-augsburg.de), Augsburg University, Germany
Trauth, Anna (anna.trauth@mrm.uni-augsburg.de), Augsburg University, Germany
Weidenmann, Kay (kay.weidenmann@mrm.uni-augsburg.de), Augsburg University, Germany

Metallic glasses exhibit remarkable properties due to their amorphous structure compared to crystalline metals. These include high strength and hardness combined with a high elastic deformation limit and the associated possibility of high elastic energy storage. On the other hand, they exhibit low toughness and a high susceptibility to brittle fracture, which makes them less suitable monolithic structural components. Therefore, metallic glasses are increasingly used as a reinforcing phase in hybrid materials to compensate for brittleness, such as in metal matrix composites (MMC) with interpenetrating structures. In this contribution, a metallic glass powder with alloy composition Ni60Nb20Ta20 (atom-%) produced by gas atomization was processed into an open-pore foam by selective laser melting and infiltrated with a eutectic aluminium alloy AlSi12 by gas pressure infiltration. The resulting MMC with an interpenetration structure was investigated regarding its mechanical properties and in particular its damage behaviour under pressure. For this purpose, in-situ compression tests using scanning electron microscope (SEM) were performed to characterize the damage behaviour of the microstructure. Special attention was paid to crack initiation and propagation in the microstructure as well as to the adhesion of the metallic matrix to the metallic glass in the interfaces.

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abst. 1256
Room B032
Thursday
July 21
10h20

Predicting the effects of material system parameters and stacking sequence on the failure mechanisms of composite laminates

Minh Hoang, Nguyen (mhoangn@umich.edu), University of Michigan, United States
Anthony M., Waas (awaas@umich.edu), University of Michigan, United States

The failure mechanism of fiber-reinforced polymer composites exhibits a variety of complex damage and failure modes such as intra-ply cracks (matrix and fiber failure) and inter-ply delamination, including their interactions. Under tensile loading, matrix cracks occur and accumulate usually before the fibers break. During the failure progression, the structure dissipates energy as micro-cracks accumulate and eventually coalesce to macro-cracks. Depending on the material system and the stacking sequence, the structure dissipates energy through a particular combination of intra- and inter-laminar damage. For example, in a toughened-interlayer composite laminate, the bulk of the energy dissipation may come from intra-laminar (transverse) cracking as delamination is delayed, as shown with +/-45 tensile tests in [1]. Consequently, the mechanical response and overall energy dissipation is distinct for a given material system. By hindering delamination, but favoring transverse cracks, a plastic-like structural response with a great amount of energy dissipation can be achieved. Another example is the shift of failure modes in a quasi-isotropic tensile laminate. Given a particular stacking sequence, substantial edge delamination may occur [2], splitting the original specimen in sub-laminates. Furthermore, the edge delamination was observed to shift into the plies when a toughened-interlayer system was used [3]. The aim of this work is to reproduce the observed failure mechanisms and their sensitivity to the material system and stacking sequence. For this purpose, a high-fidelity finite element – based damage model will be used that captures the fundamental damage and failure modes in a composite laminate. The enhanced Semi-Discrete Damage Model (eSD2M) was developed to capture matrix cracks with high fidelity while maintaining computational efficiency [4]. By using compatible meshes, the interaction between intra- and inter-laminar cracks can be accurately captured, which is essential for material-laminate configurations where both failure modes may occur. Moreover, the eSD2M framework includes material non-uniformity to capture the stochastic details of properties in a real structure. The final paper will demonstrate the capability of the eSD2M to capture the damage and failure modes described above. The numerical results will be compared with detailed experimental observations. Additionally, the sensitivity of the numerical prediction to the material parameters and stacking sequence will be examined. Hence, the proposed model may be a powerful tool to predict the response and the shift in failure modes of a composite structure before the material system is even manufactured and tested. References: [1] Nguyen, Minh Hoang, Paul Davidson, and Anthony M. Waas. "Particle-toughened interlayers enhance mechanical response of composite laminates." Composites Science and Technology 182 (2019): 107761. [2] O'brien, T. K. "Characterization of delamination onset and growth in a composite laminate." In Damage in composite materials: basic mechanisms, accumulation, tolerance, and characterization. ASTM International, 1982. [3] Nguyen, Minh Hoang, Avinkrishnan A. Vijayachandran, Paul Davidson, Damon Call, Dongyeon Lee, and Anthony M. Waas. "Effect of automated fiber placement (AFP) manufacturing signature on mechanical performance of composite structures." Composite Structures 228 (2019): 111335. [4] Nguyen, Minh Hoang, and Anthony M. Waas. "Modeling delamination migration in composite laminates using an enhanced semi-discrete damage model (eSD2M)." International Journal of Solids and Structures 236 (2022): 111323.

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abst. 1313
Repository

Tensile and shear response of epoxy and carbon/epoxy materials at different loading rates

Choi, Tae-Seong (chlxotjd81@unist.ac.kr), Ulsan National Institute of Science and Technology, South Korea
Kim, Hye-gyu (hekkim@unist.ac.kr), Ulsan National Institute of Science and Technology, South Korea
Ji, Wooseok (wsji@unist.ac.kr), Ulsan National Institute of Science and Technology, South Korea

These days, composite materials are commonly considered one of the best replacements of metal alloys in response to the ever-increasing demand for lightweight automobiles. Although the practical usage of the composites for some primary load-bearing components is proven to be feasible, crashworthy

structures are still designed and built mostly with metal alloys. It is well known that a loading rate often greatly alters the stress-strain response of a material. While numerous researches have been performed on the rate-dependent behavior of metallic materials, polymeric and composite materials are seldom studied. The present study is concerned with the rate-dependent behavior of a thermoset polymer-based textile composite. Especially, the effects of the matrix material and fiber orientation on the stress-strain responses at various strain rates were experimentally investigated. Test specimens were fabricated according to ASTM D638 and ASTM D7078 for tension and shear tests, respectively. Virgin matrix specimens were manufactured using the epoxy resin system of INF-114/INF 213 from PRO-SET Inc., and textile specimens were composed of the same resin system with 13 plies of plain weave, T300 3K carbon fiber fabric from Toray Inc. Tension tests on the epoxy and 0-degree textile specimens were performed at various loading rates; 5, 50, 200, and 800 mm/min. It was found that the epoxy became slightly stiffer and more brittle as the loading rate increased while the stiffnesses of the textile composites were almost identical. The elongation strains at break and the peak stresses of both epoxy and composite specimens decreased as the rate increased. The failure patterns of the textile specimens were examined through computed tomography and scanning electron microscopy, and it was observed that transverse matrix cracks occurred first before fibers were broken. Therefore, it can be concluded that the rate-dependent tensile strength of the epoxy material determines that of the 0-degree textile composite. The effects of the epoxy material on the shear response of the textile composite were also investigated. V-notched shear tests at different loading rates were carried out on the epoxy specimens to obtain the rate-dependent shear behavior of the matrix material. The shear response of the textile composite at the same loading rates were obtained from the tension tests on 45-degree textile specimens. The shear strength of the epoxy material decreased as the strain rate increased while the shear strength of the composite increased. Overall, the present study found that the rate-dependent response of the textile composite was mainly caused by the decreasing strength of the epoxy material as well as the fiber orientation.

Implementation of advanced approaches based on Continuum Damage Mechanics for composite failure analysis: status and way forward

abst. 1385
Room B032
Thursday
July 21
09h40

Herman, Melanie (melanie.herman@airbus.com), Airbus Operations, Toulouse, France
Leon-Dufour, Jean-Luc (jean-luc.leon-dufour@airbus.com), Airbus Operations, Toulouse, France
Peters, Philippe (Philippe.Peters@airbus.com), Airbus Operations, Toulouse, France
Laurin, Frédéric (frederic.laurin@onera.fr), ONERA , France
Turon, Albert (albert.turon@udg.edu), University of Girona, Spain
Arteiro, Albertino (aarteiro@fe.up.pt), University of Porto, Portugal

Considerable research efforts in the mechanics of composites have been provided during the last decades to improve the methods for failure prediction of composite materials, to understand their behavior and to model or calculate them. Static failure prediction of composite remains a big challenge to accelerate the development of aircraft components. Today, the use of stratified composites in the aerospace industry induces characterization procedures consisting of extensive experimental tests, due to a limited level of confidence in failure models. Those tests have an important impact on the cost and the lead time of development projects. It is then necessary to develop a numerical alternative to predict the strength and the composite material behavior to decrease the amount of tests. Airbus has implemented in scope of some RT activities two major damage models at meso scale, both based on Continuum Damage Mechanics. - U.Porto (University of Porto) 3D Smeared Crack Band (SCM) VUMAT, considering Albert Turon's damage law for delamination simulation; - ONERA3D (V)UMAT. The paper is exposing the results of comparative studies between models prediction and experimental tests, at coupon level on some elementary failure modes, for some thermoset prepreg materials in Unidirectional Tape format. A way forward is proposed while detailing the remaining challenges for implementation of those models at a larger scale.

FRP in concrete, steel and composite steel/concrete structures

abst. 1124
Virtual Room 1
Wednesday
July 20
12h50

Delamination buckling of FRP strips in the strengthening of beam elements

Capozucca, Roberto (r.capozucca@staff.univpm.it), Polytechnic University of Marche, Italy
Magagnini, Erica (e.magagnini@staff.univpm.it), Polytechnic University of Marche, Italy
Bettucci, Elisa (eli_bt@hotmail.it), Polytechnic University of Marche, Italy

In recent years there has been an increase in the use of composite materials for the strengthening of damaged structural elements. In general, strengthening of beams with FRP strips on both compressive and tensile slides may be an efficient way to increase stiffness and strength of damaged beams, although the FRP strips on the compressive side may be subjected to critical loads and corresponding buckling mode. In a hybrid system such as beam elements strengthened with externally bounded (EB) Fiber Reinforced Polymers (FRPs) strips, glued on the tensile side and compressed side, the availability of strengthening is due to the maintenance of bond of FRP under loading without detachment. Loss of adhesion causes delamination to the interface with consequences on the strength of the whole hybrid system. In this work, analytical models to study the delamination behaviour of FRP strips under compression in beam elements, under bending, are presented to predict delamination buckling. Investigations on beam models undamaged and damaged strengthened with FRP on the compression and tension side are shown. Homogeneous steel beam models and reinforced concrete (RC) beams were subjected to four-point bending tests. Experimental results and theoretical models are discussed, and a comparison of experimental and theoretical data is provided.

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abst. 1176
Room B032
Wednesday
July 20
16h30

SHORT AND LONG TERM DEFLECTION ANALYSIS OF FRP STRENGTHENED RC MEMBERS

Slaitas Justas (justas.slaitas@vilniustech.lt), Vilnius Gediminas Technical University, Lithuania
Valivonis Juozas (juozas.valivonis@vilniustech.lt), Vilnius Gediminas Technical University, Lithuania

The use of fibre-reinforced polymer (FRP) materials has grown steadily in civil engineering for the last decades, and retrofitting of reinforced concrete (RC) structures was not an exception. However, despite its commonly agreed benefits, it can be corrupted by not full composite action of concrete and FRP material. While the structure is not cracked, both elements deform together and it can be considered as a full composite action. However, after cracking of the concrete, the stress concentration appears in the cracks and reduces the contact stiffness of the concrete and the FRP. Therefore, to predict the real deflection response, the actual values of the concrete and FRP contact stiffness and the stiffness of the entire element are required. The recently proposed calculation technique based on the built-up bars theory by the authors has proven to be appropriate for prediction of the short-term deflection response. However, the strengthened members operate under sustained load action. Against this background, a new improved analytical solution is proposed that covers the effects of both short- and long-term loading. Such a prediction model based on the general laws of deflection and the built-up bars theory improves the current state-of-the-art by allowing full prediction of the deflection response of the retrofitted member at each stage of the structures live cycle, including the effects of prestressing and partial stiffness of the concrete-FRP joint. An extended database of retrofitted element studies was also compiled for the experimental validation of the proposed methodology. The results validate the proposed methodology, which could be considered for practical application in the design of retrofitting of real structures.

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abst. 1308
Repository

EFFECT OF SPECIMEN SIZE ON COMPRESSIVE BEHAVIOR OF FRP-CONFINED RECTANGULAR CONCRETE COLUMNS

Pronnoy Bhat (2019RCE0022@iitjammu.ac.in), Indian Institute of Technology Jammu, India
Rimen Jamatia (rimen.jamatia@iitjammu.ac.in), Indian Institute of Technology Jammu, India

The effect of specimen size on compressive stress vs. strain behavior was studied numerically on FRP-confined rectangular concrete columns. All the specimens considered are self-similar i.e. the ratio between FRP thickness to columns characteristic dimensions are kept constant to ensure equal effective confinement pressure. It was observed that size effect exists in FRP-confined concrete columns under axial compression. It was also observed that mode of failure in FRP-confined rectangular concrete columns changes with specimen size; in case of smaller specimen size, failure of the specimen coincides with the rupture of FRP material from the corner end of the rectangular section driven by concrete plasticity, whereas in large self-similar columns, failure of the specimen occurs due to shear band formation by damage localization of concrete. Sufficient condition of confinement specified to ensure strain hardening type response by various earlier researchers on laboratory size specimens also found to be size dependent. Various design-oriented model over predicts the compressive behavior of large self-similar specimens and their reasons were discussed. KEYWORDS:Non-uniform confinement, FRP, Rectangular Columns, Concrete, Size effect.

FRP reinforced concrete structures

abst. 1031
Repository

Design-Oriented Stress-Strain Model for FRP-Confined Ultra-High Performance Concrete (UHPC)

Jun-Jie ZENG (jjzeng@gdut.edu.cn), Guangdong University of Technology, China
Jinjing Liao (jinjingl@student.unimelb.edu.au), Guangdong University of Technology, China

Current axial stress-strain models of FRP-confined concrete mainly focuses on FRP-confined normal concrete, however the research work on studying the stress-strain relationship of FRP-confined ultra-high performance concrete (UHPC) is limited so far. To fill this research gap, the purpose of this study is to develop a new design-oriented stress-strain model for describing the stress-strain relationship of FRP-confined UHPC cylinders under axial compression. The developed model has two versions, i.e., the Version I model is applicable to the specimens experiencing stress reduction, and the Version II model is a typical model with a parabolic first portion and an ascending linear second portion. A large amount of compressive test data collected from five previous experimental studies involving 117 FRP-confined UHPC cylinders was used for the model development. The assessment results reveal that both versions of the developed design-oriented model have the capability of accurately estimating the characteristic stresses and strains at characteristic points. In addition, it demonstrates that the full stress-strain curves predicted by the developed model agree reasonably well with most of the test results, especially for the slopes of the last linear portions.

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abst. 1044
Virtual Room 1
Wednesday
July 20
11h30

One-way High Strength plain and FRC Slabs Reinforced with Basalt FRP Bars: A Study on the Experimental and Analytical Shear Behavior

Al-Hamrani, Abathar (wnahhal@hotmail.com), Qatar University, Qatar
Alnahhal, Wael (wael.alnahhal@qu.edu.qa), Qatar University, Qatar

The purpose of this work is to experimentally and analytically investigate the shear behavior of high-strength one-way plain and basalt fiber reinforced concrete (BFRC) slabs reinforced with basalt fiber reinforced polymers (BFRP) bars. A total of 8 slabs having 2550 mm length, 600 mm width and 150 mm height were tested under four-point loading until failure. The main test variables were the volume fraction V_f of basalt macro fibers (BMF) and the reinforcement ratio. The BMF was added to the concrete mix at a V_f of 0% and 0.75%, whereas slabs were longitudinally over-reinforced with 0.792% and 1.27% reinforcement ratios. In the analytical part, two approaches were comparatively analyzed. The first approach considers the individual contribution of concrete and BMF to shear strength, while the second approach considers a direct modification to the concrete contribution due to the addition of fibers. The experimental results showed that the shear capacity was enhanced by 25% to 29% when the reinforcement ratio was increased from 0.792% to 1.27%. In addition, the shear capacity of the slab containing 0.75% of BMF was notably enhanced over the plain concrete slab, however, this enhancement was less notable when a higher reinforcement ratio was used. The analytical investigation revealed that the proposed model, which calculates the individual contribution of concrete based on the model of Razaqpur and Isgor (2006) and the contribution of BMF based on the modified model of Aoude et al (2012), has accurately and conservatively predicted the experimental data with a mean experimental to predicted shear capacity of 1.10 and a coefficient of variation of 7.95%.

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abst. 1046
Virtual Room 1
Wednesday
July 20
11h50

Shear Capacity Prediction of FRP-RC Beams Using Single and Ensenble exPlainable Machine Learning Models

Wakjira, Tadesse (twakjira@qu.edu.qa), Qatar University, Qatar
Al-Hamrani, Abathar (aa1205725@student.qu.edu.qa), Qatar University, Qatar
Ebead, Usama (uebead@qu.edu.qa), Qatar University, Qatar
Alnahhal, Wael (wael.alnahhal@qu.edu.qa), Qatar University, Qatar

Corrosion in steel reinforcement is a central issue behind the severe deterioration of existing reinforced concrete (RC) structures. Nowadays, fiber-reinforced polymer (FRP) is increasingly being used as a viable alternative to conventional steel reinforcement due to its anti-corrosive nature. The accurate estimation of the shear capacity of FRP reinforced concrete (FRP-RC) elements is critical for a reliable and accurate design and performance assessment of such members. However, existing shear models are often developed based on a limited database and important factors, limiting their prediction effectiveness. Hence, this paper presents novel machine learning (ML) based models for predicting the shear capacity of FRP-RC beams. A total of eleven ML models starting from the simplest white-box models to advanced black-box models are developed based on a large database of FRP-RC beams. Such investigation helps in examining the necessity of complex ML models and identify the most accurate predictive model for the shear capacity of FRP-RC beam. Moreover, a unified framework known as SHapley Additive exPlanation (SHAP) is used to identify the most important factors that influence the shear capacity of FRP-RC beams. Among all investigated ML models, the extreme gradient boosting (xgBoost) model showed the best performance with the lowest error (mean absolute error, root mean squared eror, and mean absolute percent error) and highest coefficient of determination (R2), Kling-Gupta efficiency, and index of agreement between the experimental and predicted shear capacities. Moreover, the accuracy of the proposed xgBoost model was compared with that of the available code and guideline equations and resulted in a superior prediction capability.

Study on shear resistance of GFRP reinforced seawater sea-sand concrete beams without stirrups

abst. 1056
Repository

Yao Zhu (skinyao@163.com), Fuzhou, China
Yuhang Fang (15859153861@163.com), Fuzhou, China
Yu Chen (kinkingingin@163.com), Fuzhou, China
Xiaoyong Zhang (cheungxiaoyong@163.com), Fuzhou, China
Wenyuan Kong (200520033@fzu.edu.cn), Fuzhou, China

The combination of seawater sea-sand concrete (SWSSC) and fiber reinforcement polymer (FRP) bar is considered as a feasible alternative to solve the resources shortages. This paper investigates the shear behavior of SWSSC beams reinforced with glass-fiber reinforcement polymer (GFRP) bar as longitudinal reinforcements without stirrups. Taking the section-height of beam, GFRP reinforcement ratio and shell content as parameters, totally seventy beams comprising sixty SWSSC beams and ten ordinary concrete beams were tested under four-point loading. Experimental results showed that the use of SWSSC had a negligible effect on the shear strength of GFRP reinforced SWSSC beams without stirrups in the short term. The presence of shell in sea-sand resulted in the obvious weak interface of concrete, thereby reducing the shear strength and cracking strength of specimens. The shear strength of SWSSC beams reinforced with GFRP bars tended to decrease with the increase of shell content. In addition, the applicability of existing guidelines on the shear strength of GFRP reinforced SWSSC beams was evaluated. Furthermore, the theoretical model was proposed to estimate the shear strength of GFRP reinforced SWSSC beams without stirrups, the comparison of shear strength between predictions and experiments demonstrated that the proposed design formula derived from tension–compression model achieved sufficient accurate predictions for practical engineering.

Structural Behavior of Negative Moment Region NSM CFRP Strengthened T-Beams with Various Embedment Depth under Monotonic and Cyclic Loading

abst. 1108
Room B032
Tuesday
July 19
17h30

Haryanto, Yanuar (yanuar_haryanto@yahoo.com), National Cheng Kung University, Taiwan
Hu, Hsuan-Teh (hthu@ncku.edu.tw), National Cheng Kung University, Taiwan
Hsiao, Fu-Pei (fphsiao@ncree.narl.org.tw), National Center for Research of on Earthquake Engineering, Taiwan
Han, Ay Lie (hanaylie@live.undip.ac.id), Universitas Diponegoro, Indonesia

Wiranata, Chua Andre (wiranataandre@gmail.com), National Cheng Kung University, Taiwan
Salim, Fernando (fernandosalimm@gmail.com), National Cheng Kung University, Taiwan
Nugroho, Laurencius (laurenciusnugroho@gmail.com), National Cheng Kung University, Taiwan

Reinforced concrete (RC) structures may be vulnerable to failure under cyclic loading conditions. These structures might require strengthening to resist static and cyclic loads as they may exhibit inadequate capacity due to the design errors or material properties degradation because of severe environmental effects or an increase in service loads. With this in mind, a series of experiments have been conducted to investigate the behavior of the bare and moment negative region strengthened RC T-beams under both monotonic and low-rate cyclic loading. A near-surface mounted (NSM) technique with carbon fiber reinforced polymer (CFRP) rods having different embedment depth are used as the strengthening system in the present study. The experimental study conclusively showed that the impact of NSM CFRP rods was adequate on expanding the ultimate load as well as stiffness of the beams, and dissipation of energy capacity along with ductility of the specimens was decreased. Additionally, under cyclic loading, the negative moment region NSM CFRP strengthened beams showed enhancement in hysteresis behavior, higher stiffness and energy dissipation capacity compared to their bare counterparts. Moreover, the experimentally obtained moment capacities match reasonably well with the theoretically predicted moment capacities.

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abst. 1141
Virtual Room 1
Wednesday
July 20
12h30

Fire behaviour of concrete structures reinforced with GFRP bars: Experimental tests, numerical simulations and design

Rosa, Inês C. (ines.rosa@tecnico.ulisboa.pt), CERIS, Instituto Superior Técnico, Universidade de Lisboa, Portugal
Duarte, António P. C. (antonio.duarte@tecnico.ulisboa.pt), CERIS, Instituto Superior Técnico, Universidade de Lisboa, CERIS, Instituto Superior Técnico, Universidade de Lisboa
Arruda, Mário R. T. (mario.rui.arruda@tecnico.ulisboa.pt), CERIS, Instituto Superior Técnico, Universidade de Lisboa, CERIS, Instituto Superior Técnico, Universidade de Lisboa
Firmo, João P. (joao.firmo@tecnico.ulisboa.pt), CERIS, Instituto Superior Técnico, Universidade de Lisboa, Portugal
Correia, João R. (joao.ramoa.correia@tecnico.ulisboa.pt), CERIS, Instituto Superior Técnico, Universidade de Lisboa, Portugal

This paper presents a comprehensive study about the fire behaviour of reinforced concrete (RC) structures with glass fibre reinforced polymer (GFRP) bars, conducted along three complementary paths: (i) an experimental campaign, which included the characterization of the rebars' mechanical properties at a wide range of temperatures, their bond behaviour with concrete at elevated temperatures, and the fire resistance of RC slabs; (ii) the numerical modelling of the bond and fire behaviours; and (iii) the drafting of fire design recommendations. Different types of GFRP reinforcements were tested, presenting different surface finishes (sand coated, two types of ribs) and geometries (straight vs. 90º bent). The first part of the paper presents the investigations about the properties and bond behaviour of the GFRP rebars at elevated temperatures. First, steady-state tensile tests were performed to determine the rebars' modulus and strength up to 715 ºC. Next, pull-out tests between GFRP rebars and concrete were conducted up to 300 ºC. Local bond laws for the GFRP-concrete interaction at elevated temperatures were then numerically calibrated using the test data. These laws were implemented in 3D FE models, duly validated with the results of the bond tests, in order to perform parametric studies that allowed proposing design-oriented anchorage lengths for straight and 90º bent GFRP rebars as a function of temperature. The second part of the paper provides an in-depth study about the fire behaviour of GFRP-RC slabs. In a first stage, fire resistance tests were performed in loaded GFRP-RC slab strips subjected to the ISO 834 fire curve. A total of 22 slab strips were tested to evaluate the influence of the following parameters: (i) concrete cover; (ii) concrete strength; (iii) type of rebars (material and surface finish); and (iv) presence of straight- or 90º bent tension lap splices directly exposed to fire with different overlap lengths. In a second stage, 3D FE models were developed to simulate the thermomechanical fire behaviour of the slab strips and to perform parametric studies. The temperature dependant properties of the rebars and concrete were implemented in the models, and the

GFRP-concrete interaction was modelled through the local bond laws (independently) calibrated for different temperatures. Finally, in the third part of the paper, based on the experimental and numerical results, fire design recommendations are drafted, including (i) critical temperatures and (ii) minimum concrete cover thicknesses for the GFRP rebars, and (iii) positions and lengths for their end anchors and overlapped lap-splices. Overall, the study presented in this paper proved that in spite of the high vulnerability of GFRP rebars to elevated temperatures, GFRP RC slabs can endure over 3 hours of fire exposure with considerably lower concrete covers than those recommended in existing FRP-RC design codes, provided that the rebars remain well anchored in cool zones of the structure. If this requirement is fulfilled, failure is governed by the tensile strength of the rebars at very high temperatures, well above their glass transition temperature (Tg). Moreover, it was shown that the progressive and severe bond degradation of the GFRP rebars with temperature must be considered in the design of both "cold" anchorage zones and lap splices, aiming to prevent premature debonding failures when the rebars' temperature increases above their Tg. In this regard, the adoption of bent rebars was proven to be beneficial to decrease the "cold" end anchorage lengths, as well as to significantly improve the bond behaviour in splicing zones. These results will contribute to improve existing design guidelines for FRP-RC structures, which currently provide insufficient and overconservative recommendations for their fire design – ultimately, these findings will promote a safer, and more economic and sustainable use of FRP reinforcement in civil engineering applications.

Energy Equivalence Dependent Mathematical Model for Homogenization of Carbon Fiber-Reinforced Concrete Panels under Impulsive Load

abst. 1167
Room B032
Tuesday
July 19
17h10

Singamsetty, Sreenitya (sreenitya.singamsetty@civil.iitd.ac.in), Indian Institute of Technology (IIT) Delhi, India
Matsagar, Vasant (matsagar@civil.iitd.ac.in), Indian Institute of Technology (IIT) Delhi, India

Advanced engineered composite materials are used in protective structures for improving their resilience under impulsive loads as well as increasing longevity. Carbon fiber-reinforced polymer (CFRP) bars replace the conventional corrosion-prone steel reinforcing bars in concrete structures. Reinforced concrete (RC) is the most common material used in the civil engineering constructions, performance of which under impulsive loads is enhanced by using high strength CFRP bars provided as internal reinforcement. However, the detailed analysis of the carbon fiber-reinforced concrete panels subjected to impulsive loading using the traditional finite element (FE) model is highly time consuming, as it requires modelling of the individual reinforcement bars embedded inside the concrete member and their interaction (bond) with the surrounding concrete, while duly accounting for high strain rate material properties and nonlinearities in the materials used in the composite. Several trials are required to be made before a final design could be arrived at. In the current study, a new energy equivalence dependent mathematical model has been developed for homogenization of carbon fiber-reinforced concrete panels subjected to impulsive load, to reduce the computational time in performing trials. Variationally consistent homogenization technique has been employed to arrive at the effective properties of the considered representative volume element (RVE). In performing the RVE analysis, concrete is considered as homogeneous, and the only heterogeneity in the RC member is through the embedment of the CFRP reinforcement bars in composite action. The effect of external loading applied on the macroscopic element is transferred to the microscale level through appropriate boundary conditions to the RVE. Since the panels are subjected to high strain rate of loading, dynamic properties of the composite materials are accounted for in the RVE analysis. The microscale response in terms of strains, displacements, and stresses thus obtained by analyzing the RVE is upscaled to the macroscopic level using the scale transition laws in the homogenization technique. The response thus evaluated from such energy equivalence-based homogenized models is validated using detailed three-dimensional nonlinear finite element (FE) analysis conducted in hydrocodes available commercially. The newly developed mathematical model for homogenization of the CFRP-reinforced concrete panels under impulsive loads is found to be computationally efficient and easy to implement. Thus, a novel mathematical procedure has been contributed here to obtain dynamic response of the carbon fiber-reinforced concrete panels subjected to impulsive loading by effectively taking in to account the complexities in the material models

and interaction between different materials in the composite, while reducing the computational time considerably.

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abst. 1310
Virtual Room 1
Wednesday
July 20
12h10

Redistribution of moments in two-span externally post-tensioned beams with FRP rebars

Lou, Tiejiong (tjlou@whut.edu.cn), Wuhan University of Technology, China
Li, Zhangxiang (), Wuhan University of Technology, China
Pang, Miao (), Zhejiang University, China

External post-tensioning has many attractive merits such as the ease of tendon inspection and replacement, flexible choice of cross section of structures, reduction in dead load by permitting thinner web, and low friction loss. This technique has been widely used for strengthening or construction of various concrete bridges, especially continuous ones. In externally post-tensioned beams, a certain amount of bonded rebars needs to be provided for favorable structural behavior. Bonded rebars in continuous externally post-tensioned beams play an important role in structural behavior including the ability to redistribute moments. Conventional steel rebars are prone to corrosion. The corrosive problem can be solved by replacing steel rebars with fiber reinforced polymers (FRPs), e.g. carbon and glass FRPs (CFRP and GFRP). FRP composites are linearly elastic material without ductility. Since moment redistribution is closely related to flexural ductility, the redistribution behavior of continuous externally post-tensioned beams with FRP rebars needs to be adequately addressed. This work evaluates the effect of using FRP rebars instead of steel rebars on moment redistribution in continuous beams post-tensioned with external tendons. A numerical model is developed. A comparative study is performed on two-span continuous externally post-tensioned beams with CFRP, GFRP or steel rebar. In addition, typical rules about permissible moment redistribution are investigated and a simplified equation for calculating the moment redistribution in these beams is proposed.

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abst. 1335
Repository

Study on the flexural and debonding performance of Externally Bonded Reinforcement on Groove (EBROG) FRP strengthened RC beams

Codina, Alba (alba.codina@udg.edu), University of Girona, Spain
Barris, Cristina (cristina.barris@udg.edu), University of Girona, Spain
Aghabagloo, Mehdi (mehdi.agha@udg.edu), University of Girona, Spain
Baena, Marta (marta.baena@udg.edu), University of Girona, Spain
Torres, Lluís (lluis.torres@udg.edu), University of Girona, Spain

The use of Carbon Fibre Reinforced Polymers (CFRP) as strengthening material for reinforced concrete (RC) structures has gained widespread acceptance in recent years since it has many advantages over traditional techniques. So far, two techniques have been mainly studied: the Externally Bonded Reinforcement (EBR), where the CFRP is bonded onto the concrete tensile face through a structural adhesive, and the Near-Surface Mounted (NSM), where the CFRP and adhesive are placed into a groove previously cut in in the concrete cover. Despite the benefits of CFRP solutions, it is widely recognized that failure of RC structures strengthened with CFRP almost always occur due to debonding of the CFRP from the concrete substrate, especially when the EBR technique is used. The debonding of CFRP strengthened RC beams typically includes interfacial debonding of the FRP from the substrate (intermediate crack debonding or end debonding) and concrete cover separation at the FRP end. A good preparation of the concrete surface (i.e. sandblasting, water jetting, grinding, etc.) must be conducted to improve the bond between the FRP and the concrete and delay interfacial debonding, but research shows that these conventional methods are not enough to attain a high level of strain in the FRP before debonding. Anchorage of the CFRP, as a method to delay or prevent the critical premature bond failure mode, can significantly improve the efficiency and robustness of CFRP strengthened RC elements. In that sense, the Externally Bonded Reinforcement on Grooves (EBROG) has been recently presented in the literature as an alternative to conventional surface preparation methods. It has been proven to be an effective strategy to improve bonding behaviour and delay premature debonding in flexural RC beams strengthened with CFRP. This technique consists of increasing the contact surface between concrete and adhesive through additional grooves cut into the concrete cover so as to increase the concrete-CFRP shear strength. Although some studies showing the good performance of this technique have been carried out, there is still a lack of experimental data to provide better knowledge on the bond and flexural behaviour of RC elements with EBROG. There have been several investigations to study mainly the bond behaviour of FRP sheets using different geometries and configurations but there is little research on the use of this technique with FRP pre-cured laminates. This paper aims to study the contribution of the EBROG technique to delay or eventually prevent the premature debonding in RC beams strengthened with CFRP pre-cured laminates. For this purpose, the preliminary results on an experimental programme consisting on 1 unstrengthened (control) RC beam and 10 CFRP strengthened RC beams are presented. The beams had a cross section of 140 mm x 180 mm and a total length of 2400 mm, with a clear distance between supports of 2200 mm. All beams were subjected to a four-point bending test with a distance between loads of 400 mm. The geometry and beam setup was designed to theoretically obtain intermediate crack debonding prior to end debonding. The equations provided by the different levels of approximation in the Bulletin 90 of the International Federation of Structural Concrete (fib) were used for this purpose. The main test parameters were the tensile internal steel reinforcement (2ø8 and 2ø10), FRP width (50 and 80 mm), groove distribution and geometry in EBROG. Three configurations of longitudinal grooves have been employed (1 groove of 10x13mm, 2 grooves of 5x13mm and 3 grooves of 3.5x13mm), all of them with the same depth and total volume of resin. The experimental results, in terms of load-deflection response, ultimate load, strains and mode of failure are presented and discussed, showing an improvement in the performance of the strengthening system when using the EBROG technique.

Functionally graded materials and structures

abst. 1017
Repository

Transient Response of Collinear Griffith Cracks in a Functionally Graded Strip Bonded between Dissimilar Elastic Strips under Shear Impact Loading

Singh, Ritika (ritikasingh071195@gmail.com), Indian Institute of Technology (BHU), India

This article analyses the interaction between a central and two symmetrically placed collinear Griffth cracks subject to transient response under anti-plane shear impact loading. The cracks are situated in a strip constituted by functionally graded material (FGM) bonded between two dissimilar elastic strips of equal thickness. The material properties of FGM are assumed to vary exponentially as a function of thickness. Applying integral transforms, the boundary value problem reduces to a system of singular integral equations in the Laplace transformed domain. These equations are solved numerically using the Lobatto-Chebyshev collocation quadrature approach. The inverse Laplace transform is used to find the approximate expressions of dynamic stress intensity factors (DSIFs). The striking feature of the article is the study of phenomenal changes of shielding and amplification through dynamic stress magnification factor (DSMFs) at the tips of the cracks under the sudden impact loading applied at the upper material surface. The effects of impact load applied at different surfaces, positions of cracks' axis and the thickness of the strips of the composite material on the possibilities of cracks' arrest are depicted graphically for different particular cases.

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abst. 1022
Repository

Static and dynamic analysis of re-entry vehicle nose structures made of different functionally graded materials

Balaraman, P (balaraman@mech.sastra.edu), SASTRA Deemed University, India
Sreehari, VM (sreehari_vm@mech.sastra.edu), SASTRA Deemed University, India

Most of the high-speed aerospace applications such as re-entry vehicles involve slender structural components with high strength to weight ratio and high-temperature resistance. The present novel work comprises the structural analysis of nose of the re-entry vehicle made of functionally graded material. The base re-entry vehicle model considered for present study is the Orion model. The structural analysis of the re-entry vehicle nose model made of FGM has been studied in ANSYS environment. FGMs can be designed by varying the material composition from pure metal to ceramic rich. Their advantages include better thermal stress relaxation, high heat and wear resistance, breakage resistance, etc. The gradual change of composition contributed to the elimination of stress concentration caused by material composition discontinuities. Six functionally graded shell structures made of Aluminum/Silicon carbide, Aluminum/Aluminum oxide, Ti-6Al-4V/Silicon carbide, Aluminum/Boron carbide, Ti-6Al-4V/Boron carbide and Ti-6Al-4V/Aluminium oxide respectively are considered for the nose of the re-entry vehicle in present study. Structural analysis is performed to study the bending, buckling and vibration characteristics of re-entry vehicle model having nose structure made of FGM.

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abst. 1030
Repository

Buckling of Sigmoid Functionally Graded Sandwich Plates

Hadji, Lazreg (had_laz@yahoo.fr), University of Tiaret, Algeria
Avcar, Mehmet (mehmetavcar@yahoo.com), Suleyman Demirel University, Turkey
Civalek, Omer (civalek@yahoo.com), China Medical University, Taiwan
Akgoz, Bekir (bekirakgoz@yahoo.com), Akdeniz University, Turkey

Sandwich structures are a type of composite material that is made up of one core and two layers that are bonded together, and they have been used in many engineering fields such as spacecraft, aircraft, railway, and car structures, wind turbine blades, boat or ship superstructures, due to their impressive properties, such as high stiffness to weight ratio. Due to sudden changes in material properties at face-to-core interfaces of bonded three-layers, traditional sandwich structures are typically vulnerable to numerous failures such as stress concentration, delamination, matrix fractures, and so on. As a result,

scientists have proposed employing Functionally graded materials (FGMs) in sandwich constructions to fulfill the needed function, where the volume percentage of two materials varies as a function of position across defined dimensions of the structure. Material characteristics of FGMs alter unidirectionally (through thickness or length) or bi-directionally (both through thickness and length) gradually and constantly depending on a function with the aim of the intended tasks. FGMs may be found in a wide range of industries, including aerospace, medical, military, energy, optoelectronics, automotive, biotechnology, aviation, civil, and mechanical engineering constructions. The power-law material distribution of FG sandwich structures is often studied, in the open literature. In a power-law distribution, however, stress concentrations may develop at one of the sandwich structure's interfaces, where the material's characteristics are continuous yet rapidly vary. The usage of FGMs with the sigmoid law distribution model with a volume fraction comprising two power-law functions has been suggested as a way to overcome this problem. In the present work, buckling of sandwich rectangular plates made of FGMs with simply supported edges is investigated using a refined theory. Unlike other shear deformation theories, there are only four unknown functions in this one, as opposed to five in others. In many ways, the theory provided is variationally consistent and closely resembles the conventional plate theory. It does not require a shear correction factor and produces transverse shear stress variation, with transverse shear stresses varying parabolically over the thickness to fulfill free surface shear stress requirements. The three layers of the sigmoid FG sandwich plate are an isotropic core and two FG face layers. Based on a refined shear deformation plate theory, the equilibrium equations of the sigmoid FG sandwich plate are provided. The Navier method is used to obtain closed-form solutions. The impact of material distribution and sandwich plate geometry on the buckling of sigmoid FG sandwich plates is exhibited using numerical data.

Functionally graded "Ti – Ta(O,N)" structure and its production using high-temperature induction PVD

abst. 1055
Repository

Fomin, Aleksandr (afominalex@rambler.ru), Yuri Gagarin State Technical University of Saratov, Russia
Fomina, Marina (mafomina@rambler.ru), Yuri Gagarin State Technical University of Saratov, Russia
Koshuro, Vladimir (dimirion@rambler.ru), Yuri Gagarin State Technical University of Saratov, Russia

Due to simulation by the finite element method, the temperature fields in the "inductor – tantalum target – titanium sample" system were calculated depending on the inductor current and exposure time during induction physical vapor deposition (IPVD). The conditions under which the tantalum target was heated to the evaporation temperature T = 2400–2800 °C in low vacuum (not more than 40 Pa) were determined. It was experimentally established that after IPVD at an inductor current I = 8.0–12.8 kA and exposure t = 30–300 s (multi-cycle deposition modes), there was an increase in the content of tantalum C[Ta] = 0.4–26.3 at.%, oxygen C[O] = 14.6–55.7 at.%, and nitrogen C[N] = 1.2–21.2 at.% on the surfaces of titanium samples. According to the XRD data, the resulting layer on the surfaces of samples was a tantalum-containing oxide and nitride mixture coating. It was found that during IPVD, hard functionally graded "Ti – Ta(O,N)" structure H = 9.6–35.7 GPa with superhard thin layer H = 36.9–59.5 GPa was obtained. The research was supported by the Russian Science Foundation (project No. 18-79-10040).

Limit states of infinitely wide and stiffened plates made of FGM under compression in the elastic range

abst. 1057
Virtual Room 2
Wednesday
July 20
10h20

Teter Andrzej (a.teter@pollub.pl), Lublin University of Technology (LUT), Faculty of Mechanical Engineering, Department of Applied Mechanics, PL – 20-618 Lublin, Nadbystrzycka 36 Str., Poland, Poland
Kolakowski Zbigniew (zbigniew.kolakowski@p.lodz.pl), Lodz University of Technology (TUL), Faculty of Mechanical Engineering, Department of Strength of Materials (K12), PL – 90-924 Lodz, Stefanowskiego 1/15 Str., Poland, Poland

To the Memory of Professor Arkadiy I. Manevich from Dnipro, Ukraine. In presented studies, particular attention was paid to an interaction of the lowest global buckling mode with two types of local buckling, i.e., local buckling of the skin and local buckling of the stiffeners. The research was financed within the framework of the Lublin University of Technology –Regional Excellence Initiative project, funded by the Polish Ministry of Science and Higher Education (contract no. 030/RID/2018/19). The plate skin was made of a Functionally Graded Material (FGM), whereas longitudinal rectangular reinforcing stiffeners with a rectangular cross-section were isotropic. The plates under analysis were simply supported at both ends and subjected to uniform compression. Numerical models of thin-walled structures under analysis were built with the Abaqus system. A plate of infinite width was divided into periodicity cells. A plate model of the stiffener was used in the simulations. In the FEM model, second-order four-node shell elements with eight degrees of freedom in each node (S8R-type element) were applied. The element dimension was defined within an analysis of convergence. A nonlinear problem was solved with the Riks algorithm to trace stable and unstable equilibrium paths. Dimensions of the stiffened plate were selected to make the eigenvalues close, and thus to ensure a very strong interaction between the modes. Values of the ultimate load-carrying capacity determined in the limit states. While comparing the behavior of 15 wide plates that differed as regards geometrical dimensions and proportions in the thickness of FGM layers in the plane skin, it was found that the most dangerous was an interaction of the stiffener local buckling mode with the global mode, for which a decrease in the load-carrying capacity was even over 65% when compared to the lowest value of the bifurcational load. It should be underlined that it does not matter whether the local buckling mode of stiffeners is the lowest local eigenmode. If this mode is not accounted for in the interactive analysis, it leads to a significant overestimation of the ultimate load-carrying capacity. An interaction of the global buckling mode and the lowest local mode when the skin loses stability results in a decrease in the load-carrying capacity up to 50% regarding the minimal bifurcational load. This phenomenon occurs only when flexural rigidities of the plate skin and the stiffener are comparable. High over-rigidity of the stiffener causes that only the plate skin is subject to buckling and the load-carrying capacity of the whole structure improves. Here, an interaction between the global mode and the lowest local mode decides about the load-carrying capacity on the assumption that the eigenvalues are close to each other. Otherwise, one-mode buckling occurs.

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abst. 1084
Repository

Thermoelectroelastic deformation of a FGM-coated half-space

Vasiliev Andrey (andre.vasiliev@gmail.com), Don State Technical University, Russia
Volkov Sergei (fenix_rsu@mail.ru), Don State Technical University, Russia
Aizikovich Sergei (saizikovich@gmail.com), Don State Technical University, Russia

Elastic half-space with a functionally graded coating is considered with all group of properties varying arbitrary with depth of the coating. Electric potential difference is applied trough the circular electrode on the surface of the coating and the substrate. This circular area is also heated to a constant temperature. Outside the circular area the surface is stress-free, thermally and electrically insulated. Using the Hankel integral transformation technique, the problem is reduced to the solution of the system of dual integral equations which is solved using the bilateral asymptotic method. Approximated analytical expressions for the distribution of displacements, temperature and electric potential of the surface are obtained. The expressions are asymptotically exact for small and large values of the relative coating thickness. Features of the thermoelectroelastic deformation of coated materials are discussed and illustrated by the numerical examples. This work was supported by the Government of the Russian Federation (grant No. 14.Z50.31.0046).

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abst. 1090
Repository

Application of DSQ element for static bending, free vibration and buckling analysis of FGM plate

Maknun, Imam Jauhari (jauhari.imam@gmail.com), Universitas Indonesia, Indonesia
Natarajan, Sundararajan (sundararajan.natarajan@gmail.com), Indian Institute of Technology Madras, India
Katili, Irwan (irwan.katili@ui.ac.id), Universitas Indonesia, Indonesia

This paper presents a discrete shear quadrilateral (DSQ) element to study the static bending, free vibration, and buckling analysis of functionally graded material plate structures. The effective properties of the FGM plate are computed using the rule of mixtures. The plate kinematics is based on Resinner-Mindlin plate theory with discrete shear constraints introduced to relate the kinematical and the independent shear strains. The effectiveness of the present element is demonstrated with a few examples for Static bending, free vibration and mechanical and thermal buckling. The influence of various parameters such as the plate aspect ratio, material gradient index and boundary conditions are systematically studied. From the study, it is obvious that the DSQ element yields accurate results and converges optimally.

Nonlinear bending of functionally graded metamaterial composite beams

abst. 1092
Virtual Room 2
Wednesday
July 20
09h40

Zhao, Shaoyu (shaoyu.zhao@uq.edu.au), The University of Queensland, Australia
Zhang, Yingyan (yingyan.zhang@rmit.edu.au), RMIT University, Australia
Zhang, Yihe (henin.zhang@rmit.edu.au), RMIT University, Australia
Yang, Jie (j.yang@rmit.edu.au), RMIT University, Australia
Kitipornchai, Sritawat (s.kitipornchai@uq.edu.au), The University of Queensland, Australia

This paper investigates the nonlinear bending responses of functionally graded multilayer metamaterial nanocomposite beams based on first-order shear deformation beam theory. The beam is composed of graphene origami (GOri) enabled metal metamaterials that possess negative Poisson's ratio (NPR) and enhanced mechanical properties where the GOri content and folding degree vary layer-wise along its thickness direction. Material properties including Young's modulus, coefficient of thermal expansion (CTE), Poisson's ratio, and density of the metamaterials are determined by genetic programming-based micromechanical models. The nonlinear governing equations are solved using the Ritz method to obtain static bending deflections and normal stresses. A detailed parametric investigation is conducted to examine the effects of GOri folding degree, GOri content, GOri distribution pattern, temperature, slenderness ratio, and boundary condition on the linear and nonlinear bending properties of functionally graded metamaterial beams. Numerical results show that the metamaterial distributed in a gradient achieves a considerable enhancement on the linear and nonlinear bending behaviors of composite beams.

Thermal Buckling in a functionally graded Magneto-Electro-Elastic microbeam model including microstructure effect

abst. 1142
Repository

Zhang, Gongye (gyzhang@seu.edu.cn), Southeast University, Nanjing, Jiangsu, China
Hao, Yingjie (1520792335@qq.com), Southeast University, Nanjing, Jiangsu, China
Mi, Changwen (mi@seu.edu.cn), Southeast University, Nanjing, Jiangsu, China

A new transversely isotropic functionally graded magneto-electro-elastic (FG-MEE) Bernoulli-Euler beam model is established to investigate the microstructure effect under a uniform temperature load. The equations of motion and complete boundary conditions are determined by applying an extended modified couple stress theory and employing a variational approach. The new FG-MEE microbeam model can account for both the microstructure and temperature effects. To study the microstructure effect, temperature effect and FG material parameter distribution influence in thermal buckling of new FG-MEE microbeam models, the critical buckling temperature in simply supported beams is analytically solved. Numerical results show that the presence of the microstructure effect leads to enlarged critical buckling temperatures. In addition, it is found that FG parameter can be used to tailor the critical values.

Geometrically nonlinear study of functionally graded saturated porous plates under thermal environment based on refined shear deformation plate theory and Biot's theory

abst. 1230
Virtual Room 2
Wednesday
July 20
17h30

Naveen Kumar H S (naveenhsk@gmail.com), National Institute of Technology Karnataka, Surathkal, India
Subhaschandra Kattimani (subhaskatti@nitk.edu.in), National Institute of Technology Karnataka, Surathkal, India
Flavio D Marques (fmarques@sc.usp.br), São Carlos School of Engineering, University of São Paulo, São Carlos, SP, Brazil, Brazil

This research presents the geometrically nonlinear investigation of thermally loaded functionally graded saturated porous material plate (FGSPMP) under undrained conditions. In conjunction with von Karman's nonlinearity, the refined shear deformation plate theory (RSDPT) is implemented to model the FGSPMP. The effective material characteristics of the saturated porous plate change constantly in the thickness direction under a thermal environment. The pores of the saturated porous plate are examined in fluid-filled conditions. Thus, the constitutive equations are established using Biot's linear poroelasticity theory. The governing equations are developed by combining a nonlinear finite element technique with Hamilton's principle. Then, the direct iterative approach is utilized to extract the geometrically nonlinear numerical results. The emphasis is placed on exploring the effects of numerous parameters such as Skempton coefficient, temperature distribution, volume fraction grading index, porosity volume index, porosity distributions, and boundary conditions during the extensive numerical analyses on the linear frequency, large amplitude frequencies, and nonlinear central deflection of the FGSPMP. It is evident from the investigation that saturated fluid in the pores substantially impacts the nonlinear deflection and vibration behavior of FGSPMP.

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abst. 1235
Virtual Room 2
Wednesday
July 20
10h00

Wave propagation in Axially Functionally Graded Timoshenko-Ehrenfest Nanobeams

Arda, Mustafa (mustafa.arda@taltech.ee), Tallinn University of Technology, Department of Mechanical and Industrial Engineering, Estonia
Majak, Jüri (jüri.majak@taltech.ee), Tallinn University of Technology, Department of Mechanical and Industrial Engineering, Estonia
Mehrparvar, Marmar (marmar.mehrparvar@taltech.ee), Tallinn University of Technology, Department of Mechanical and Industrial Engineering, Estonia

Axially graded composite nano-structures will have wide range of application areas in near future. Designing of a material in graded composition can give a huge advantage in specific applications. Propagation of transverse and rotational waves in axially graded carbon nanotube will be studied in the present work. Variation of material properties in the nanotube will be considered in exponential form. The nonlocal Timoshenko-Ehrenfest beam model will be used in the modeling of nanotubes. Solution of the differential equation of motion with variable coefficients will be obtained with the numerical Higher Order Haar Wavelet method. The effect of material grading index on the wave response of axially graded nanobeam will be investigated. Present results could be useful in the design of composite nano-wires.

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abst. 1270
Room B032
Wednesday
July 20
16h50

Linear and Nonlinear Analysis of Composite and Hybrid Axisymmetric Shells

Moita,José S. (jmoita50@gmail.com), .IDMEC, ISE-Universidade do Algarve, Campus da Penha, Faro, Portugal, PORTUGAL
Araújo, Aurélio .L. (aurelio.lima.araujo@tecnico.ulisboa.pt), IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboal, PORTUGAL
Correia, Victor F. (victorfranco@enautica.pt), IDMEC-Escola Superior Náutica Infante D. Henrique, Av. Eng. Bonneville Franco, 2770-058, Paço de Arcos, PORTUGAL
Mota Soares , Cristóvão M. (cristovao.mota.soares@tecnico.ulisboa.pt), IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboal, PORTUGAL

In this work are presented the formulations for static and free vibrations analyses of hybrid axisymmetric shell structures. The hybrid structures (F/C/F) are made by laminas of composite material(C) sandwiched by two functionally graded material laminas (F). The analyses are performed using a semi-analytical finite element model. The numerical solution is obtained by expanding the variables in Fourier series in the circumferential direction and using conical frustum finite elements in the meridional direction. The implemented finite element is a simple conical frustum with 2 nodal circles, with 10 degrees of freedom per nodal circle. This model uses a small number of discrete layers to model the continuous variation of the mechanical properties through the thickness of the Functionally Graded Material (FGM) laminas.It needs a reduced number of finite elements to model the geometry of even complex axisymmetric structures, and the integration procedures uses only 1 Gauss point. This model reveals to be extremely efficient in the analysis of axisymmetric shells – easy to model the geometry, low number of total degrees of freedom, very good results, and extremely fast. A specifique in-house program has been developed, and the solutions of some illustrative examples are performed, and the results are presented, discussed and compared with numerical alternative models, when available. Due to the lack of results in the literature some of the applications will be very for benchmark purposes. ACKNOWLEDGEMENTS: This work was supported by FCT, Fundação para a Ciência e Tecnologia, through IDMEC, under LAETA, project UIDB/50022/2020.

Influence of skewness on the dynamic response of graphene reinforced FG-porous sandwich plates resting on elastic foundation considering blast impact

abst. 1325
Virtual Room 2
Thursday
July 21
16h30

Shakir, Mohammed (d18050@students.iitmandi.ac.in), Indian Institute of Technology Mandi, India
Talha, Mohammad (talha@iitmandi.ac.in), Indian Institute of Technology Mandi, India

The present study demonstrates the influence of skewness on the dynamic response of sandwich plates subject to blast impact. The sandwich plates consist of graphene reinforced functionally graded porous core embedded between two metallic facets which is resting on Winkler–Pasternak elastic foundation. The core of metal matrix has been reinforced with graphene nano-platelets (GNPs) and the microstructural gradation has been accomplished along the thickness direction while creating pores. The symmetric, asymmetric, and uniform distributions of porosity have been achieved throughout the volume of the core by employing certain functions. The effective elastic modulus has been obtained using the Halpin -Tsai model whereas the rule of mixture has been adopted to attain mass density and Poisson's ratio. Governing equations based on a C0 – continuous higher-order shear deformation theory (HSDT) have been derived using variational approach. The numerical results in terms of center displacement have been obtained using finite element method in conjunction with Newmark's integration technique. The present study explores the influence of various parameters such as porosity coefficient, weight fraction of GNPs, and skewness etc. on the centre displacement of the sandwich plates.

Influence of material uncertainty on free vibration characteristics of cracked functionally graded plates with microstructural defects

abst. 1359
Virtual Room 2
Thursday
July 21
16h50

Raza, Ahmed (razaiitmandi@gmail.com), Indian Institute of Technology Mandi, Himachal Pradesh-175075, India
Pathak, Himanshu (himanshu@iitmandi.ac.in), Indian Institute of Technology Mandi, Himachal Pradesh-175075, India
Talha, Mohammad (talha@iitmandi.ac.in), Indian Institute of Technology Mandi, Himachal Pradesh-175075, India

The present work uses the stochastic extended finite element method to investigate the influence of material uncertainty on vibration characteristics of the cracked functionally graded plates with microstructural defects. A higher-order shear deformation theory (HSDT) is incorporated for the plate kinematics. The crack information in the functionally graded plate domain is collected by employing the

level set method. The primary variable is enriched with additional functions by employing the partition of unity technique to address the crack in the functionally graded plate domain. The gradation of material properties across the thickness is done using power law. The porosity index determines the porosity distribution in the FGM plate. Stochastic analysis is done using the first-order perturbation technique (FOPT) to study the influence of material uncertainty on the free vibration analysis of functionally graded plates with initial crack. The convergence and comparative study have been presented to check the current formulation's efficacy, accuracy, and reliability. The effects of different influential parameters like material uncertainty, porosity, crack, volume fraction with various boundary conditions on the vibration characteristics have been discussed in detail. The inclusion of these influential parameters in the analysis can anticipate the actual response of the structure in a real-world application, which can provide a reference for future research by researchers.

Computer vision-based deformation analysis of tunnel structure

abst. 1029
Repository

Xu Xiangyang (x.y.xu@suda.edu.cn), Soochow university, China
Hao Yang (190648049@qq.com), Nantong University, China

Nowadays, with the development of demand for construction, the use of composite structures in architectures become more and more popularity. The deformation analysis of the tunnel is crucial for structural safety evaluation. This paper proposed a novel approach for structural deformation monitoring based on computer vision method that has advantages such as, noncontact, time-efficiency, long-distance, and so on. In this investigation, a long-term 3-D deformations of the tunnel structure including vertical settlement and horizontal deformation in two directions during the shield tunneling construction were obtained. The results indicate that the proposed computer vision-based method provides an efficient and cost-effective approach to monitor the 3-D deformation of the tunnel structure and further for structural safety evaluation.

In-situ detection of aging effects in hybrid specimens using resonant inspection techniques - Part III: Separation, identification and quantification of superposing changes in multi-material structures

abst. 1255
Virtual Room 1
Tuesday
July 19
17h10

Gundlach, Christian (c.gundlach@tu-braunschweig.de), TU Braunschweig - Institute of Joining and Welding, Germany
Karch, Jens (j.karch@tu-braunschweig.de), TU Braunschweig - Institute of Joining and Welding, Germany
Hopmann, Chris (chris.hopmann@web.de), TU Braunschweig - Institute of Joining and Welding, Germany
Dilger, Klaus (k.dilger@tu-braunschweig.de), TU Braunschweig - Institute of Joining and Welding, Germany
Hartwig, Sven (s.hartwig@tu-braunschweig.de), TU Braunschweig - Institute of Joining and Welding, Germany

Aging tests under cyclic temperature load are an important mean to evaluate the lifetime of multi-material parts as additional mechanical loads appear 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 (in this case especially metal and potting material) under temperature load was introduced and validated experimentally. Furthermore, a non-destructive Structural Health Monitoring setup for continuously obtaining the specimens' frequency spectra by using the Electromechanical Impedance (EMI) method showed promising results to achieve a deeper understanding of the structure's ageing behavior during the experiment. Nevertheless, the high sensitivity turned out to be challenging as variations in the spectra could be due to numerous specimen-related changes superposing each other. To unveil their individual influence on the spectra a bottom-up approach was introduced, in which three important changes of the specimen's polymer part namely curing, initiation and growth of cracks as well as the appearance of stresses were studied separately on simplified, mono-material test pieces. The results indicated that any of these changes could be correlated with changes in the spectra of the test pieces showing well-distinguishable patterns. Going ahead with the bottom-up approach, the aim of this work is to focus again on the practical use case of the measurement setup, where overlapping changes in the multi-material structures have to be separated, identified and quantified. The influence on the frequency spectra of both, the interaction of the changes studied before and new changes with regard to multi-material structures will be studied. Following the workflow from our previous work, the frequency spectra of simplified test pieces are obtained, which combine different changes at the same time. In the next step, the hypotheses created in this way are validated performing resonant measurements of prepared hybrid specimens in various ambient conditions. Concurrently, the 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 all steps. Finally, the models derived from the previous steps are tested on other more complex multi-material structures to evaluate their performance and general applicability.

Impact Problems

Numerical evaluation of compression after impact in second generation of fibre metal laminates

abst. 1098
Room B032
Thursday
July 21
11h30

Podolak, Piotr (p.podolak@pollub.pl), Department of Materials Engineering, Faculty of Mechanical Engineering, Lublin University of Technology, Poland
Jakubczak, Patryk (p.jakubczak@pollub.pl), Department of Materials Engineering, Faculty of Mechanical Engineering, Lublin University of Technology, Poland

The unexpected collisions with the composite structures may significantly reduce their load carrying ability. The decrease of load capacity is highly visible in the terms of compression, where even the 60% of initial compressive strength of fibre reinforced polymers (FRPs) may be lost due to low velocity impact (LVI). In the fibre metal laminates (FMLs), the addition of metal layers allows for absorbing the energy not only by the elastic strain, but the plastic strain likewise. Thus, the presence of metal in this kind of hybrid structure makes the prediction of structure post-impact behaviour a significant challenge. Another major factor determining the damage tolerance of the FMLs is the quality of metal-composite interface, which is highly correlated with the delamination resistance. The issue of FML behaviour while compression after impact (CAI) is focused not only on experimental procedure, but also on proposing the reliable finite element analysis (FEA) able to simulate the carried-out test with high accuracy and reasonable computation effort. The above mentioned accuracy requires not only the high-fidelity prediction of post-impact compressive strength. The focus on damage initiation and propagation prognosis is desired likewise. The main objective of the authors was to build the numerical model of CAI test for second generation of FMLs. The simulation was conducted for the titanium-based hybrid laminates impacted by 5 J, 10 J, 20 J and 35 J of energy. The boundary conditions of CAI test were designed in the way enforcing the buckling appearance in the impact area. Such an approach allowed to determine the influence of impact energy on further damage propagation while compressing the FML. The FEA was carried out in the ABAQUS/Explicit software due to expected non-linear effects. The behaviour of metal layers was predicted with the use of the ductile damage model. The simulation of the fibrous layers damage was performed by the Hashin-3D VUMAT subroutine. The cohesive zone model (CZM) based on volumetric elements COH3D8 was implemented for analysing the interlaminar behaviour. The created FEA model confirmed the tendency found while analysing the experimental data. The specimen displacement in performed simulation mostly covered with the displacement registered while experiment. Also, the prediction accuracy of the studied criteria of damage tolerance was acceptable. The delamination growth while compression, lateral fibre fracture and localization of excessive plastic strain of metal in the moment of critical failure were simulated properly.

The numerical analysis of titanium-carbon laminates impact behaviour using ductile damage model and Johnson-Cook damage model

abst. 1109
Room B032
Thursday
July 21
11h50

Droździel-Jurkiewicz, Magda (m.drozdziel@pollub.pl), Department of Materials Engineering, Faculty of Mechanical Engineering, Lublin University of Technology, Poland, Poland
Podolak, Piotr (p.podolak@pollub.pl), Department of Materials Engineering, Faculty of Mechanical Engineering, Lublin University of Technology, Poland, Poland
Jakubczak, Patryk (p.jakubczak@pollub.pl), Department of Materials Engineering, Faculty of Mechanical Engineering, Lublin University of Technology, Poland

One of the most important properties of composite materials, which are widely used in the aerospace industry, is their impact resistance. Hybrid fibre metal-laminates based on titanium and its alloys are characterized by high impact resistance and the interest in their usage is constantly growing. Both experimental and numerical studies are carried out to determine their impact resistance. Nevertheless, none of the studies take into account the influence of the used metal constitutive model, while titanium plays a significant role in energy absorption. The ductile damage model and Johnson-Cook damage model were used during the FEA examination to determine the effect of the used metal constitutive

model. A multi-aspect analysis of the impact resistance of titanium-carbon laminates was carried out, comparing the results of numerical tests with the experimental investigation. Moreover, the comparison showed that with the use of both models it is possible to prediction of impact behavior with acceptable accuracy in relation to the data revealed in experimental studies. It was noticed that when simulating the impact resistance of titanium-carbon laminates at low energies of 2.5 and 5 J, the ductile damage model was more effective, resulting in the lower mismatch, taking into consideration parameters like maximum force, total displacement, and final displacement or df/dt coefficient. Nevertheless, it changes at the energies 15 J, 20 J, and 30 J, when the effectiveness of the Johnson-Cook damage model increases with increasing impact energy for the aforementioned parameters. The highest convergence of damage area was observed for ductile damage model, and the mismatch did not exceed 12%. Taking into consideration computation time cost, it was noted that both models are comparable. However, in the case of computation efficiency, there were some important differences. It was noted that for ductile damage model considering the case of 2.5 J the efficiency was equal to 2900 s/%, while for Johnson-Cook damage model it was 570 s/%. Considering the most accurate prediction at the energy 15 J for Johnson-Cook damage model the efficiency was 3680 s/% contrary to ductile damage model with an efficiency 1520 s/%. It was noted that for energies above 15 J the efficiency of the ductile damage model was at a constant level, although lower than for the second model.

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abst. 1186
Room B032
Thursday
July 21
12h10

An experimental and numerical study on the local and structural influence of the skin fiber pattern on the behavior of sandwich composite plates with foam core under low-velocity impact loadings

Merle, Maxime (maxime.merle@ensma.fr), Département Physique et Mécanique des Matériaux, Institut Pprime CNRS, ISAE ENSMA, Université de Poitiers, Poitiers, France, France
Gigliotti, Marco (marco.gigliotti@ensma.fr), Département Physique et Mécanique des Matériaux, Institut Pprime CNRS, ISAE ENSMA, Université de Poitiers, Poitiers, France, France
Grandidier, Jean Claude (jean-claude.grandidier@ensma.fr), Département Physique et Mécanique des Matériaux, Institut Pprime CNRS, ISAE ENSMA, Université de Poitiers, Poitiers, France, France
Dupré, Jean Christophe (jean.christophe.dupre@univ-poitiers.fr), Département Génie Mécanique et Systèmes Complexes, Institut Pprime CNRS, ISAE ENSMA, Université de Poitiers, Poitiers, France, France
Egea, William (william.egea@rescoll.fr), Rescoll - Société de Recherche, ZA de Beligon, Rochefort, France, France

This work is part of a project about the Head Injury Criterion that measures the probability of head injuries. This research highlights the influence of the skin fiber pattern on sandwich composite behavior during low-velocity impact loadings. The knowledge of such behavior under these test conditions might allow more specific understanding and modeling of the sources of dissipation. Numerical models with damages are usually built inside continuum mechanics framework and estimate the anisotropy with complex damage models. It must describe the mesoscale through characteristic lengths to ensure mesh independence [1]. However, local information is vanished due to homogenized properties [2]. In recent studies, a discrete approach was implemented, made of a combination of truss and shell finite elements [3], to allow for the local effects of skin architectures. In a similar framework, estimating the compressive strength of composites also requires such an approach by integrating the flexural stiffness of the fibers [4]. The present work focuses on modeling sandwich composite panels composed of a thermoplastic styrene-acrylonitrile foam suited for impact loadings. Skins are in carbon fibers inside an epoxy matrix. Panel dimensions are 362 x 127 x 10 mm3. Samples were created by stacking fiber sequences with a robotic arm and by water jet cutting. These skins are halfway between the notion of laminate and woven composites. The architecture is a superposition of three 0 and 90-degree orientation plies characterized by continuous (in one direction) or sequenced (in the other direction) fiber deposits. There are various skin stacking sequences that should produce identical mechanical behavior under tensile tests or homogenized property determinations. The aims are to capture and model expected differences in skin architecture behavior. A discrete model composed of truss or beam and shell elements to model the fibers and the matrix respectively was implemented in Abaqus software. The impact tests are conducted with a drop weight testing machine on clamped samples. The impactor is a 52.5 mm diameter with a 50 mm radius of curvature hemispherical surface with a weight of 13.3 kg. Impact energies are around 30 J. The testing machine sensors measure the impactor force and displacement. A manual 1 mm diameter speckle pattern is applied on the 127 x 127 mm2 lower surface of samples. A 45-degree mirror is used to perform digital image correlation. Two ultra-high-speed cameras are pointing to the speckled surface. The vertical displacement of the sample is captured by a third camera. Acoustic emission sensors are positioned on the upper surface to locate specific events during the impact. The experimental setup enables the creation of the entire 3D displacement and strain fields. Differences in limit loadings to failure are observed. Further tests have to be conducted although experimental results linked to numerical simulations allow distinguishing multiple mechanical responses between the various architectures that have equal stiffness in the two plane principal directions. Pprime Institute gratefully acknowledges "Contrat de Plan Etat - Région Nouvelle-Aquitaine" as well as the "Fonds Européen de Développement Régional" for their financial support to the reported work, part of the FEDER HIC project (convention number BI 787231 /UP 2019-R-090 / LSP : 195194), in collaboration with Rescoll. References: [1] Oliver J. (1989), A consistent characteristic length for smeared cracking models, Int. J. Numer. Methods Eng., 28, 461-474. [2] Bažant Z.P. (1983), Crack band theory for fracture of concrete, Mat. and Struct., 16, 155–177. [3] Pascal F. (2018), Impact damage prediction in thin woven composite laminates Part I: Modeling strategy and validation, Compos. Struct., 190, 32-42. [4] Bettadahalli A. (2020), Non-local modeling of the compressive strength of composite structures, Doctoral dissertation, ISAE-ENSMA, Poitiers. ***[Maxime Merle is one of the Winner of the Ian Marshall Award for Best Student Paper]***

A global-local approach to the high-fidelity impact analysis of composite structures based on node-dependent kinematics

abst. 1198
Virtual Room 1
Tuesday
July 19
17h30

Nagaraj, Manish H. (manish_nagaraj@uml.edu), University of Massachusetts Lowell, USA
Carrera, Erasmo (erasmo.carrera@polito.it), Politecnico di Torino, Italy
Petrolo, Marco (marco.petrolo@polito.it), Politecnico di Torino, Italy

Fibre-reinforced composites are prone to damage under the application of transverse loads, as in the case of impact, leading to a significant reduction in the load carrying capability of the structure. The high-fidelity numerical modelling of such a class of problem is challenging and computationally very expensive, which presents a bottleneck to the full exploitation of virtual testing methodologies in composites design and analysis. The current work aims to reduce the computational costs associated with impact analysis by developing numerical models based on the Carrera Unified Formulation (CUF), which is a generalized framework to derive higher-order structural theories. In such an approach, 1D and 2D finite elements are enhanced using additional kinematic terms known as expansion functions, resulting in full 3D displacement and stress fields. This leads to an accuracy approaching that of 3D-FEA, but at significantly reduced computational costs [1]. An explicit time integration framework is developed which uses CUF-based higher-order layer-wise theories, and composite damage is simulated using the continuum damage mechanics-based CODAM2 material model. This leads to a higher-order numerical platform capable of high-fidelity impact analysis in a computationally efficient manner [2]. The present work extends previous developments by employing the Node-Dependent Kinematics (NDK) technique, wherein different nodes of the same finite element can be assigned kinematic expansion functions of different type and polynomial order. Such an approach is possible due to CUF, and allows for the construction of numerical models where only critical regions within the structure are modelled using higher-order theories, with lower-order theories being used in the remainder of the structure. The use of NDK thus leads to a global-local modelling of the structure, where both regions are evaluated simultaneously within a single model, and further reduces the computational overheads of the analysis. Numerical assessments are performed to validate the capability of the proposed framework in the high-fidelity analysis of composite laminates subjected to impact loads, and to demonstrate the reduction in computational effort that can be achieved via global-local modelling using NDK. REFERENCES: [1] Carrera, E., Cinefra, M., Petrolo, M., Zappino, E. (2014). Finite element analysis of structures through unified formulation. John Wiley Sons. [2] Nagaraj, M. H., Carrera, E., Petrolo, M. (2020). Progressive damage analysis of composite laminates subjected to low-velocity impact using 2D layer-wise structural

models. International Journal of Non-Linear Mechanics, 127, 103591. ***[Manish Nagaraj is one of the Winner of the Ian Marshall Award for Best Student Paper]***

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abst. 1207
Room B032
Thursday
July 21
12h30

Impact Damage Modelling in Composite Structures Including Strain Rate Effects

Ivančević, Darko (divancevic@fsb.hr), University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Croatia
Stanić, Luka (luka.stanic@fsb.hr), University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Croatia

The work deals with the numerical simulation of impact damage in laminated CFRP structures. Impact problems are a special concern in the design of CFRP structures due to the inherent susceptibility of the material to these loading conditions. To improve the accuracy of numerical methods in the simulation of crashworthiness problems and other impact related scenarios, strain rate effects have been implemented in the constitutive behaviour of the composite material. These effects are a consequence of the epoxy matrix behaviour, where the elevated strain rates cause apparent rise in the elasticity modulus and more brittle failure modes. Consequently, a similar effect of elevated strain rates is visible also in the matrix-dominated properties of the composite material. The numerical damage prediction methodology proposed in this work is based on the implementation of the strain rate effects in the constitutive behaviour of the composite material using the user-defined material modelling subroutine VUMAT in Abaqus/Explicit. The developed constitutive model includes the dependence of the composite elasticity tensor and the failure initiation criterion on the strain rate. The elasticity tensor and the failure criteria are modified using logarithmic functions to include the effects caused by elevated strain rates. Various forms of the scaling functions, that are used in the available references for including the strain rate effects on the engineering constants and the strength values, are evaluated in this work. A phenomenological-based failure theory, that predicts failure initiation in the fracture plane is implemented into the methodology. Furthermore, a mesh-objective Continuum Damage Mechanics approach has been used in the model to predict the damage mechanisms of the composite material. The methodology has been validated using available experimentally measured failure curves at quasi-static and dynamic loading rates for the IM7/8552 material. As the methodology is still in development within an ongoing research project, only the matrix failure modes at the low velocity impact conditions are investigated in this research.

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abst. 1254
Repository

Experimental and numerical investigation of the low velocity impact behavior of stochastic tow based discontinuous composite beams

Ryatt, Jeremy (ryatt@uw.edu), University of Washington, United States
Ramulu, Mamidala (ramulum@uw.edu), University of Washington, United States
Pahuja, Rishi (pahujar@uw.edu), University of Washington, United States

The low velocity impact response of stochastic tow-based discontinuous composite beams was investigated. Beams fabricated from sheets of HexMC were impacted in a three-point bending configuration. High speed photography of the impact events captured the initiation and evolution of damage along the edge of the coupons. To understand the different failure mechanisms, mesoscale finite element models of the tests were constructed, using a voxel-based framework to define the stochastic mesostructures. The failure of the chips is modeled using the Hashin damage initiation criteria using the VUMAT subroutine interface in Abaqus/Explicit, while inter-sheet delamination is modeled using cohesive contact. The results from the simulations compare well with the experimental results, demonstrating similar failure characteristics and striker response. Based on the results of the experiments and simulations, a damage initiation threshold of a flexural strain of 0.21% is established for the configuration investigated. Additionally, a design of experiments is performed to investigate the sensitivity of the impact response to material failure and inter-sheet delamination parameters, indicating a sensitivity to the fracture energy of the tensile matrix damage mode.

Damage assessment of sandwich structures with CNT reinforced carbon-epoxy composite face sheets under impact load at elevated temperatures

abst. 1290
Virtual Room 1
Wednesday
July 20
10h00

D, Muniraj (muniraj@sastra.ac.in), SASTRA Deemed to be University, India
VM, Sreehari (sreehari_vm@mech.sastra.edu), SASTRA Deemed to be University, India

The damage evaluation of aluminium honeycomb sandwich structures with carbon nanotube (CNT) reinforced carbon/epoxy composite face sheets under high velocity impact at elevated temperatures was investigated in the present study. CNTs up to 0.8 percentage by weight were introduced into the epoxy matrix in 0.2 percentage intervals to improve impact resistance, and the carbon/epoxy composite was manufactured using a vacuum assisted resin transfer technique. Sandwich structures were prepared and tested under high velocity impact at various temperatures using single stage gas gun. Quasi-static indentation test was conducted to obtain the quantitative measurement of the impact resistance of the sandwich structure. Tensile and flexural tests were conducted as per ASTM D3039 and D7264 respectively, to evaluate the material properties of composites having various weight percentage of CNT. Dynamic mechanical thermal analysis was performed to determine the glass transition temperature based on the storage modulus, loss modulus and phase angle. SEM analysis were carried out and the influence of CNT distribution on the impact resistance were discussed. In order to get more insights on the impact damage mechanism, numerical simulation was carried out using LS-DYNA. Contact force, deflection and energy histories were acquired and specific energy absorption were evaluated. The values obtained from numerical simulation are in good agreement with the experimental measurements. Experimental results shows that the impact resistance of CNT reinforced composite samples are higher than the neat samples.

Low velocity impact response of inter-ply S2-glass and aramid woven composites: A numerical study

abst. 1296
Virtual Room 1
Wednesday
July 20
10h20

Rezasefat, M (Mohammad.rezasefat@polimi.it), Politecnico di Milano, Italy
Silva, AAX da (amanda.albertin@ufrgs.br), PPGE3M. Federal University of Rio Grande do Sul, Brazil
Amico, C (amico@ufrgs.br), PPGE3M. Federal University of Rio Grande do Sul, Brazil
Giglio, M (marco.giglio@polimi.it), Politecnico di Milano, Italy
Manes, A (andrea.manes@polimi.it), Politecnico di Milano, Italy

In the recent years there has been much attention to hybrid composites in both research and industry due to the lower weight, lower cost, and better mechanical and impact properties. This paper presents a numerical investigation on the low velocity impact response of the aramid/S2-glass/epoxy hybrid laminates. Plain-weave Kevlar®29 fabrics from Dupont and Hexcel® 8 harness satin S2-glass fabrics with Epoxy resin AR260 with AH260 hardener were used to manufacture eight different monolithic and hybrid laminate configurations of different hybridizations and stacking sequences. The composite laminates of this study include two monolithic configurations made of only aramid fabrics (8 layers, [K]4S), one with only S2-glass fabrics (16 layers, [G]8S) and six interply hybrids stacking of [G10K3], [G8K4], [G6K5], [G2K]S2, [G4K2]S and [K2G4]S in which K stands for Kevlar®29 fabrics and G for S2-glass fabrics. Drop weight tests were performed at three different impact energies of 18, 36 and 72 J to characterize the impact response of laminates at different energy ranges. A novel numerical FE model was developed which considered the non-linear material constitutive behaviour and different interlaminar and intralaminar failure modes. The non-linear material behaviour in normal directions is considered by definition of instantaneous stiffnesses by using third-degree polynomials which are shown to be accurate in predicting the accumulated inelastic strains and impact dent. The results showed that the hybridization may have a meaningful effect on the impact response of the laminate which led to lower impact peak displacement and peak force while increasing the energy absorption capacity of the panels.

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abst. 1309
Room B032
Thursday
July 21
13h10

MODELING AND SCALING LAWS FOR LOW VELOCITY IMPACTS OF COMPOSITE PLATES

Di Mauro, Gennaro (gennaro.dimauro@unina.it), University of Naples Federico II – Department of Industrial Engineering, Italy
Russo, Pietro (pietro.russo@ipcb.cnr.it), Institute for Polymers, Composites and Biomaterials, National Research Council, Italy
Guida, Michele (michele.guida@unina.it), University of Naples Federico II – Department of Industrial Engineering, Italy

The development of the laws that regulate a similarity passes from the certain knowledge of the structural parameters, so that it is possible to build a scaled model that can replicate the response of the "full-scale" system. The similarity theory has found wide use in fluid mechanics thanks for example to the dimensionless Reynolds or Froude numbers. In this case, the similarity laws between model and prototype are well known and the results achieved are particularly valid. The study, on the other hand, of the behavior of a structure subjected to the action of a load impact (dynamics of structures) through the similarity method is a relatively recent activity. In this paper the aim is to apply the theory of scaling to composite materials widely used in the field aerospace and subjected to low-speed impact loads. This work describes the experimental activities about samples with different dimensions tested with a drop weight machine using different impact energy values so to characterize the behavior in and out elastic zone. The idea is to identify a common factor so to show the impact behavior and the evolution of the damage suffered by the specimen examined evaluating the importance of the geometrical scaling on the output results. Results are also discussed in terms of strain rate sensitivity of the specimens in relation of the dissipative interlaminar phenomena and a more marked influence of the dimension on the laminates is investigated. Drop tests results are then compared to numerical ones, obtained by simulating a hemispherical dart impacting a thin composite laminate. Thus, a finite element analysis (FEA) is performed using the explicit finite element code LS-DYNA. Attention is specifically devoted to composite laminate samples, consisting of polyamide 6 and polyamide 11, both reinforced with basalt fiber fabric, and polypropylene reinforced with a flax fabric, having the same layup but with different scaled dimensions to identify the scaling law for the time histories of the impact load. Low speed impact tests are performed with a drop tower equipped with a movable frame that allows measurements with different falling heights. A supporting plate is used to fix the laminate on the ground and a MEMS accelerometer (X16-1D) is placed on the specimen, recording the local acceleration. Moreover, a sensorized hemispherical dart is used to capture the load time history into the impacting zone. The dimensions and geometric specifications of all the equipment is compliant with ASTM D7136 standard.

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abst. 1332
Room B032
Thursday
July 21
12h50

Investigating the effect of impactor shape and hardness on the low velocity impact performance of carbon fibre reinforced polymer panels for aerostructures

Hall, Zoe (zoe.hall15@imperial.ac.uk), Imperial College London, United Kingdom
Liu, Jun (j.liu16@imperial.ac.uk), Imperial College London, United Kingdom
Brooks, Richard (richard.brooks16@imperial.ac.uk), Imperial College London, United Kingdom
Ding, Yuzhe (yuzhe.ding17@imperial.ac.uk), Imperial College London, United Kingdom
Liu, Haibao (haibao.liu@imperial.ac.uk), Imperial College London, United Kingdom
Kinloch, Anthony (a.kinloch@imperial.ac.uk), Imperial College London, United Kingdom
Dear, John (j.dear@imperial.ac.uk), Imperial College London, United Kingdom

Historically, metals, such as aluminium and steel, made up the majority of aerostructures due to their good strength to weight ratios and ease to be machined. However, in the last few decades, the use of composites has become more prominent, with modern commercial aircraft increasing the percentage of composite components. This adjustment in materials can be seen when comparing the Boeing 777 and 787, with the former comprising of 50% aluminium and 12% composite materials but the more modern Dreamliner flipping these values to give 50% composites and only 12% aluminium [1]. These changes have happened due to the advantageous features of composites such as the ability to

alter their properties according to purpose. To allow composite materials to be used in aerostructures, rigorous testing is required, including under impact loading conditions. Aircraft are subjected to a large number of impact scenarios during use from tool drop – an example of a hard, low velocity impact – to bird strikes – an example of a soft, high velocity impact – meaning that the performance under a variety of impact conditions of materials to be used in aircraft must be examined. In this research, low velocity impacts of carbon fibre reinforced polymer (CFRP) panels were the focus, with flat-ended, round-nosed and rubber-ended impactors being utilised to compare the shape and hardness of each and how this influenced the damage mechanisms observed after impact. 1, 1.5 and 2 mm thick disks of rubber were adhered to flat-ended impactors to produce the rubber-ended impactors. Three different impact energy levels were used, 7.5, 15 and 30 J, with no damage initiating at the two lower energies when using a flat-ended impactor. However, when a higher energy was used, the damage area from a flat-ended impactor was larger than that of a round-nosed impactor, even when using the rubber-ended impactors, and the maximum load was ca 4 kN higher for the flat-ended impactor and ca 2 kN higher for the rubber-ended impactors. These results show that the impactor shape and hardness affect the impact performance of the CFRP, with a larger energy value being required for damage to occur with a flat-ended impactor but adhering rubber aiding in reducing the maximum load due to softening the impact. References: [1] – Bob Griffiths. (2005) Boeing sets pace for composites usage in large civil aircraft. https://www.compositesworld.com/articles/boeing-sets-pace-for-composite-usage-in-large-civil-aircraft [Accessed 18th January 2022].

Joints

abst. 1069
Repository

The mode-II and mix mode-I/II fracture behaviour of hybrid joints obtained by co-curing epoxy composite on to PEEK and PPS composites

QUAN DONG (quandong@sdu.edu.cn), Shandong University, China
Zhao Guoqun (zhaogq@sdu.edu.cn), Shandong University, China
Rene ´ Alderliesten (R.C.Alderliestn@tudelft.nl), Delft University of Technology, Netherlands

The application of carbon fibre reinforced Poly-etherether-ketone (PEEK) and Polyphenylene- sulfide (PPS) composites in aerospace industry has extensively expanded over the last decade, with a more rapid growth being foreseen. Accordingly, it is desperate to develop effective joining method to produce high-performance joints between PEEK and PPS composites and other dissimilar materials, such as carbon fibre reinforced epoxies. Herein, the surfaces of PEEK and PPS composites were rapidly treated by a high-power UV-irradiation technique, that proved to significantly improve their intrinsically low surface activities. Carbon fibre reinforced epoxy composites were then directly co-cured onto the PEEK and PPS composites with or without an aerospace film adhesive in between. The mode-II and mix mode-I/II fracture behaviour of the hybrid joints were investigated, and the fracture mechanisms were also studied. The failure of the hybrid joints without adhesives mainly took place at the epoxy/PEEK and PPS interfaces, owing to the lack of resins at the fracture plane. That resulted in relatively low fracture energies. Encouragingly, a cohesive failure was observed for the hybrid joints with adhesives in all the cases, owing to the enhanced adhesion between theadhesive and the PEEK and PPS composites by the UV-treatment. This phenomenon typically indicated a best fracture performance of the hybrid adhesive joints for the given material combinations, and resulted in high mode-II and mix mode-I/II fracture energies.

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abst. 1140
Virtual Room 1
Thursday
July 21
15h30

Effect of nanostructures fabricated on aluminum alloy on mode [U+2160] fracture toughness in dissimilar joints of carbon fiber reinforced thermoplastics and aluminum alloy

Shima Momoka (mo2ka_4ma@moegi.waseda.jp), Department of Applied Mechanics and Aerospace Engineering, Waseda University, Japan
Harada Kazuki (kazuki100302@ruri.waseda.jp), Department of Applied Mechanics and Aerospace Engineering, Waseda University, Japan
Saito Kei (fj63-tyo65611pcr@fuji.waseda.jp), Department of Applied Mechanics and Aerospace Engineering, Waseda University, Japan
Hosoi Atsushi (hosoi@waseda.jp), [U+30FB]Department of Applied Mechanics and Aerospace Engineering, Waseda University [U+30FB]Department of Materials Science, Waseda University [U+30FB]Kagami Memorial Research Institute for Materials Science and Technology, Japan
Kawada Hiroyuki (kawada@waseda.jp), [U+30FB]Department of Applied Mechanics and Aerospace Engineering, Waseda University [U+30FB]Department of Materials Science, Waseda University [U+30FB]Kagami Memorial Research Institute for Materials Science and Technology, Japan

In recent years, carbon fiber reinforced thermoplastics (thermoplastic CFRP), which have excellent specific strength and rigidity, are increasingly replaced with steels, which are widely used for vehicles, in order to reduce weight and improve the vehicles' performance. Then, the development of joining methods for multi-material structures is required. Currently, adhesive bonding and mechanical joining method are mainly used for joining dissimilar materials. However, they have some weak points such as long curing time, stress concentrations and weight increase. Therefore, an excellent direct joining method, which has great strength and toughness by fabricating nanostructures on the aluminum alloy surface and applying a silane coupling treatment, was developed. In order to apply this method for transportation equipment, it is essential to evaluate the interlaminar crack growth characteristics quantitively by obtaining the interlaminar fracture toughness. However, there is a problem that it is impossible to assess it accurately because of residual thermal stress which is caused by differences in the linear expansion coefficient of the adherends. Thus, in this study the influence of residual thermal stress

was removed, and the effect of interfacial nanostructures on the interlaminar mode [U+2160] fracture toughness for directly bonded aluminum and thermoplastic CFRP was determined. An aluminum alloy A5052 and thermoplastic CFRP with polyamide 6 (PA6) matrix resin were used. The dimensions of the adherends were determined to satisfy the condition E1h12=E2h22(E: Young's modulus, h: height). Thereby, mixed mode deformation caused by the difference in bending rigidity was prevented. Two kinds of specimens were prepared. One was subjected to both anodizing and etching processes and a silane coupling treatment, which is called Si-NS (Silane coupling treatment- Nanostructured specimen). The other was only subjected to a silane coupling process, which is called Si-AR (Si- As-rolled specimen). Firstly, nanostructures were manufactured on the aluminum alloy surface by anodizing and etching processes. These treatments were conducted three times for fabricating multi-tiered structures. Then, a silane coupling treatment was applied to improve the adhesive strength by providing an interfacial chemical bond between the PA6 resin and the aluminum alloy. Afterwards, the specimen was heat-welded with a hot press machine. In order to introduce a pre-crack, a release film was inserted at the end of the specimen. The dimensions of the specimens conformed with Japanese industrial standard (JIS) K 7086 standard. Then, mode [U+2160] fracture toughness was measured from Constant Load Double Cantilever Beam test (CL-DCB test), which cancels mode [U+2161] deformation due to residual thermal stress by applying a constant load during the DCB test, which is a testing method for interlaminar fracture toughness of carbon fiber reinforced plastics based on JIS standard. As a result of the CL-DCB test, the mode [U+2160] fracture toughness of Si-NS was 7.8 times higher than that of Si-AR. So, it would be concluded that manufacturing interfacial nanostructures improves mode [U+2160] fracture toughness. In addition to this, large plastic deformation of aluminum alloy base materials of Si-NS specimen may have an effect on the overestimation of mode [U+2160] fracture toughness of Si-NS. After the CL-DCB test, the fracture surface was observed using scanning electron microscopy (SEM) to investigate the difference in the damage mechanism resulting from the interfacial nanostructure. It is found that the crack propagated inside the matrix resin. The fracture surface of Si-AR was relatively smooth. On the other hand, the ductile fracture surface was observed in Si-NS specimens. So, it can be inferred that the nanostructure induced the plastic deformation of the matrix resin, and the energy was released through the plastic deformation. Therefore, the interfacial nanostructure improved the mode [U+2160] fracture toughness.

Processes and device arrangements for making shape memory fiber reinforced debondable adhesives

abst. 1159
Repository

Moktadir, Monem (mechmma25@gmail.com), Andong National University, Republic of Korea
Hwang, Hui Yun (hyhwang@anu.ac.kr), Andong National University, Republic of Korea

The recycling of adhesively-bonded metal-composite hybrid structures without compromising their reusability is a compelling issue. Currently, various kinds of mechanical, thermal, or chemical separation processes had been tried, but they don't provide satisfactory results. To ensure easy debonding during recycling without damaging the structures, we require two contradictory properties together in an adhesive. They are high adhesion strength and low separation forces. To solve this problem we have come up with the unique idea of debondable adhesive. In this work, the processes and the device arrangements to make such adhesives have been discussed. The addition of functional additives like microcapsules or polymer additives in the adhesives provide easy debondability but less adhesion strength. To solve this issue we can use a shape memory alloy instead of functional additives. Nitinol (Ni-Ti), which is a shape memory alloy, can be embedded in fibrous shape in the adhesive layers. Contrary to the functional additives, the inclusion of nitinol fibers in the adhesive layers renders very little effect on the adhesion strength of the joint; but during recycling its' shape memory effect can be pretty useful. To make this, the nitinol fibers need to be pre-strained and then embedded in the adhesives. For recycling, we just have to increase the temperature of the joints to nitinol's austenite finish temperature (Af). It will induce shape recovery of the nitinol fibers thus fracturing adhesive layers and the interfaces consequently easy debonding. In this work, we have considered a single lap cleavage peel joint. The length, width, and thickness of the substrates are 150mm, 25mm, and 3mm. Bondline length is 25mm. The diameter of the fibers is 0.025mm. Considering 5% of nitinol fiber volume fraction and 0.2mm epoxy adhesive layer, we need to embed 20 fibers/mm. So, in total 500 fibers have to be embedded in a 25mm adhesive bondline. We have to embed 500 nitinol fibers in the epoxy adhesive maintaining a 0.1mm distance between each fiber's center axis. This job is the most challenging one as these fibers are very thin; handling them is very difficult let alone embedding them in an equal-distanced manner. To achieve this equal-distanced manner embedment, we have considered many ways. We started with the idea of using mini pins but we abandoned this plan soon as these pins will not be able to tolerate the stress generated during the process. Then we checked the possibility of using perforated plates where we will have holes with 0.03mm dia. and the distance between two hole centers will be 0.1mm. It will have 500 holes to support 500 fibers, but we have abandoned this technique also. Fabricating a fiber embedment device using perforated plates would be much more difficult and costly. Then we designed a fiber embedment device using 30mm high 0.03mm thick and 32mm high 0.07mm thick feeler gauges. Here, fibers will be placed on the 0.03mm feeler gauges and the 0.07mm ones will restrict the movement of the fibers. It has 250 sets of 0.03mm feeler gauges to support 500 fibers in two layers. We have fabricated this device and after using it we got some moderate success. Besides, we have also designed a filament winding process to embed the fibers. We designed to convert a mini CNC machine into a dry filament winding machine. Here, the fiber spool will move in linear motion, and from the spool the fiber will be wound on the mandrel. The key components of this device are stepper motors, controller, power supply, and motor driver. By changing the motion speed we can even control the percentage of embedded fibers. This process will be easier and much more accurate than the other techniques mentioned above. Out of all these devices, the feeler gauge device produces some successful embedment possibilities, but the designed filament winding process shows the biggest potential. So, in this work, we have forwarded with filament winding process.

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abst. 1232
Room B035
Thursday
July 21
11h50

Enhancing the quasi-static strength of co-cured bonded laminate joints via multiscale toughening

Inal, Oguzcan (oguzcan.inal@manchester.ac.uk), The University of Manchester, United Kingdom
Potluri, Prasad (prasad.potluri@manchester.ac.uk), The University of Manchester, United Kingdom
Soutis, Constantinos (constantinos.soutis@manchester.ac.uk), The University of Manchester, United Kingdom
Katnam, Kali-Babu (kali-babu.katnam@manchester.ac.uk), The University of Manchester, United Kingdom

Composite laminate structures are widely used in load-carrying applications in various industries (e.g. aerospace and automotive) due to their lightweight and superior material properties (e.g. high specific stiffness and strength). Structural joining of load-carrying laminate components is of utmost importance as joints play a critical role in transferring loads between structural parts. In this perspective, the co-curing strategy (i.e. curing and bonding of the parts together in the same manufacturing step) can reduce manufacturing effort, cost and time. Furthermore, carefully incorporating different material combinations with co-curing can improve structural integrity. This study evaluates co-cured NCF/epoxy joints with different toughener combinations. An interlaminar toughener (polyphenylene sulfide (PPS) non-woven microfibre veil), a resin toughener (core-shell rubber (CSR) particles) and the multiscale toughening (the combination of both tougheners) are applied and compared against the baseline (untoughened) material system. Firstly, the fracture properties of the selected tougheners are measured in mode-I and mode-II fracture conditions. The largest improvement in mode-I fracture toughness is obtained with multiscale toughening (i.e. 141% and 190 in GI,C and GI,R, respectively), while thermoplastic veil interleaving-alone is outperformed both core-shell rubber particle toughening and the multiscale-toughening in mode-II fracture (i.e. 84% and 129% in GII,C and GII,R, respectively). Then, these tougheners are applied to co-cured joints of the same NCF/epoxy material system. The load-carrying capability of differently toughened co-cured joints is measured. In addition, co-cured joint specimens are instrumented with back-face strain gauges, and the full field strain/displacement measurements are carried out with a 3D-digital image correlation (DIC) system. 3D-DIC is validated against the back-face strain gauges. A good correlation is achieved. The results showed that the co-cured joint strength could be improved up to 50% with multiscale toughening. Surface strains obtained with 3D-DIC indicated that the toughened joints can arrest sub-critical damage and delay the final failure at the bondline. Similarly, the strain gauge measurements showed that the back-face strain at

failure could be significantly improved. To sum up, this study shows that an enhanced toughening in mode-I and mode-II fracture toughness could be transferred to co-cured joint strength, leading to enhanced structural integrity. Furthermore, a balance between the interlaminar fracture toughness and co-cured joint strength can be obtained by the selective use of different toughening routes.

Particle-based micromechanical modelling of adhesive joint considering microscale surface roughness

abst. 1299
Virtual Room 1
Thursday
July 21
15h50

Wang, Xinger (x.wang96@lancaster.ac.uk), Lancaster University, United Kingdom
Hou, Xiaonan (x.hou2@lancaster.ac.uk), Lancaster University, United Kingdom
Ye, Jianqiao (j.ye2@lancaster.ac.uk), Lancaster University, United Kingdom
Pang, Kai (k.pang3@lancaster.ac.uk), Lancaster University, United Kingdom
Yang, Jian (j.yang.1@sjtu.edu.cn), Shanghai Jiao Tong University, China

Microstructures of constituents and interfaces yield significant influences on the failure mechanism of adhesive joints. However, limited reports can be found concerning the micromechanical behaviours in numerical models of these joints. This work developed a refined particle-based model introducing the microscale features such as surface roughness, micro-pattern and depth of resin infiltration. Aluminium adherends with mechanical surface treatments were firstly scanned using 3D laser scanning microscope. The interfacial microstructures were then simplified into a regular pattern of triangular or trigonometric function with rational roughness thresholds based on the scanning results. Single lap shear tests using joints made of epoxy adhesive (Loctite EA 9497) and none-treated aluminium adherends were performed to provide standard testing data, which was used to calibrate the microscale parameters of particle bonds to suit the bulk and interlaminar-like properties of the adhesive. The refined numerical models were subsequently developed to examine the influences of the concerned microstructural features on the joint performance and the failure mechanism. The associated effects as well as those by adhesive thickness on the fracture energies were also discussed. The results indicate that, with decreasing the adhesive thickness, the differences of fracture strength amongst various roughness see a decline. The fracture energy increment by higher surface roughness decreases when the adhesive thickness rises. It is also found that a stronger adhesive can further magnify the improvement of joint ability from increasing the surface roughness.

Modal analysis of adhesive joints using a radial point interpolation method

abst. 1301
Virtual Room 1
Thursday
July 21
16h10

Ramalho, LDC (lramalho@inegi.up.pt), INEGI, Portugal
Sánchez-Arce, IJ (isidrodjsa@gmail.com), INEGI, Portugal
Gonçalves, DC (costa.goncalves.diogo@gmail.com), INEGI, Portugal
Campilho, RDSG (raulcampilho@gmail.com), INEGI, Portugal
Belinha, J (job@isep.ipp.pt), INEGI, Portugal

Adhesive bonding is an increasingly important joining method due to the advantages it offers over traditional joining methods, like bolting or riveting. Unlike those methods, adhesive bonding does not introduce holes in the adherends, which can introduce relevant stress concentrations and, consequently, lead to failure. This feature is even more relevant in the case of composites because the holes required by bolting or riveting can also lead to tears, burrs or delamination. Since nowadays adhesive joints are used in industries like the automotive industry, where dynamic behaviour must be taken into account, it is important to perform a modal analysis of adhesive joints. A modal analysis enables the estimation of the natural frequencies and the modal shapes of adhesive joints, which in turn should be used to aid their design and ensure that the working conditions of an adhesive joint are outside its natural frequencies. Therefore, the main goal of this work is to study the modal behaviour of an adhesive joint using a radial point interpolation method, to determine the natural frequencies and modal shapes of that adhesive joint.

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abst. 1303
Repository

Influence of Low and High Temperature on Hygrothermal Aged Aluminum-CFRP (plain woven) Hybrid Joints under Tensile–Shear Loading

Hanyu Zhang (zhanghanyu@sjtu.edu.cn), State Key Laboratory of Mechanical System and Vibration, Shanghai Jiao Tong University, Shanghai 200240, PR China, China
Zhouzhou Song (), State Key Laboratory of Mechanical System and Vibration, Shanghai Jiao Tong University, Shanghai 200240, PR China, China
Lei Zhang (), State Key Laboratory of Mechanical System and Vibration, Shanghai Jiao Tong University, Shanghai 200240, PR China, China
Zhao Liu (), School of Design, Shanghai Jiao Tong University, Shanghai 200240, PR China, China
Ping Zhu (pzhu@sjtu.edu.cn), State Key Laboratory of Mechanical System and Vibration, Shanghai Jiao Tong University, Shanghai 200240, PR China, China

Environmental temperature and hygrothermal aging have significant effects on the mechanical properties of joints, but the research on the coupling effect of the two is insufficient. In this work, the combined effects of the short-term factor of ambient temperature and the long-term factor of hygrothermal aging on the mechanical properties of Al/CFRP hybrid joints (HJs) are investigated by quasi-static tensile experiments and a newly refined simulation method. The mechanical properties of HJs with four kinds of aging degrees are tested at four temperatures (-40[U+2103], 20[U+2103], 50[U+2103] and 80[U+2103]). Experimental results show that although the joint stiffness and strength decrease significantly as the temperature increases or the aging degree deepens, the three-stage characteristics of failure (first, the adhesive bond and the rivet share the load; and then the adhesive bond gradually fractures; finally, the rivet bears the load alone) do not change. Compared with the high-temperature condition, the change of the aging degree under the low-temperature condition will lead to a more obvious change in the strength properties of HJs. In the simulation research, by integrating the effects of hygrothermal aging and temperature on the properties of composite materials and adhesive bond into the material model, the simulation and prediction of HJs' performance are achieved. Furthermore, the simulation results show new light on the failure mechanisms of the HJs on the coupling effect of environmental temperature and hygrothermal aging. In conclusion, this research helps to deepen the understanding of the changing laws of mechanical behavior of Al/CFRP hybrid joints under actual service conditions.

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abst. 1316
Room B035
Thursday
July 21
12h10

Influence of aging effects on the bond strength of aluminum die castings and thermoplastics

Julian, Steinberg (j.steinberg@tu-braunschweig.de), Technische Universität Braunschweig - Institute of Joining and Welding, Germany
Sven, Hartwig (s.hartwig@tu-braunschweig.de), Technische Universität Braunschweig - Institute of Joining and Welding, Germany

The application of hybrid components produced by combining thermoplastic and die-cast aluminum parts is a promising way to improve lightweight design in automotive production. It can help to reduce vehicle weight and thus decrease carbon dioxide emissions from vehicles with combustion engines and increase the range of battery-electric vehicles. For the production of hybrid components, in-mold assembly (IMA) by injection molding is a promising approach. In addition to reducing process steps by combining injection molding and joining, IMA can also meet the requirements of high-volume production in terms of short manufacturing times. An overmolding process is the basis of the joining process. By injecting a molten fiber-reinforced thermoplastic (FRTP) onto the surface of the die-cast part, the bond is achieved by the adhesive character of the thermoplastic matrix. In this process, adhesion between the die-cast aluminum and the FRTP is of major interest to ensure an aging-resistant bond and extend the life of a hybrid component. Comparable to the pretreatment of die casting surfaces for adhesive bonding applications, a pretreatment is necessary to guarantee bonding using IMA. Besides residues of release agents on the aluminum die casting surface from the casting process, the oxide layer of the die casted aluminum has a great influence on the bonding strength, especially on long-term resistance. Its structure depends on the environmental conditions during its formation and thus can be influenced.

In addition to the surface conditions, the high complexity of the IMA process with its dependence to various variables such as preheating temperature of the inserts also is an influence on the bonding strength. In this work a nanosecond pulsed fiber laser with a wavelength of 1062±2 nm and a pulse peak power of 20 kW is used to locally pretreat the die casting surface. The high energy fluence in the irradiation regime structures the surface and influences the surface chemistry, including the oxide layer. Based on this, the investigations focus on the influences of the pretreatment on the surface morphology and the long-term resistance of the bond. Therefore, various combinations of pretreatment settings are considered and tested before and after aging. 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 bonding strength.

Water contact angle measurements revisited - statistical analysis of the potential to distinguish CFRP surface treatments reliably

abst. 1318
Room B035
Thursday
July 21
12h50

Koskinen, VV (ville-veikko.koskinen@tuni.fi), Tampere University, Faculty of Engineering and Natural Sciences, Finland

Lahtonen, K (kimmo.lahtonen@tuni.fi), Tampere University, Faculty of Engineering and Natural Sciences, Finland

Jokinen, J (jarno.jokinen@tuni.fi), Tampere University, Faculty of Engineering and Natural Sciences, Finland

George, L (lijo.george@tuni.fi), Tampere University, Faculty of Engineering and Natural Sciences, Finland

Hakala, P (pauli.hakala@tuni.fi), Tampere University, Faculty of Engineering and Natural Sciences, Finland

Kanerva, M (mikko.kanerva@tuni.fi), Tampere University, Faculty of Engineering and Natural Sciences, Finland

Surface treatments of carbon fibre reinforced plastics (CFRP) are a necessary step in making strong adhesive joints. The qualification of the success of CFRP treatment is still nowadays challenging and even slightest chemical changes on bond surfaces might lead to failure [1,2]. Contact angle (CA) measurements are the basis of techniques offered by many commercial device manufacturers. This study focuses on detailed CA measurements and statistical analysis of results of CA measurements. The factors of treatments are 1) roughness level 2) final step by wiping or alternatively solvent cleaning. Additional studies are made via x-ray photoelectron spectroscopy (XPS). The measurements are carrier out for carbon fibre reinforced plastic (CFRP) laminate prepared of prepreg according to manufacturer instructions. The surface treatments with different levels of roughening and cleaning are applied on laminates directly after peel ply removal. A protocol at an accuracy of seconds is applied to ensure systematic comparison and measurement for different surface treatments. DSA100 (Krüss) is used, using two microliter droplet volume and five second dwell time. Different probe liquids are considered for surface energy analysis along with purified water. According to the results, the student t-test based statistical analysis indicates that side-view CA measurements with water can highly reliably (p-value of 6.759*10-9) distinguish reference (peel ply removed) surface and sanding up to black dust (i.e. hard treatment). Similarly, very high reliability is indicated by CA data to distinguish (p-value of 3.475*10-9) methyl ethyl ketone (MEK) wiped surface from dry-wiped surface, when the hard treatment is applied prior to the (either of) last cleaning step. The effect of the much-argued final step of treatments procedures – the solvent cleaning compared to dry wiping – remains an issue, based on the XPS measurements, to be studied in more details. References: [1] Mueller E., Starnes S., Strickland N., Kenny P., Williams C., The detection, inspection, and failure analysis of a composite wing skin defect on a tactical aircraft. Composite Structures 145 (2016) 186-193. [2] Lindgren M., Bergman G., Kakkonen M., Lehtonen M., Jokinen J., Wallin M., et al. Failure analysis of a leaching reactor made of glass-fiber reinforced plastic. Engineering Failure Analysis 60 (2015) 117-36.

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abst. 1355
Room B035
Thursday
July 21
12h30

CONNECTIONS IN MIXED STRUCTURES WITH H-SHAPED STEEL COLUMNS WITH PRE-INSTALLED THREADED RODS AND NORMAL STRENGTH CONCRETE BEAMS FOR ZONES OF HIGH SEISMIC ACTIVITY

Gutierrez, Oscar (osagutierrezbo@unal.edu.co), Universidad Nacional de Colombia, Colombia
Bermúdez, Carlos (cabermudezm@unal.edu.co), Universidad Nacional de Colombia, Colombia

This research aims to assess the suitability of a new type of connections between H-shaped steel columns and rectangular normal strength concrete beams. Spanish researchers performed the first experimental campaigns of connections using stud connectors welded to flanges of steel columns, which involves monitoring welding procedures. These researchers concluded that their connections offer good resistance to static load and that the contribution of resistance by adhesion between steel column and beam concrete is important. It is noteworthy that there are no guidelines of experimental trials for validation for this type of connections. The innovative components in this research are the implementation of threaded rods passing through column flanges and the evaluation of this connection to cyclic loading. Within the framework of this research three specimens were tested under cyclic load for assessing and characterizing the behavior of these connections under seismic events corresponding to zones of high seismic activity.

Keynote Lectures

Energy absorbing lightweight materials

abst. 2001
Virtual Room 1
Tuesday
July 19
11h30

Cantwell, Wesley (wesley.cantwell@ku.a.ae), Khalifa University, United Arab Emirates
Alia, Ruzanna (alia.aziz@tii.ae), Technology Innovation Institute, United Arab Emirates
Zhou, Jin (jin.zhou@xjtu.edu.cn), Xi'an Jiaotong University, China
Umer, Rehan (r.umer@ku.ac.ae), Khalifa University, United Arab Emirates

This talk will outline recent advances in the development of lightweight materials and structures for energy absorption in high-performance engineering structures. Initial attention will focus on conventional energy-absorbing materials that have been used in dynamic applications for many years. Such materials include metal and polymeric foams and honeycombs. Consideration will also be given to discussing energy absorbing composite tubes, an area that has offered significant promise for energy absorption in automotive structures. Here values of specific energy absorption as high a 100 kJ/kg are regularly measured on such structures. The talk will then continue be discussing more recent developments, including structures based on embedded composite and metal tubes, all-composite honeycomb structures based on carbon fibre reinforced epoxies, as well as biomimetic designs. Here, specific energy absorption values can be measured that are up to three times those measured on more traditional materials can be achieved, being comparable to those reported previously on individual tube-like samples. Attention will focus on discussing the failure mechanisms and energy-absorbing processes that occur in these materials, both at quasi-static and dynamic rates of loading.

NONLINEAR MECHANICS OF SANDWICH PLATES

abst. 2002
Virtual Room 1
Tuesday
July 19
14h30

Amabili, Marco (marco.amabili@mcgill.ca), McGill University, Canada
Reddy, J.N. (jnreddy@tamu.edu), Texas AM University, USA

The nonlinear mechanics of sandwich plates is studied using a layerwise third-order thickness and shear deformation theory. The two face sheets are modelled using a second-order shear deformation theory (well-justified in case of a zero-shear stress only at one outer surface) and the core is modelled with a third-order thickness and transverse shear deformation theory. After introducing continuity of displacements at the interfaces between the core and the face sheets, 16 independent kinematic parameters are retained. A parameter is kept to describe the thickness deformation, which allows for introduction of the corresponding boundary condition; this represents a significant novel contribution. Geometric nonlinearity in all the kinematic parameters is introduced. Numerical results are presented for deflection of a sandwich plate under pressure. A thin core was considered, since it is numerically more critical, and a wide range of core stiffnesses was studied in order to verify the validity of the proposed model till the limit case of two plates joined by a core of negligible stiffness (i.e., two independent plates). Numerical results are compared to those obtained by a commercial finite element (FE) program with three-dimensional solid elements till the limit when the FE code fails for large deformations of the extremely weak core.

FINITE ELEMENT UNIFIED FORMULATION COMBINED WITH PROGRESSIVE DAMAGE ANALYSIS: A NEW APPROACH TO PREDICT FAILURE MECHANISMS IN COMPOSITE LAMINATES

abst. 2003
Virtual Room 2
Tuesday
July 19
14h30

Tita, Volnei (voltita@sc.usp.br), University of Sao Paulo, Brasil
Ferreira, Antonio (ferreira@gcloud.fe.up.pt), University of Porto, Portugal

A novel approach is proposed by using higher-order finite elements combined with progressive damage in the formulation to predict failure mechanisms in composite laminates. The approach is based on Unified Formulation (UF) while the damage model is based on Continuum Damage Mechanics (CDM) principles, which is implemented as a UEL (User Element subroutine) written in FORTRAN and

linked to Abaqus. The proposed approach is assessed in two steps: (I) Linear elastic analysis and (II) Non-linear analysis. Thus, in the first step, benchmarking cases are evaluated investigating laminated plates under concentrated and distributed load. The displacement fields and, mainly, stress profiles are predicated by three different approaches: i) in-house Matlab framework; ii) standard shell and solid finite elements from Abaqus; and iii) from self-developed finite elements via UEL. In the second step, the proposed approach is assessed by simulating a plate under distributed and sinusoidal loads. Besides, a progressive damage analysis of a composite coupon under bending is simulated, and the numerical predictions are compared to experimental results. In the end, it is discussed the advantages and disadvantages of the new approach mainly in terms of accuracy and time processing to predict progressive failure mechanisms in composite laminates.

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abst. 2005
Virtual Room 2
Thursday
July 21
14h30

Varicomposites: spatially and temporally variable properties for sustainable performance

Weaver, Paul (paul.weaver@bristol.ac.uk), University of Bristol, UK

To be defined

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abst. 2006
Room B032
Wednesday
July 20
14h30

Recent advances in the optimisation of variable stiffness composite structures: challenges and prospects

Montemurro, Marco (marco.montemurro@ensam.eu), Arts et Métiers Sciences et Technologies, France

The development of additive manufacturing (AM) technologies for composite structures allows overcoming the classical design rules, thus leading the designer to find innovative solutions more efficient than the classical ones. By means of modern AM processes it is possible to manufacture new types of variable stiffness composites (VSCs). An AM machine allows the filament to be placed along a curvilinear path within the constitutive lamina, thus implying a point-wise variation of the material properties (stiffness, strength, etc.). Therefore, the trajectory of the tows can be properly conceived to optimise the properties of the resulting structure and can be adapted to the local distribution of stress and strains (within each ply). Furthermore, through AM technology, one can conceive VSCs with variable thickness, provided that technological requirements, like blending constraints, are correctly integrated within the design process. In previous works [1-3], the author (with his co-workers) presented the new version of the multi-scale two-level optimisation strategy (MS2LOS) for the optimum design of VSCs, also in the case of variable thickness [4] by providing an efficient formulation of the blending constraints [5]. In the framework of the MS2LOS, the design problem of a VSC is split in two related sub-problems. The first-level problem (FLP) focuses on the macroscopic scale, where the VSC is modelled as an equivalent single layer anisotropic plate, whose mechanical response is described through the polar parameters (PPs), which vary pointwise over the structure. The goal is, thus, to find the optimum distribution of the PPs over the structure satisfying the requirements of the problem at hand. Conversely, the second-level problem (SLP) focuses on the VSC mesoscopic scale, and the aim is to retrieve the optimum stacking sequence and the optimum fibres-path in each layer satisfying the optimised PPs fields and thickness resulting from the FLP. The effectiveness of the MS2LOS has been proven through different benchmarks dealing with the maximisation of the first buckling factor [1, 3], the minimisation of the compliance [2] and the maximisation of the VSC strength [4]. Moreover, a suitable formulation of the AM process-related constraints (which intervene mostly at the composite mesoscopic scale, i.e., at the tow-level) has been developed in the PPs space, by taking advantage from the tensor invariant-based representation [1, 4]. The goal of this study is to present the recent developments about the formulation of both FLP and SLP and to discuss some interesting prospects about the formulation of the manufacturing requirements related to the AM process (like minimum steering radius, tows gap/overlap, tow width, etc.) as equivalent constraints at the macroscopic scale in the PPs space by exploiting an analogy with topology optimisation problems [6-9] Moreover prospects on the simultaneous optimisation of the topology and the anisotropic fields describing the behaviour of the composite at the macroscopic scale will be also discussed. References: [1] M. Montemurro and A. Catapano. On the effective integration of manufacturability constraints within the multi-scale methodology for designing variable angle-tow laminates. Composite Structures, 161:145-159, 2017. [2] Montemurro, M., Catapano, A.: A general B-Spline surfaces theoretical framework for optimisation of variable angle-tow laminates. Compos. Struct. 2019; 209: 561–578. [3] G. A. Fiordilino, M. I. Izzi, M. Montemurro. A general isogeometric polar approach for the optimisation of variable stiffness composites: application to eigenvalue buckling problems. Mechanics of Materials, v. 153, art. num. 103574, 2021. [4] M. I. Izzi, A. Catapano, M. Montemurro. Strength and mass optimisation of variable-stiffness composites in the polar parameters space. Structural and Multidisciplinary Optimization, v. 64, pp. 2045-2073, 2021. [5] M. Picchi Scardaoni, M. Montemurro, E. Panettieri, A. Catapano. New Blending Constraints and a Stack-Recovery Strategy for the Multi-Scale Design of Composite Laminates. Structural and Multidisciplinary Optimization, v. 63, pp. 741-766, 2021. [6] G. Costa, M. Montemurro, J. Pailhès. A 2D topology optimisation algorithm in NURBS framework with geometric constraints. International Journal of Mechanics and Materials in Design, 2018; 14 (4), 669-696. [7] G. Costa, M. Montemurro, J. Pailhès. NURBS Hypersurfaces for 3D Topology Optimisation Problems. Mechanics of Advanced Materials and Structures, URL : https://doi.org/10.1080/15376494.2019.1582826, 2019 (in press). [8] G. Costa, M. Montemurro, J. Pailhès. Minimum Length Scale Control in a NURBS-based SIMP Method. Computer Methods in Applied Mechanics and Engineering, 2019; 354: 963-989. [9] M. Montemurro. On the structural stiffness maximisation of anisotropic continua under inhomogeneous Neumann-Dirichlet boundary conditions. Composite Structures, v. 287, art. num. 115289, 2022.

Nonlinear vibration of composite beams, plates and shells subjected to compression and shear loadings by unified finite elements and comparison with VCT experiments

abst. 2007
Room B035
Wednesday
July 20
09h00

Carrera Erasmo (erasmo.carrera@polito.it), Politecnico di Torino, Italy
Pagani Alfonso (alfonso.pagani@polito.it), Politecnico di Torino, Italia
Augello Riccardo (riccardo.augello@polito.it), Politecnico di Torino, Italy
Azzara Rodolfo (rodolfo.azzara@polito.it), Politecnico di Torino, Italy

This work discusses some advances in the nonlinear vibration analysis of beam, plate and shell elements. Based on the Carrera Unified Formulation (CUF), trivial linearized and full nonlinear governing equations are developed in the framework of a hierarchical finite element formulation to study the effect of pre-stress states on the vibration of composite structures. Thanks to CUF and by making use eventually of full Green-Lagrange strain tensor, the proposed methodology is able to characterize simple to complex nonlinear phenomena, including those related to deep post-buckling regimes. Particular attention is given to the characterization of the natural frequencies of thin to thick laminated structure subjected to progressively increasing compression and shear loads. It is demonstrated that whenever stable pre-buckling exists, trivial linearized equations and low kinematics models can be adopted with no loss of generality. In contrast, in the case of unstable pre-buckling regimes and whenever the interlaminar stress state is complex three-dimensional, high order kinematics and full displacement-strain relations must be used for describing vibration. Several problem are discussed, including cylindrical laminated shell under compression and plates in shear. It is demonstrated that the proposed formulation is effective for all the problem considered and, among the others, can be used to validate non-destructive buckling tests such as Vibration Correlation Technique (VCT).

Buckling of sandwich panels with piezoelectric sensors and actuators

abst. 2008
Room B032
Tuesday
July 19
11h30

Afonso, Alexandre (alexandreafonso@tecnico.ulisboa.pt), Instituto Superior Técnico, Portugal
Tomé, Marta (marta.tome@tecnico.ulisboa.pt), IDMEC, Instituto Superior Técnico, Portugal
Araujo, Aurelio (aurelio.araujo@tecnico.ulisboa.pt), IDMEC, Instituto Superior Técnico, Portugal

In the past years, sandwich plates have been widely used in the aerospace, marine, aircraft and automobile industries, due to their superior structural properties, such as their high strength-to-weight ratio, lightweight, good energy and sound absorption capabilities, impact and damage resistance, fatigue resistance, heat and acoustic insulation, durability, ability to include fasteners and attachments, and often low production costs. When subjected to in-plane compressive loads, sandwich plates experience some failure modes that do not occur in metallic sheets or laminated composite plates. Hence, stability analysis of sandwich panels with flexible core is an important research topic, given the complexity of the instability mechanisms that are usually found in these structures. On the other hand, the use of piezoelectric sensors and actuators can allow some control over these instability mechanisms, when both static and dynamic loads are applied. Recently, finite element models have been developed to perform dynamic and buckling analyzes of laminated sandwich composite plates with piezoelectric layers. In this work we will present the recent developments of this formulation, extended for the analysis of buckling of sandwich panels with a flexible viscoelastic core, equipped with piezoelectric sensors and actuators.

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abst. 2009
Room B035
Thursday
July 21
09h00

High-performance carbon felt electrodes of vanadium redox flow batteries

Kwang Il Jeong (lightone@kaist.ac.kr), KAIST, Republic of Korea
Jae-Moon Jeong (jaemoon.jeong@kaist.ac.kr), KAIST, Republic of Korea
Seong Su Kim (seongsukim@kaist.ac.kr), KAIST, Republic of Korea

Energy-storage systems (ESSs) are indispensable for renewable-energy sources such as solar and wind power, which supply intermittent electricity. Vanadium redox flow batteries (VRFBs) are promising as next-generation ESSs owing to their weak explosive properties and stability in a broad range of operation temperatures. In addition, their independent capacity and power enable an effective large-scale installation of ESSs. Nevertheless, the low energy density and energy efficiency are critical issues that need to be addressed. In the present study, a novel surface treatment for carbon felt (CF) electrodes used in VRFBs is proposed to solve the problems of the conventional heat-treatment method. To prevent extreme oxidation of the CF surface, which inevitably occurs in the conventional heat-treatment process, the carbon fibers in the CFs were coated with glucose and subsequently carbonized to form a carbon-coating layer. In addition, we suggest a method to induce uniform electrolyte distribution by patterning on the CPs at uniform intervals without any machining process of the bipolar plates was developed to apply flow-through type VRFBs. Lastly, we introduce a novel in-situ fabrication method to integrate electrodes and bipolar plates without contact resistance. The integrated structure was fabricated with a single sheet of graphite felt so that the electrode and bipolar plate could be interconnected with graphite fibers.

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abst. 2010
Room B035
Tuesday
July 19
11h30

Modelling the mechanical behaviour of natural fibre reinforced composites

Santiuste, Carlos (csantius@ing.uc3m.es), Universidad Carlos III de Madrid, Spain
Jaio-Wang, Liu (lwang@pa.uc3m.es), Universidad Carlos III de Madrid, Spain
Diáz-Álvarez, Antonio (andiaza@ing.uc3m.es), Universidad Carlos III de Madrid, Spain

The mechanical behaviour of traditional composites reinforced with synthetic fibres can be assumed linear-elastic up to failure. However, the mechanical behaviour of biodegradable composites is quite different: their elastic response is non-linear, plastic strains can be observed, and strain-rate has a strong influence on their behaviour. Thus, the modelling of biocomposites requires the use viscoplastic constitutive equations. A three branches rheological model is described in this work. The model includes seven parameters that are fitted by quasi-static tensile tests and relaxation tests. The model has been successfully validated by tensile tests at different strain rates. The constitutive model has proved to be valid for composites reinforced with cotton, flax and jute fibres, allowing a greater understanding of the behaviour of those biocomposites. These tests were conducted on specimens manufactured with compression moulding method using PLA as matrix to produce a 100% biodegradable composite. The existence of a constitutive model for biocomposites can lead to get a better understanding of the mechanical behaviour of these materials and to find future industrial applications. The constitutive

equation was implemented in a Finite Element Model to predict the behaviour of biocomposites under different dynamic conditions. The behaviour of biocomposites reinforced with natural fibres under low-velocity impacts was studied. The predictions of the numerical model were compared with experimental tests developed in a drop-weight tower founding an excellent agreement. The results of impacts on flax/PLA plates were compared with carbon/epoxy specimens and two important differences were observed. First, delamination was the main failure mode in carbon/epoxy composites but it was not observed in flax/PLA plates where fibre failure was the main failure mode. Second, the normalized after impact residual strength of flax/PLA plates was higher than that of carbon/epoxy composites. The absence of delamination can explain the better after impact behaviour of flax/PLA biocomposites. Thus, biocomposites showed some advantages with respect to carbon/epoxy composites in the impact behaviour. The different mechanisms of damage induced in drilling of biocomposites has been studied. Induced damage under different cutting speeds, feed rates and drill geometries was analysed, noting that in this case delaminations were not found as failure mode, revealing a good cohesion between fibre and matrix. Is also remarkable the damage reduction with increasing drill feed rate, which is a novelty that can reduce the processing times of these materials in the industry. These results provided by the numerical model were verified by experimental tests on flax/PLA biocomposites. Finally, the buckling behaviour of biocomposites was analysed. The buckling Euler theory based on lineal-elastic behaviour cannot be applied to natural fibre reinforced composites because their mechanical behaviour is not linear. A modified buckling theory using the modified Ludwick nonlinear elastic model was used to predict the critical load of biocomposites columns. Experimental tests were conducted on flax/PLA columns and the accuracy of the Ludwick model was verified.

The effects of interlayer toughening on progressive damage and failure of composite laminates

abst. 2011
Room B032
Thursday
July 21
14h30

Waas, Anthony M. (awaas@umich.edu), University of Michigan, United States

Toughened composite materials, where the toughening agents are micro-particles dispersed within the interlayer resin rich regions, provide enhanced delamination resistance. This delay in delamination promotes intralaminar micro- and macro-cracking, thus providing superior toughness. In this talk, results from a thorough study of damage accumulation conducted to identify and quantify failure mechanisms in the $\pm$ 45 laminate axial tensile test will be presented. Progression of damage accumulation was captured with digital image correlation techniques, in-situ inspection with high-resolution cameras and interrupted tests at different loading stages. Detailed cross-section microscopy of specimens were used to observe progression of crack formation, density of cracks formed and crack branching at the toughened interfaces. These results are then modeled using a single scale, novel failure modeling approach that is seen to capture the complex series of events that are observed in the experimental study.

Theoretical and numerical models for shells

abst. 2012
Room B032
Wednesday
July 20
09h00

Polit, Olivier (opolit@parisnanterre.fr), Univ. Paris Nanterre, France

A general overview on theoretical and numerical models for shell is presented.

FE model for global buckling analysis of composite beams

abst. 2013
Room B032
Tuesday
July 19
14h30

Lanc, Domagoj (dlanc@riteh.hr), Faculty of Engineering, University of Rijeka, Croatia
Turkalj, Goran (goran.turkalj@riteh.hr), Faculty of Engineering, University of Rijeka, Croatia
Banic, Damjan (dbanic@riteh.hr), Faculty of Engineering, University of Rijeka, Croatia
Kvaternik Simonetti, Sandra (sandra.kvaternik@riteh.hr), Faculty of Engineering, University of Rijeka, Croatia

The paper presents a finite element beam model for global buckling analysis of composite beam type structures. Buckling phenomena can be generally manifested in three ways: as a global buckling with primary deformation of global axis, local buckling as local plate deformation as well as distortional buckling involving change in cross-sectional shape. The classical approach to the problem, assuming that the cross-section is not deformed in its own plane, can capture only the global modes. Such an approach, although not typical for composite cross sections, delivers acceptable results for structures consist of relatively slender beam members and in the cases when the global modes occur before the local or distortional. The nonlinear stability analysis is performed in the framework of updated Lagrangian incremental formulation. In order to illustrate the application of the proposed model, several numerical examples are presented. For validation purposes, the obtained results are compared with results reported in the literature and the ones obtained with shell finite elements.

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abst. 2014
Virtual Room 2
Tuesday
July 19
11h30

Non Classical/Non-Local Descriptions in Microstructured Composite Materials via Discrete-Continuous Models

Trovalusci, Patrizia (patrizia.trovalusci@uniroma1.it), Sapienza Università di Roma, Italy

The mechanical behavior of materials with microstructure strongly depends on their microstructural features. In particular, in the modelling of these materials, such as particle composites that are polycrystals with interfaces or with thin or thick interfaces, as well as rock or masonry-like materials, the discrete and heterogeneous nature of the matter must be taken into account, because interfaces and/or material internal phases dominate the gross behaviour. And this is definitely ascertained. What is not still completely recognized, is the possibility of preserving memory of the microstructure, and of the presence of material length scales, resorting to non-classical/non-local continuum descriptions [1, 2, 3]. The classical/local Cauchy continuum (grade1), lacking in material internal scale parameters, does not seem appropriate for describing the macroscopic behavior in problems dominated by the material internal size, such as strain/stress localization phenomena, occurring even in the elastic regime in the presence of geometrical or load singularities (cracks/holes/inclusions, concentrated loads) [4, 5, 6, 7]. Moreover, the absence of proper kinematical descriptors inhibits the possibility of taking into account of the orientation of micro-heterogeneities (inclusions/voids) and to adequately represent anisotropic behavior [4, 7]. Especially for materials made of particles of prominent size and/or strong anisotropy anisotropic media, the resort to non-classical/non-local continuum descriptions is then required. This talk wants to firstly focus on the origins of multiscale modelling, related to the original discrete(molecular)-continuous models, developed in the 19th century to give explanations 'per causas' of elasticity (Cauchy, Voigt, Poincare), in order to find conceptual guidelines for deriving discrete-to scale-dependent continua, that are essentially non-local models with internal length and dispersive properties [1, 2]. Then, a discrete-to-scale dependent continuous formulation, developed for particle composite materials basing on a generalized version of Voigt's molecular/continuum approach, is proposed [8, 9, 10]. Finally, with the aid of some numerical simulations - concerning ceramic matrix composites (CMC), microcracked media and masonry assemblies – focus will be on the advantages of the micropolar modelling with respect to other non-classical/non-local continuum formulations [4, 5, 6, 7]. References: [1] I. A. Kunin (1984), On foundations of the theory of elastic media with microstructure, Int. J. Engng. Sci., 22(8-10):969-968. [2] P. Trovalusci (2014), Molecular approaches for multifield continua: origins and current developments. CISM (Int. Centre for Mechanical Sciences) Series, 556: 211-278, Springer. [3] P. Trovalusci, Ed. (2016), Materials with Internal Structure. Multiscale and Multifield Modeling and Simulation, Springer Tracts in Mechanical Engineering, Vol.18:109-131, Springer. [4] N. Fantuzzi, P. Trovalusci, S. Dharasura (2019), Mechanical behaviour of anisotropic composite materials as micropolar continua, Frontiers, 59 (6):1-11 (https://doi.org/10.3389/fmats.2019.00059). [5] M. Tuna, L. Leonetti, P. Trovalusci, M. Kirka (2019), 'Explicit' and 'implicit' non-local scale dependent continuous descriptions for a plate with a circular inclusion in tension, Meccanica (https://doi.org/10.1007/s11012-019-01091-3).[6] M. Tuna, P. Trovalusci (2020), Scale dependent continuum approaches for discontinuous assemblies: 'explicit' and 'implicit' non-local models", Mech. Res. Comm, 103, 103461, (https://doi.org/10.1016/j.mechrescom.2019.103461). [7] N. Fantuzzi, P. Trovalusci, R. Luciano (2020), Multiscale analysis of anisotropic materials with hexagonal microstructure as micro-polar continua, Journal for Multiscale Computational Engineering, x(x): 1–29, 2020. In print. [8] P. Trovalusci, V., Varano,,

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

Metamaterials and Bio-Composites for Sustainable Aviation and Transport

abst. 2015
Room B035
Thursday
July 21
14h30

Scarpa, Fabrizio (F.Scarpa@bristol.ac.uk), University of Bristol, UK

The Fly Net Zero initiative has set the challenge for civil aviation to reach zero carbon emissions by 2050. This objective can be achieved by accelerated efficiency measures, energy transition and strong innovation across the aviation sector. Climate Change also obliges us to use materials and manufacturing tools that are sustainable for the environment and society. Amongst paradigmatic and potentially game-changing materials and technologies, this talk focuses on the potential use of metamaterials and bio-based composites for airframe applications. Metamaterials are architected and multiscale materials systems that provide combinations of unusual properties, not typically found in nature. We will discuss cases related to the assessment of metamaterials for morphing surfaces (from trailing edges to morphing nacelles inlets), to acoustic and energy absorption offered by fractal structures, to auxetic (negative Poisson's ratio) foams. Bio-based and sustainable composites made of thermoset matrices and flax/hemp reinforcements offer structural performances very similar to the one of fossil-based composites used in secondary load bearing applications. The lecture will propose some examples of the current evaluation of biobased composites for aircraft interiors, like a cockpit dashboard made of hemp, epoxy and syntactic foam recently developed for a 10 PAX full-electric fixed wing aircraft. We will also describe how bio-based composites and coatings could be developed for bio-effective surfaces, for pandemic-resilient aircraft. We will finally describe a possible vision on how meta and biobased materials could be integrated for future zero carbon emission aircraft designs, by interfacing synthetic biology and sustainable composite materials science.

Micromechanical Modelling of Composites Based on Asymptotic Homogenization Method

abst. 2016
Room B035
Tuesday
July 19
14h30

Kalamkarov, Alexander L. (alex.kalamkarov@dal.ca), Dalhousie University, Canada

Advanced composite materials and structures are widely used in various areas of modern engineering. Commonly, these materials are highly inhomogeneous with the dimensions of unit cell much smaller than the overall dimension of the structure. As a result, the coefficients of the differential equations describing mechanical behavior of these composite materials are rapidly varying functions in spatial coordinates. Consequently, the resulting boundary-value problems are very complex. They are so complex that the numerical methods (e.g., Finite Elements) applied directly to the original boundary-value problem for a composite structure are inappropriate in their standard form. Therefore, it is very important to develop rigorous analytical methods in order to reduce the complexity of the original boundary-value problems. An issue of a high significance in micro-mechanics of advanced composites is determination of the effective properties of highly inhomogeneous composite materials, which will naturally depend on the spatial distribution, geometric characteristics and mechanical properties of the constituent materials of the composite. The micro-mechanical analysis of composite materials made up of reinforcements embedded in a matrix has been the focus of investigation for many years. At present, different methods are developed and applied in micro-mechanics of composites. Various asymptotic approaches to the analysis of composite materials of a regular structure have reached their conclusion within the framework of the mathematical theory of multi-scale asymptotic homogenization. Indeed, the proof of the possibility of homogenizing the composite material of a regular structure, i.e., of examining a homogeneous material instead of the original highly inhomogeneous composite material, is one of the principal results of this theory. Asymptotic homogenization method has also indicated a method of transition from the original problem (which contains in its formulation a small parameter related to the small dimensions of the unit cell of the composite) to a problem for a homogeneous material described by a set of the effective properties. This transition is accomplished through the solution of the problems formulated on the unit cell of the composite material. The solution of these unit cell problems allows determining the effective properties and distribution of local fields, e.g., displacements and stresses. The indicated results are fundamentals of the asymptotic homogenization. The presentation will cover the basics of multi-scale asymptotic homogenization method. Simple example will be used to illustrate the asymptotic homogenization technique. The general asymptotic homogenization models will be further introduced and applied to the analysis of composite materials and thin-walled composite structures of a practical importance, including wafer-reinforced shells, orthotropic grid-reinforced composite shells and plates, and sandwich composite shells with cellular cores of different geometrical configuration. In particular, one of considered examples represents micromechanical modelling of the carbon nanotubes. The analytical expressions for the effective stiffness moduli of these composite reinforced shells and plates will be presented.

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abst. 2017
Room B035
Wednesday
July 20
14h30

Wood as a sustainable material for transportation industry

Bruno Castanié (bruno.castanie@insa-toulouse.fr), Institut Clément Ader, France

Wood was used in the past in different fields of transportation like naval, automotive or aerospace industry. Some selected example of theses field will be presented. It will be shown that wood was used for very lightweight and performant structures for race cars or aircraft. Then some recent researches performed at Institut Clément Ader on the manufacturing methodologies, the static response, the impact and post-impact behavior of plywood- based sandwiches with skins made of glass fibers, carbon fibers, flax fibers or aluminum will be showed. The very good compression characteristics observed convinced us to analysis the crash behavior of sandwich tubes with composite skins and polar, birch or oak cores. This research shows that these tubes are very efficient for crash absorption with SEA up to 70 kJ/kg while the cost of wood veneers is 40 times less. Finaly some recent application in the French aeronautic industry, in Automotive and in space will be showed, demonstrating the real reneweval of interest for this material in the context of a sustainable development.

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abst. 2018
Virtual Room 1
Wednesday
July 20
14h30

Advances in Peridynamics

Madenci, Erdogan (madenci@email.arizona.edu), University of Arizona, USA

Peridynamics (PD) started gaining approval in the solid mechanics community since its inception in 2000. It dispenses with the principle of local action, a fundamental axiom in the classical continuum mechanics (CCM) which permits contact interaction only. PD permits long-range interactions occurring over a finite domain which makes it a nonlocal continuum theory. The governing equations of PD are integro-differential in nature and do not require the smoothness of field variables. This is a significant improvement over CCM which involves partial differential equations and does not allow non-smooth solutions by its very construction. PD, for the first time, offered a physically and mathematically consistent theory through which spontaneous emergence and propagation of cracks can be achieved. The integral nature of the governing equations in PD remains valid even if a crack appears. Over the past 20 years, a considerable number of research articles has been published on PD. The applications range from static or dynamic loading, failure of brittle, quasi-brittle, and ductile type materials, multi-physics, and multi-scale problems, reduced dimensional structures, structured continua, etc. The success in accurately predicting crack propagation in various materials and for a large range of space, time, and loading scales, has established PD as an effective tool for engineers and scientists. Despite this initial success, PD is still new, and its applications are expanding in many areas. The focus of this presentation is to share some of these recent advances of PD theory and its applications with an emphasis on non-ordinary state-based (NOSB) PD which offers a direct way of converting a CCM-based constitutive equation to its PD form. It begins with an overview of the fundamentals of PD and PD differential operator. It discusses the shortcoming of the current PD models and proposed refinements. Also, it presents recent developments in PD theory such as the direct imposition of local boundary conditions and its coupling with finite element method in ANSYS framework. Furthermore, it presents PD simulations of finite elastic deformation and rupture in rubber like materials, soft polymers, viscoelastic adhesives in bonded lap joints, and creep at high temperature.

High-precision computation in mechanics of composite structures through a strong sampling surfaces formulation

abst. 2019
Virtual Room 1
Thursday
July 21
09h00

Kulikov Gennady (gmkulikov@mail.ru), Tambov State Technical University, Russia

The work is devoted to the three-dimensional stress analysis of laminated composite shells of revolution with general boundary and loading conditions using the strong sampling surfaces (SaS) formulation and the extended differential quadrature (EDQ) method. In the strong SaS formulation, the SaS parallel to the middle surface and located at Chebyshev polynomial nodes in layers are utilized to introduce displacements of these surfaces as shell unknowns. This choice of unknowns with the use of Lagrange polynomials in the approximation of displacements, strains and stresses through the thickness leads to an efficient shell formulation. The outer surfaces are not included into a set of SaS that makes it possible to minimize uniformly the error due to Lagrange interpolation. Therefore, the strong SaS formulation based on direct integration of the equilibrium equations of elasticity in the thickness direction in conjunction with the EDQ method can be effectively applied to high-precision calculations for laminated composite cylindrical shells and panels with arbitrary boundary conditions. This is due to the fact that in the SaS/EDQ formulation the displacements, strains and stresses of SaS are interpolated in a rectangular domain, which is mapped into the middle surface by using the Chebyshev-Gauss-Lobatto grid and the Lagrange polynomials are also utilized as basis functions.

Data-driven multiscale analysis for composite structures

abst. 2020
Virtual Room 2
Wednesday
July 20
14h30

Heng Hu (huheng@whu.edu.cn), Wuhan University, China

Multiscale simulation methods for composite materials and structures have been intensively developed during the past decades. However, the balance between the computational efficiency and accuracy still remains one of the main issues. In this work, we proposed a data-driven framework for composites from constitutive data collection to material-structure-integrated analysis, where the multilevel finite element technique (FE2) is applied to construct accurate constitutive database, and the distance-minimizing data-driven approach is employed to reduce the online computing time. The results showed that the proposed data-driven FE2 method ensures high accuracy and efficiency in comparison with classical FE2 method.

Relative entropy in homogenization of the fiber-reinforced composites

abst. 2021
Room B032
Thursday
July 21
09h00

Kamiński, Marcin (Marcin.Kaminski@p.lodz.pl), Łódź University of Technology, Poland

Probabilistic entropy has been invented to introduce some universal measure of disorder in the information theory to compare various files and datasets with each other. It may serve also as some uncertainty measure, alternatively to classical statistical estimators, not only in computer science but also in mechanical, civil or aeronautical engineering. Considering the fact that designing process is based upon verification of some limit functions defined as the differences in-between structural capacity and actual structural effort, probabilistic distance (divergence) seems to be more applicable. The main aim of this work is numerical determination of the relative entropies for the homogenized characteristics of various fiber-reinforced composites including uncertainties in the elastic moduli of their components. Kullback-Leibler [1], Bhattacharyya as well as Jensen-Shannon [2] relative entropies would be computationally studied and compared with each other to verify a probabilistic distance in-between probabilistic distributions of composite components elastic tensor components and the analogous distributions for the effective tensor components. These relative entropies (divergences) will be derived assuming that both initial moduli as well as the homogenized characteristics have Gaussian distribution, which has been demonstrated before [4]. Determination of the first two probabilistic moments of the homogenized tensor is delivered with the use of Finite Element Method (FEM) solution for the so-called cell problem and also thanks to simultaneous implemenation of three concurrent probabilistic methods. All these three methods, namely Monte-Carlo simulation, semi-analytical approach as well as the iterative generalized stochastic perturbation technique [4], will be based upon the Least Squares Method (LSM) recovery of the polynomial response functions. Two different computer systems would be employed to solve the cell problem – the commercial FEM system ABAQUS as well as the homogenization-oriented FEM system MCCEFF developed by the Author. It should be mentioned that statistically optimized LSM module, and also probabilistic strategies are implemented into the computer algebra system MAPLE 2019. Acknowledgments: This paper has been written in the framework of the research grant OPUS no. 2021/41/B/ST8/02432 "Probabilistic entropy in engineering computations" sponsored by the National Science Center in Cracow, Poland. References: [1] S. Kullback and R.A. Leibler, "On information and sufficiency", The Annals of Mathematical Statistics, vol. 22 (1), pp. 79–86, 1951. [2] C.E. Shannon, "A mathematical theory of communication, Part I". Bell Systems Technical Journal, no. 27, pp. 379-423, 1948. [3] A. Bhattacharyya, "On a measure of divergence between two statistical populations defined by their probability distributions". Bulletin of the Calcutta Mathematical Society, no. 35, pp. 99–109, 1943. [4] M. Kamiński, The Stochastic Perturbation Method for Computational Mechanics, Chichester: Wiley, 2013.

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abst. 2022
Virtual Room 1
Wednesday
July 20
09h00

Verification of the effect of flexible composite prostheses on bone healing by using a novel simulation method

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

Various types of fibrous composites are widely used in many fields including medical device industry. There are tremendous combinations of fibrous composites whose functions are precisely designed for a special application. Among those functional composites biocompatible and biodegradable composites are contributing on treatment of diseases especially for bone fracture healing. Flexible composite prostheses provide affirmative environment for bone healing, which stimulates granulation tissues to be promptly developed bone tissues, as a result, this induces early bone union. To verify the effect of mechanical stimuli on bone healing process a novel simulation technique using a Mechano-regulation algorithm with biphasic stimuli (deviatoric strain and fluid velocity) is introduced. To simulate the actual condition of the fracture site just after the operation callus volume estimation algorithm is also applied to precisely estimate the callus volume variation, which controls early bone stabilization, during the healing process. This simulation is dealing with cell and tissue developing pathway by estimating cell's whole life (cell migration, proliferation and apoptosis). Based on animal test data the cell and tissue phenotypes were accurately estimated and as a result, the effect of mechanical stimuli on bone healing process was precisely predicted and this provides design methodology of composite prostheses for better healing.

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abst. 2023
Virtual Room 2
Wednesday
July 20
09h00

Structural Design and High-accuracy Manufacturing Process of Filament Wound Composite Pressure Vessels

Zu, Lei (zulei@hfut.edu.cn), Hefei University of Technology, China
Zhang, Qian (zq_hfut@hfut.edu.cn), Hefei University of Technology, China
Zhang, Guiming (449313170@qq.com), Hefei University of Technology, China
Xia, Xianzhao (769400931@qq.com), Hefei University of Technology, China
Liu, Honghao (793473224@qq.com), Hefei University of Technology, China

Filament winding is one of the major manufacturing methods for composite pressure vessels and its productions have become the key components of the power unit and the fuel-cell on-board system. The conventional filament winding process cannot simultaneously achieve the manufacturability and the desired mechanical properties and significantly confines the structural performance improvement of filament-wound structures. One of the key solutions to this limitation is the exploration of a novel winding pattern with more degrees of freedom, which is able to fully utilize the laminate strength of the overwrap while satisfying the requirements for the winding process. Accordingly, the objective of this research is to present a systematical approach based on a new non-geodesic pattern with variable slippage coefficients along the fiber paths, and to obtain the optimal structural parameters of composite pressure vessels. The mathematical model, mechanical model and the optimization model will be established for the designed pressure vessels. The design method that integrates the winding pattern, the windability and the structural performance, will be systematically outlined. Several manufacturing methods will be given to ensure the high accuracy of the filament winding process. The simulation software dedicated to the structural optimization and the winding process design of composite pressure vessels will also be outlined. The results show that the structural performance can be improved by 20%-30% using the present method and a variety of non-symmetrical bodies can be fully overwrapped using the present winding patterns. The present methods simultaneously satisfy the windability and fully utilize the laminate strength. This research is of great scientific and application significance for effectively improving the mechanical performance of filament-wound composite pressure vessels.

Modelling of Quasi-static and Dynamic Damage Process of Interpenetrated Metal-Ceramic Composites

abst. 2024
Virtual Room 2
Thursday
July 21
09h00

Tomasz Sadowski (sadowski.t@gmail.com), Lublin University of Technology, Poland
Eligiusz Postek (ewpostek@googlemail.com), Institute of Funadametal Technological Research, Polish Academy of Sciences, Poland
Daniel Pietras (pietras140t@gmail.com), Lublin University of Technology, Poland
Jajnabalkya Guhathakurta (guhathakurta@ct-lab-stuttgart.de), 3CT-LAB Stuttgart, Stuttgart, Germany, Germany
Marek Boniecki (Marek.Boniecki@imif.lukasiewicz.gov.pl), Lukasiewicz Scientific Network, Poland

Quasi-static degradation of interpenetrated composite (IPC) AlSi12/SiC reveal different mechanical response under uniaxial tension and uniaxial compression. In this paper we analysed cracking processes and failure under quasi-static loading of 2 phase IPC made of alumina alloy AlSi12 reinforced by SiC ceramic foam subjected to tension and compression. Constitutive modelling of two phase ceramic composites obeys description of: (1) elastic deformations of initially porous material, (2) limited plasticity and (3) cracks initiation and propagation.Modelling of the IPCs at mesoscopic level under mechanical loading is related to analysis of the real internal structure of the material obtained with μ-CT which create Representative Volume Element (RVE). The basic elements of the defect structure inside the RVE are: micro- and meso-cracks, kinked and wing cracks. To get macroscopic response of the material one can calculate averaged values of stress and strain over the RSE with application of analytical approach. Dynamic degradation process corresponds to experimental tests done with Split Hopkinson Pressure Bar. The samples were hit with the velocity up to 30 m/s. The numerical analysis of the damage and fragmentation process was performed using the finite element method. The internal structure of the composite was assessed using micro-CT selecting both phases, i.e., ceramic foam and aliminum alloy. The phases are joined by a continuous very small thickness interface. The numerical calculations allow for the description of the whole degradation process of the analysed IPC up to the final failure by fragmentation and confirm the novel applicability of the material as a protective layer against the high-velocity impact.

Micromechanics

abst. 1086
Room B035
Wednesday
July 20
13h10

Multiscale thermoelastic analyses of fibre-reinforced composites by high-order unified finite element models

Racionero Sanchez-Majano, Alberto (alberto.racionero@polito.it), Politecnico di Torino, Italy
Masia, Rebecca (rebecca.masia@studenti.polito.it), Politecnico di Torino, Italy
Pagani, Alfonso (alfonso.pagani@polito.it), Politecnico di Torino, Italy
Zappino, Enrico (enrico.zappino@polito.it), Politecnico di Torino, Italy
Carrera, Erasmo (erasmo.carrera@polito.it), Politecnico di Torino, Italy

Multiscale models have been demonstrated to be a solution when analysing hierarchic materials, such as composites, in which the different scales play a role in the structural problem. These approaches comprise a bottom-up transfer of information that links the analyses from the constituent level to the macroscopic structure [1]. This manuscript proposes a methodology for conducting multiscale thermoelastic analyses of composite laminates in a computationally-efficient manner. For doing so, the Carrera Unified Formulation (CUF) [2] is used to numerically model the different scales. On the one hand, CUF is coupled with Mechanics of Structure Genome (MSG) [3,4] for providing the homogenised thermoelastic properties and retrieving the local stress state at the constituent level. On the other hand, two-dimensional CUF models are employed to predict the coupled thermo-mechanical [5] performance of the macrostructural problem. References: [1] J. Llorca, C. Gonzalez, J.M. Molina-Aldareguia, et al. Multiscale Modeling of Composite Materials: a Roadmap Towards Virtual Testing. Advanced Materials 23(44), 2011. Pages 5130-5147. [2] E. Carrera, M. Cinefra, M. Petrolo, E. Zappino. Finite Element Analysis of Structures through Unified Formulation. Wiley Sons. 2014. ISBN: 978-1-119-94121-7. [3] W. Yu. A unified theory for constitutive modelling of composites. Journal of Mechanics of Materials and Structures 11(4) 2016. Pages 379-411. [4] A.G. de Miguel, A. Pagani, W. Yu, E. Carrera. Micromechanics of periodically heterogeneous materials using higher-order beam theories and the mechanics of structure genome. Composite Structures 180, 2017. Pages 484-496. [5] E. Carrera, F.A. Fazzolari, M. Cinefra. Thermal stress analysis of Composite Beams, Plates and Shells: Computational Modelling and Applications. Academic Press. 2017. ISBN: 978-0-12-420066-1.

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abst. 1123
Repository

The Effect of Poisson's Ratio on the Static and Dynamic Behavior of Carbon Nanotubes Through Doublet Mechanics

Koc, Hilal (hilal.koc@itu.edu.tr), ISTANBUL TECHNICAL UNIVERSITY, TURKEY
Tüfekci, Ekrem (tufekcie@itu.edu.tr), ISTANBUL TECHNICAL UNIVERSITY, TURKEY

Recently, doublet mechanics theory has been utilized in the examination of the static and dynamic behaviors of nanorods and/or nanobeams. Although the value of the small-scale effect is acquainted implicitly in doublet mechanics, it is handled differently and alternates in respect of cases taken in size-dependent theories like stress gradient theory [1], strain gradient theory [2], nonlocal theory of elasticity [3]. Bandow [4] states that the internal characteristic scale of carbon is 0.1421 nm. It is observed that plane-stress assumption is performed and Poisson's ratio is tackled as 1/3 to simplify stress expressions and solve problems tackled in the studies analyzing static behavior [5-7] and dynamic behavior [8-14] of nanorods and/or nanobeams via doublet mechanics. Tu and Qu-Yang [15] specify that Poisson's ratio can be taken from 0.149 to 0.34 for single-walled carbon nanotubes. Lu [16] procures Poisson's ratios as 0.28 and 0.27 in the single and double-walled carbon nanotubes, respectively. This research draws attention to the effects of Poisson's ratio in the investigation of mechanical behaviors of single and double-walled carbon nanotubes in the cases where Poisson's ratio is different from 1/3. To get symbolic stress expressions, implying the connection between micro stress and strain, the micro modulus matrix is presented based on Poisson's ratio. In the literature, diagonal elements of this matrix are equal elasticity modulus and off-diagonal elements are zero, that is to say, this matrix is invariable. Unlike most of the studies presented in the literature, all elements of this matrix depend on elasticity modulus and Poisson's ratio. Elongation micro-strain by using the first three terms in Taylor series expansion is substituted in the elongation micro-stress and the relationship between

macro and micro stress is obtained by executing required arrangements. Thus, stress statements can be ascertained as subject to Poisson's ratio symbolically by making use of this matrix without any hypothesis in the plane stress condition. So, the static and dynamical behaviors of zigzag and armchair carbon nanotubes with variation Poisson's ratio can be scrutinized. To the best of the authors' knowledge, there are no similar studies in the literature to this one. It is thought that the mechanical behaviors of carbon nanotubes can be better understood when they are modeled by considering different Poisson's ratios. Moreover, stress expressions can be easily attained by taking into account less common materials rather than carbon nanotubes. To be procured stress statements can be employed to solve the governing equations with analytical methods and/or numerical methods. REFERENCES: [1] Sudak L.J. Column buckling of multiwalled carbon nanotubes using nonlocal continuum mechanics, Journal of Applied Physics, 2003; 94: 7281-7287. [2] Mindlin R.D. Micro-structure in linear elasticity, Arch. Ration. Mech. Anal. 1964; 16: 51–78. [3] Eringen A.C. Linear theory of nonlocal elasticity and dispersion of plane waves. International Journal of Engineering Science, 1972; 10: 425-435. [4] Bandow S., Asaka S., Saito Y., Rao A. M., Grigorian L., Richter E., Eklund P. C. Effect of the Growth Temperature on the Diameter Distribution and Chirality of Single-Wall Carbon Nanotubes, Phys. Rev. Lett.,1998, 80 (17): 3779-3782. [5] Ebrahimian M.R., Imam A., Najafi M. Doublet mechanical analysis of bending of Euler[U+2010]Bernoulli and Timoshenko nanobeams. Journal of Applied Mathematics and Mechanics, 2018; 1-24. [6] Aydogdu, M., Gul, U. Buckling Analysis of Double Nanofibers Embeded in an Elastic Medium Using Doublet Mechanics Theory, Composite Structures, 2018, doi: https://doi.org/10.1016/j.compstruct. 2018.02.015. [7] Ebrahimian M. R., Imam A. ve Najafi M. The effect of chirality on the torsion of nanotubes embedded in an elastic medium using doublet mechanics. Indian J Phys, 2020; 94(1): 31–45. [8] Fatahi-Vajari A., Imam A. Axial vibration of single-walled carbon nanotubes using doublet mechanics. Indian J Phys, 2016a; 90(4): 447-455. [9] Fatahi-Vajari A. A new method for evaluating the natural frequency in radial breathing-like mode vibration of double-walled carbon nanotube. Journal of Applied Mathematics and Mechanics, 2017; 1-15. [10] Gul U., Aydogdu M and Gaygusuzoglu G. Axial Dynamics of a nanorod embedded in an elastic medium using doublet mechanics. Composite Structures, 2017; 160, 1268-1278. [11] Gul U, Aydogdu M. Noncoaxial vibration and buckling analysis of embedded double-walled carbon nanotubes by using doublet mechanics, Composites Part B 2017b, doi: 10.1016/ j.compositesb.2017.11.005. [12] Gul U., Aydogdu M. Vibration analysis of Love nanorods using doublet mechanics theory, Journal of the Brazilian Society of Mechanical Sciences and Engineering, 2019; 41, 351, https://doi.org/10.1007/s40430-019-1849-x. [13] Fatahi-Vajari A., Azimzadeh Z. Axial vibration of single-walled carbon nanotubes with fractional damping using doublet mechanics. Indian J Phys, 2020; 94(7): 975–986. [14] Eltaher M.A., Mohamed N. Nonlinear stability and vibration of imperfect CNTs by Doublet mechanics, Applied Mathematics and Computation, 2020; 382, 125311, https:/doi.org/10.1016/j.amc.2020.125311. [15] Tu Z-C, Ou-Yang Z-C. Single-walled and multiwalled carbon nanotubes viewed as elastic tubes with the effective Young's moduli dependent on layer number, Phys Rev B, 2002; 65(23): 233407-1–4. [16] Lu JP. Elastic properties of carbon nanotubes and nanoropes, Phys Rev Lett, 1997; 79(7): 1297–300.

Features of DLC + Si coating wear under microcontact conditions

abst. 1132
Repository

Kuznetsova, Tatyana (kuzn06@mail.ru), .V. Luikov Heat and Mass Transfer Institute of the National Academy of Sciences of Belarus, Minsk, Belarus

Lapitskaya, Vasilina (vasilinka.92@mail.ru), A.V. Luikov Heat and Mass Transfer Institute of the National Academy of Sciences of Belarus, Minsk, Belarus

Khabarava, Anastasiya (av.khabarova@mail.ru), A.V. Luikov Heat and Mass Transfer Institute of the National Academy of Sciences of Belarus, Minsk, Belarus

Trukhan, Ruslan (ruslan.trukhan@mail.ru), A.V. Luikov Heat and Mass Transfer Institute of the National Academy of Sciences of Belarus, Minsk, Belarus

Chizhik, Sergei (chizhik_sa@tut.by), A.V. Luikov Heat and Mass Transfer Institute of the National Academy of Sciences of Belarus, Minsk, Belarus

Torskaja, Elena (torskaya@mail.ru), Ishlinsky Institute for Problems in Mechanics, RAS, Moscow, Russia

Fyodorov, Sergei (sv.fedorov@icloud.com), Moscow State Technological University STANKIN, Moscow, Russia

Aizikovich, Sergei (s.aizikovich@sci.donstu.ru), Research and Education Center "Materials", Don State Technical University, Rostov-on-Don, Russia
Sadyrin, Evgeniy (evgeniy.sadyrin@gmail.com), Research and Education Center "Materials", Don State Technical University, Rostov-on-Don, Russia

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abst. 1183
Virtual Room 1
Thursday
July 21
16h30

A novel method of fourth-order orientation tensor approximation for stiffness prediction of short fibre composites

Ogierman, Witold (witold.ogierman@polsl.pl), Silesian University of Technology, Poland

Composites reinforced with short fibres have been applied in various industrial applications due to their myriad advantages. The majority of such materials are manufactured by injection moulding. Designing and predicting properties of composite structures made of the short fibre reinforced composites may be challenging because the fibre orientation distribution is typically non-heterogenous throughout the manufactured part. From the computational point of view involving a multiscale modelling paradigm, each integration point at the macroscale level must be linked with a micromechanical model involving appropriate information related to the orientation distribution. The complete description of the orientation distribution can be provided by the orientation distribution function but it is very often not known in practical applications. Instead, the tensorial description of the orientation state is widely used due to its concise form. The orientation tensors are the dyadic products of the orientation vector and the distribution function. There is an infinite number of these tensors in all the even orders but typically usage of second and fourth-order orientation tensors is sufficient for estimation of effective stiffness tensor with reasonable accuracy. In modern multiscale simulations of structural components made of short fibre reinforced composites the orientation tensors corresponding to the integration points can be estimated by using software for simulation of the injection moulding process. However, this type of software stores only the second-order orientation tensor. In consequence, the fourth-order orientation tensor needed for stiffness predictions must be approximated. Several closure approximations which are based on different assumptions were proposed in literature whose aim is to approximate the fourth-order orientation tensor in terms of known second-order orientation tensor. In the present work, a novel closure approximation based on the solution of the optimization problem will be presented. Accuracy of the proposed approach and capability of statistical description of the reconstructed fourth-order orientation tensor will be discussed. Moreover, the components of stiffness tensor obtained by applying a novel method will be compared with the results obtained by using closure approximations known from the literature.

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abst. 1192
Virtual Room 1
Thursday
July 21
16h50

Thermally induced residual micro-stresses in hybrid composite laminates with tow-level fibre hybridization

Romano, Giuseppe (giuseppe.romano@manchester.ac.uk), The University of Manchester, United Kingdom
Nagaraja Rao, Yeshwanth (yeshwanthn8@gmail.com), The University of Manchester, United Kingdom
Zou, Zhenmin (Zhenmin.Zou@manchester.ac.uk), The University of Manchester, United Kingdom
Potluri, Prasad (prasad.potluri@manchester.ac.uk), The University of Manchester, United Kingdom
Katnam, Kali Babu (kali-babu.katnam@manchester.ac.uk), The University of Manchester, United Kingdom

Conventional thermosetting composites laminates have high specific in-plane properties but low damage tolerance. An approach to enhance damage tolerance in composite laminates is to use tow-level fibre hybridization with thermoplastic fibres. This paper aims to investigate post-cure thermally-induced residual micro-stress fields within the matrix and at the fibre-matrix interface in tow-level fibre hybrid laminates. Three-phase 3D RUCs and RVEs are developed to study the effect of fibre volume fractions, fibre types, fibre distribution on thermally induced residual micro-stress fields. Matrix von Mises stress and interfacial normal and shear stresses are analysed to study matrix and fibre-matrix

interface debonding initiation regions. It is shown that the addition of a second fibre type can influence drastically thermally induced residual stress distribution. Keyword: effective coefficient of thermal expansion, residual stress, hybrid composite, numerical method, representative volume element

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A Numerical Investigation into the Poisson Effect under the Iso-strain and the Iso-stress Conditions

abst. 1285
Virtual Room 1
Thursday
July 21
17h10

Luo, Yunhua (Yunhua.Luo@umanitoba.ca), University of Manitoba, Canada

The Voigt and the Reuss modulus formulas, also known as the rule of mixtures and the inverse rule of mixtures, are the oldest and the simplest equations for the estimation of composite elastic properties. The formulas are derived from the iso-strain and the iso-stress assumptions respectively, which represent the two extreme scenarios that the phase materials in a composite work together. Under the iso-strain condition, the phase materials work in parallel to achieve the maximum stiffness, while under the iso-stress condition, the phase materials work in serial to have the maximum compliance or flexibility. The actual situation is somewhere between the two extremes. The Voigt and the Reuss formulas, as well as their modified versions, have wide applications not only in the study of conventional composites, for example for the estimation of the upper and lower bounds of composites properties and the prediction of the elastic moduli of unidirectionally reinforced composites, but also in the design and characterization of emerging nanocomposites. For the unidirectionally reinforced composites, if the loading is applied only in the longitudinal or in the transverse direction, it appears that the iso-strain or the iso-stress conditions are satisfied, therefore, the formulas should be accurate for the prediction of the longitudinal and the transverse moduli. Nevertheless, the predictions are inaccurate, especially for the transverse modulus. There exist a few discrepancies that are probably responsible for the inaccuracy. First, the Voigt and the Reuss formulas treat the elastic properties as completely independent to each other, for example, the effective Young's modulus and the effective Poisson's ratio of a composite are often predicted separately using the formulas. But the elastic properties are actually related to each other via the elasticity relations. Second, in the Voigt-Reuss model, phase materials are assumed perfectly bonded to each other at their interface, and the Poisson effect is not considered. However, the Poisson effect actually does exist, which can make a difference at either the macroscopic or the microscopic level. The Poisson effect induces different strains into the phase materials, but at the bonded interface the phase strains are 'forced' to be the same. The effect of the above discrepancies on the accuracy of the Voigt and the Reuss formulas have never been studied for either the original formulas or their modified versions. In this paper, we first re-derive the modulus formulas under the iso-strain and the iso-stress conditions, with the Poisson effect considered. Then, we numerically investigate how the Poisson effect influences composite stiffness, by constructing two finite element models where the phase interface is simulated as bonded and sliding respectively. The results show that for the Voigt and the Reuss formulas to be accurate, one of the following two assumptions has to be adopted: (1) the phases have zero Poisson's ratio, and (2) the phase interface is sliding; none of them are valid for composite materials. With a bonded phase-interface and non-zero phase Poisson's ratios, the Poisson effect introduces 'extra' stresses and strains in the non-loading directions, which demands extra strain energy to achieve the same deformation as in the model of sliding interface. The Poisson effect has the effect of increasing composite stiffness, the magnitude of the increase depends on the contrast of phase properties.

Micro-structural effects in phononic dielectric structures

abst. 1365
Repository

Sladek, Vladimir (vladimir.sladek@savba.sk), Institute of Construction and Architecture, Slovak Academy of Sciences, Slovakia
Sladek, Jan (jan.sladek@savba.sk), Institute of Construction and Architecture, Slovak Academy of Sciences, Slovakia
Sator, Ladislav (ladislav.sator@savba.sk), Institute of Construction and Architecture, Slovak Academy of Sciences, Slovakia
Li, Yueqiu (liyueqiu2004@163.com), Department of Mathematics, Qiqihar University, China

Based on the higher-grade continuum theory, propagation of longitudinal as well as transversal anti-plane elastic waves in normal direction to nanoscale periodic laminates of piezoelectric dielectrics is studied in this paper. The strain gradients, micro-inertia and direct flexoelectricity phenomena are incorporated into the phenomenological description. The problem is analysed as one-dimensional and the governing equations together with possible boundary conditions are derived from the variational principles. It is shown that the transversal waves are not affected by the electric polarization in contrast to the longitudinal waves. The developed formulation is applied to 1D Bloch waves obeying perfect boundary conditions periodical in bi-material laminates and the transfer matrix method is used for derivation of dispersion equation. The influence of the micro-stiffness and micro-inertial length scale parameters as well as flexoelectric coefficients on the dispersion curves and the band-gaps is investigated in parametric study. Acknowledgements: The financial supports by the Slovak Research and Development Agency through grant APVV-18-004 as well as VEGA-2/0061/20 are gratefully acknowledged.

Damage modelling of woven carbon fiber and epoxy matrix composite sandwiches under impact loadings

abst. 1070
Virtual Room 1
Tuesday
July 19
16h50

LACHAUD Frédéric (frederic.lachaud@isae-supaero.fr), Institut Clément Ader UMR CNRS 5312, France
RIGANTI Mattteo (matteo1.riganti@mail.polimi.it), Polytechnique MILAN, Italy
SIMARRO Pau (pau.simarro@gmail.com), ISAE-SUPAERO, Italy
JEZEGOU Joel (Joel.JEZEGOU@isae-supaero.fr), ISAE-SUPAERO, France

NOMEX carbon fiber skin and honeycomb core sandwich composites are used in aeronautics for secondary structures (landing gear hatch, fin or wing flap, etc.) [1], for primary structures for light aviation and for satellite panels or parabolic antennas in the space industry [2]. During their handling or during their use, these structures are subjected to impacts which can leave relatively important damage. For secondary structures, these faults are not vital but can lead to moisture pick-ups in NOMEX in particular. On the other hand, for primary structures, this damage can greatly reduce the stiffnesses and lead to local over-stresses which must be taken into account during sizing. The objective of this work is to model the response to the impact of sandwich structures for application in light aviation where the manufacturing processes used are said to be "low cost". As part of the sizing of this type of structure, a qualification of the structures for impact and post-impact resistance (damage tolerance) must be carried out. The sandwich studied is a sandwich with woven carbon fiber skin and a NOMEX honeycomb core. After fabrication and performance of mechanical tests at the material scale, the methodology for identifying ply behavior models and NOMEX is presented. The results of impact tests are compared with numerical finite element modeling in explicit analysis. The overall force-displacement-time behavior as well as the perforation of the panels are analyzed. The sandwich studied is a glued assembly of woven carbon fiber skins with an epoxy matrix of reference HexPly 914 / G803 with a Satin weave of 5, 300 g / m2 supplied by HEXCEL and a honeycomb core of reference HRH-78-1 / 8-3.0 from DuPont®. The manufacture of the sandwich panels is carried out by co-firing, that is to say that the gluing of the skins on the NOMEX honeycomb is carried out by the "flow" of the resin of the folds. The compaction pressure is 2 bars. Modélisation du comportement des peaux carbones et du NOMEX. Each component of the sandwich panel has been the subject of an experimental campaign in order, on the one hand, to determine the mechanical characteristics such as modulus of elasticity, stress and strain at break, but also to identify and model their behavior. Each component of the sandwich panel has been the subject of an experimental campaign in order, on the one hand, to determine the mechanical characteristics such as modulus of elasticity, stress and strain at break, but also to identify and model their behavior. The behavior model used derives from that initially described by Lachaud et al. [3], and applied to impact by Kinvi-Dossou et al. [4]. It was modified for the study under consideration by a non-local crack band-type approach [5] in order to better respect the breaking energies in the direction of the fibers. The ply-scale model of the tissue behavior introduces diffuse damage variables based on a thermodynamic approach and fracture variables based on the fracture energy determined in the fiber direction and in the matrix. The experimental campaign making it possible to identify this behavior model is based on cycled tensile and compression tests, fracture mechanics tests in mode I and II but also tests on notched specimen (CT) for the determination of the energies of breaking up. The NOMEX honeycomb supplied by DuPont® consists of sheets of aramid fibers impregnated with phenolic resin. The modeling of the sandwich core having been chosen at the scale of the NOMEX cell, the supposedly isotropic mechanical characteristics of the sheet constituting the NOMEX were determined by tensile tests. In order to validate the behavior model of the NOMEX honeycomb, crushing tests were carried out on 50x50mm2 specimens for a NOMEX 11.5 mm thick. The test tube consists of two 2mm thick aluminum skins glued cold to the NOMEX by epoxy glue. A test-calculation comparison is presented in figure 3b. The model is carried out explicitly under ABAQUS. The main obstacle concerning these models is the representation of the instability of the behavior (behavior peak) due to the buckling of the NOMEX cells greatly influenced by the initial geometric shape of the cells. A random displacement [6-7] of the nodes of the mesh constituting the cells of NOMEX was carried out for a better representativeness of the peak. The impact tests were performed under a drop tower. The impactor has a hemispherical shape with a diameter of 16 mm. Sandwich panels measuring 150x100x12.5 mm3 are placed on a 100x75mm window allowing the

displacement on the face opposite to the impact to be measured by a laser sensor. The impact force is measured by a piezoelectric sensor located in the impactor. The impact velocity is calculated by two photodiode cells whose signal is cut off when the impactor passes through the moment of impact. The mass of the impactor is 2.36 kg. Several speeds were used during this test campaign. A typical example of test results is shown in Figure 4 for three identical tests. The behavior has several phases attributed to: - first (first peak) at the perforation of the upper skin of the sandwich and the initiation of buckling of the NOMEX cells, - in the second phase (plateau) with the crushing of the NOMEX then with the accumulation of the NOMEX crushed under the impactor, - in the third phase (second peak) at the perforation of the lower carbon skin of the sandwich, - finally, the highest peak is due to the impactor tooling (upper part of the hemispherical impactor) which presses on the upper skin of the sandwich. The digital finite element model (figure 5) introduces the behaviors of the carbon skins and the NOMEX core identified previously. The model uses C3D8 solid elements for the skins and soul. The panel support as well as the impactor are modeled as rigid elements. A contact condition with friction is used. The skins and the soul are connected by a condition of "tie" type collages in Abaqus. The resolution algorithm is self-explanatory. The force-time behavior recorded numerically makes it possible to distinguish the phases of the behavior obtained experimentally. The perforation of the upper skin as well as the crushing of the NOMEX are transcribed by the model. References: [1] Mathilde Jean-St-Laurent, Marie-Laure Dano, Marie-Josée Potvin. Compression after impact behavior of carbon/epoxy composite sandwich panels with Nomex honeycomb core subjected to low velocity impacts at entreme cold temperatures. Composites Structures, Vol 261, 2021, 113516. [2] İsmail Özen, Kutay Çava; Hasan Gedikli, ÜmitAlver, MustafaAslan Low-energy impact response of composite sandwich panels with thermoplastic honeycomb and reentrant cores, Thin-Walled Structures, Vol 156, November 2020. [3] Lachaud F., Piquet R., Aldebert G., Huet J., Michel L. Analyse du comportement mécanique des assemblages boulonnés composites à renforts tissés, Revues des Composites et des Matériaux Avancés Vol. 24, n° 4, novembre 2014, pp. 449-464 [4] Kinvi-Dossou G., Bonfoh N., Matadi Boumbimba R., Koutsawa Y., Lachaud F., Nyoungue A., Gerard P.A mesoscale modelling approach of glass fibre/Elium Acrylic woven laminates for low velocity impact simulation. Composite structures, Vol. 252, 112671, 2020 [5] Lachaud F., Boutin M., Espinosa C., Hardy D. failure prediction of a new sandwich panels based on flax fibres reinforced epoxy bio-composites. Composite Structures, 2021. [6] Asprone D, Auricchio F., Menna C, Morganti S., Prota A. Reali A. Statistica Statistical Finite element analysis of the buckling behavior of honey comb structures, Composites Structures Vo. 105 pp. 240-255, 2013 [7] Giulia Palomba, Gabriella Epasto, Vincenzo Crupi, Eugenio Guglielmino Single and double-layer honeycomb sandwich panels under impact loading, International Journal of Impact engineering , Vol 121, November 2018, pp 77-90

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abst. 1323
Repository

Experimental and numerical study on the effect of interlaminar properties on the structural properties of steel/polymer/steel crashboxes

Harhash, Mohamed (mohamed.harhash@tu-clausthal.de), Institute of Metallurgy (IMET), Clausthal University of Technology, 38678 Clausthal-Zellerfeld; Clausthal Centre for Material Technology (CZM), Clausthal University of Technology, 38678 Clausthal-Zellerfeld, Germany
Kuhtz, Moritz (moritz.kuhtz@tu-dresden.de), Institute of Lightweight Engineering and Polymer Technology (ILK), Technische Universität Dresden, 01307 Dresden, Germany
Richter, Jonas (jonas.richter@tu-dresden.de), Institute of Lightweight Engineering and Polymer Technology (ILK), Technische Universität Dresden, 01307 Dresden, Germany
Hornig, Andreas (andreas.hornig@tu-dresden.de), Institute of Lightweight Engineering and Polymer Technology (ILK), Technische Universität Dresden, 01307 Dresden, Germany
Gude, Maik (maik.gude@tu-dresden.de), Institute of Lightweight Engineering and Polymer Technology (ILK), Technische Universität Dresden, 01307 Dresden, Germany
Palkowski, Heinz (heinz.palkowski@tu-clausthal.de), Institute of Metallurgy (IMET), Clausthal University of Technology, 38678 Clausthal-Zellerfeld, Germany; Samara National Research University, 443086 Samara, Russia, Germany

The deformation and failure behavior of components made of metal/polymer/metal (MPM) sandwich sheets are affected by several material-related parameters such as stiffness and strength of the single components. In particular, the adhesion properties of the metal-polymer interface influence the delamination behavior and the accompanying structural behavior under highly dynamical loads. Therefore, the research presented here investigates methods to selectively tune the interface properties, both globally and locally, to tailor the failure behavior and associated energy absorption capacity of hybrid double-hat and top-hat crashboxes under quasi-static as well as highly dynamical axial crush and three-point bending loads, respectively. Three conditions of global adhesion properties, i.e. no, weak and strong bonding, are considered. These conditions are obtained by controlling the sandwich processing parameters such as curing time and temperature of the adhesive agent. It was found that energy absorption of the crashboxes without adhesion was reduced by about 50%, showing a global buckling failure compared to the progressive collapse of the crashboxes with strong adhesion [1]. The local interface properties were designed, so that a 10-mm wide delamination area is created at the top side of the double-hat crashbox. The results have revealed that with these areas, the crushing collapse mode was significantly affected and improved, resembling the effect of the bead triggers applied earlier [2]. The structural failure of the MPM crashboxes under highly dynamical axial crush and three-point bending loads is modelled in LS-DYNA, using a strain rate dependent material formulation, where the delamination failure of the hybrid interfaces is the focus of the numerical investigations. A mixed experimental-numerical approach [3] is used to calibrate the interface and material model parameters, where deformation and failure results are used for a qualitative calibration. Additionally, force-displacement-curves and strain fields determined by 3D high-speed DIC on the folding behavior of the crashboxes are used for quantitative correlations. With the derived validated simulation strategy for modifying the interface properties to increase the specific energy absorption capability and crush efficiency are explored. The derived modelling results of the failure modes and the structural response are compared with the experimental investigation analyzing the influence of the global and local interface properties. Keywords: metal-polymer interface properties; delamination modelling, crashbox; crushing properties; FEA modeling and simulation; LS-DNYA; References: [1] Harhash M, Kuhtz M, Richter J, Hornig A, Gude M, Palkowski H. Influence of Adhesion Properties on the Crash Behavior of Steel/Polymer/Steel Sandwich Crashboxes: An Experimental Study. Metals. 2021; 11(9):1400. https://doi.org/10.3390/met11091400. [2] Harhash, M.; Kuhtz, M.; Richter, J.; Hornig, A.; Gude, M.; Palkowski, H. Trigger geometry influencing the failure modes in steel/polymer/steel sandwich crashboxes: Experimental and numerical evaluation. Compos. Struct. 2021, 262, 113619. [3] Richter, J.; Kuhtz, M.; Hornig, A.; Harhash, M.; Palkowski, H.; Gude, M. A Mixed Numerical-Experimental Method to Characterize Metal-Polymer Interfaces for Crash Applications. Metals 2021, 11, 818, doi:10.3390/met11050818.

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abst. 1018
Virtual Room 1
Thursday
July 21
17h30

Development of a new flexible wing concept for unmanned aerial vehicle using corrugated core made by 4D printing of composites

Hoa, Suong (hoasuon@alcor.concordia.ca), Concordia University, Canada
Abdali, Marjan (marjanabdali5@gmail.com), Concordia University, Canada
Jasmin, Anick (anickjasmin@gmail.com), Concordia University, Canada
Radeschi, Daniel (dreads.concordia@gmai.com), Concordia University, Canada
Ladous, Victor (vpratsladous@gmail.com), Concordia University, Canada
Faour, Hadi (hadifaourvanier@gmail.com), Concordia university, Canada
Kobaissi, Backar (backar_ kobaissi@hotmail.com), ,

For improved aerodynamic performance, it is desirable that aircraft wing shape can be modified and controlled during flight. The modification of the wing shape has been done using the morphing wing concept. For this, a portion of the wing trailing edge is connected to the main part of the wing. Through the connection, the tail can be rotated relative to the fixed part of the wing. The total configuration of the wing can be modified by the rotation of the tail. The rotation of the tail is usually done using some mechanical mechanism, actuated by some motor located within the wing box. In order to provide stiffness at any particular configuration, the tail part has to be fairly rigid. As such, a strong motor and strong linkage mechanism are required in order to rotate the tail. There is also a maximum limit for the angle of rotation. Wing structures are usually made of lightweight composite materials, in the form of sandwiches. The sandwiches have a core which is usually a solid honeycomb. In order to facilitate the rotation of the tail, in 2006, Yokozeki et al [1] suggested using a corrugated core. The corrugated core would provide stiffness along the span direction, while it provides flexibility along the chord direction. Yokozeki et al. [1] suggested making the composite corrugation by laying up composite layers on corrugated molds. This is possible. However, it is time- consuming and can be costly due to the need to machine molds with complex geometry. In 2019, Filipovic and Kress [2], citing the concept proposed by Hoa [3] on 4D printing of composites, proposed to make the corrugated core by the 4D printing of composite concept. In this paper, a wing tail with corrugated composite core was developed using the 4D printing of composite concept. Apart from the corrugation, composite skins were also developed to make the whole wing tail structure. The wing loading for lightweight Unmanned Aerial Vehicles has been used to size up the airfoil. A few samples have been made and tested. The results show that the concept of the flexible wing using corrugated composite is very feasible, both from the economic and performance points of view. References: 1. Yokozeki T. Takeda S., Ogasawara T., Ishikawa T., "Mechanical properties of corrugated composites for candidate materials of flexible wing structures", Composites, Part A, Applied Science and Manufacturing, Vol. 37, No. 10, 2006, pp. 1578-1586. 2. Filipovic D.T., and Kress G.R., "Manufacturing method for high amplitude corrugated thin-walled laminates", Composite structures, Vol. 222, 2019, 110925. 3. Hoa S.V., "Factors affecting the properties of composites made by 4D printing", Advanced manufacturing: Polymers Composite Science, 2017, 3, pp. 1-9.

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

THERMAL BUCKLING ANALYSIS OF LAMINATED CONICAL SHELLS CONTAINING CARBON NANOTUBE PATTERNED LAYERS WITHIN DIFFERENT SHEAR DEFORMATION THEORIES

abst. 1077
Virtual Room 2
Thursday
July 21
10h00

Mahmure, Avey (mahmureavey@gmail.com), Division of Mathematical Engineering in Graduate School of Istanbul Technical University, 34469 Istanbul Turkey, Turkey
Fantuzzi, Nicholas (nicholas.fantuzzi@unibo.it), University Bologna, Italy

Conical shells designed as load-bearing elements are exposed to a heat source, temperature fluctuations and / or boundary constraints create thermal stresses. These heat loads can increase to such an extent that buckling occurs. The increasing use of new generation heterogeneous materials such as FG-CNTRC in modern technology increases the interest in the thermoelastic behavior of laminated shells consisting of them [1-4]. This study presents the thermoelastic stability of laminated conical shells consisting of carbon nanotube (CNT) patterned layers under thermal loading in the framework of shear deformation theories (SDTs). The material properties of the layers are taken to be independent on the temperature. The Donnell shell theory is used to derive the governing equations of laminated truncated conical shells consisting of CNT patterned layers. Then the Galerkin method is applied to the basic equations to find the expression for critical temperature within SDT. The influence of changes of CNT patterns, the volume fraction, the number and arrangement of layers on the critical temperature within SDTs is investigated.

Nano-Composites

abst. 1078
Room B035
Thursday
July 21
17h30

Establishing the polymer effect on the viscoelastic properties of CNTs reinforced PEI and PEEK

Kayginok, Fulden (fkayginok@gmail.com), Aerospace Research Center and Faculty of Chemical and Metallurgical Engineering, Istanbul Technical University, Turkey
Karabal, Merve (mervekarabal1999@gmail.com), Aerospace Research Center and Faculty of Aeronautics and Astronautics, Istanbul Technical University, Turkey
Yıldız, Alptekin (alyildiz@itu.edu.tr), Aerospace Research Center and Aviation Institue, Istanbul Technical University, Turkey
Yildiz, Kaan (yildizkaa@itu.edu.tr), Aerospace Research Center and Aviation Institue, Istanbul Technical University, Turkey
Cebeci, Hulya (geyikh@itu.edu.tr), Aerospace Research Center and Faculty of Aeronautics and Astronautics, Istanbul Technical University, Turkey

Reinforcing through the integration of nanomaterials may bring several benefits to engineering plastics used in many advanced applications. One particular advancement through reinforcing carbon nanotubes (CNT) to polymers is bringing multifunctionality to the structure that also enhances durability and simplifies design by bringing structural and non-structural properties at weight, volume, or cost reductions. However, challenges such as agglomeration of CNTs and increased viscosity at high CNT loadings persist in the development of polymer nanocomposites especially in high-temperature processing polymers such a polyetherimide (PEI), polyetheretherketone (PEEK). Especially when differences arising from the chain mobility such as amorphous to semi-crystalline are considered, properties such as thermal and mechanical may be subject to change upon the operating temperatures to be above or below Tg. In this study, the effect of CNT reinforcement on viscoelastic properties of PEI and PEEK polymers was investigated by oscillator rheology and dynamic mechanical analysis (DMA) method. CNT reinforced PEI and PEEK composites were produced using a specially designed twin-screw extruder at 1, 3, and 5 wt.% at 210 rpm and 360 [U+2103] and 380 [U+2103] for CNT/PEI and CNT/PEEK composites, respectively. Thermogravimetric (TGA) and differential scanning calorimetry (DSC) analyzes were performed to examine the thermal properties of the samples. It was observed that the decomposition temperatures in PEI samples showed two-stage decomposition depending on the aromatic group and non-aromatic group decomposition, and their thermal stability was found as about up to 500 [U+2103], whereas in PEEK samples, decomposition occurred in a single step due to ether and ketone groups and their thermal stability was found as about up to 550 [U+2103]. It was seen that CNT did not significantly affect the thermal stability of polymers. In addition, CNT almost did not change the glass transition temperature of polymers, but it increased the crystal ratio by acting as the nucleation factor for PEEK composites, and the highest crystal ratio was obtained from 1 wt.% CNT/PEEK composite. Rheology analysis showed that the linear viscoelastic region (LVR) narrowed with CNT, that is, the critical strain value decreased, which was explained as evidence of the formation of a brittle solid network in the structure. In addition, the frequency-dependent results in LVR showed that the storage modulus of both polymers increased with the increase in the amount of CNT, and the frequency dependence decreased. The frequency dependence of the storage modulus was exponentially 0.7 and 1.57 for neat PEI and PEEK, and these values were calculated as 0.32 and 0.27, respectively, in 1 wt.% CNT reinforcement. The decrement of frequency dependency and sudden increase in 1 wt.% CNT reinforcement was interpreted as an indication of the structure change, and the rheological percolation threshold was determined below 1 wt.% CNT reinforcement was also proved by drawing Cole-Cole curves that are a clear representation for the transition from the liquid-like to the solid-like structure. Additionally, the complex viscosity values increased with CNT in both polymers and changed the behavior from Newtonian to shear-thinning in the low-frequency region. On the other hand, DMA results showed that CNT reinforcement increased the storage modulus of polymers in both glassy and rubbery regions, and the interaction between CNT-polymer was evaluated by some analytical approaches. It was calculated that C factor and adhesion factor values decreased while the increase in the degree of entanglement and volume of the constrained region with the presence of CNT, was explained as an indication of high interaction and effective reinforcement in CNT/PEI and CNT/PEEK composites. The C factor values were calculated as 0.34 and 0.70, respectively, for 5 wt.% CNT/PEI and 5 wt.% CNT/PEEK composites. Consequently, considering all the results related to viscoelastic

properties, it can be said that CNT caused changes in the structure of both PEI and PEEK, and an increase in storage modulus was observed.

Void Detection of Nano-Grout using Heating and Magnetic Property

abst. 1121
Repository

Heeyoung Lee (heeyoung0908@chosun.ac.kr), Chosun University, Republic of Korea
Sanggyu Park (gyu2644@gmail.com), Kyung Hee University, Republic of Korea
Yangsub Shin (yaangsub@khu.ac.kr), Kyung Hee University, Republic of Korea
Wonseok Chung (wschung@khu.ac.kr), Kyung Hee University, Republic of Korea

Voids of grout in prestressed concrete (PSC) bridge can cause a corrosion of steel strands. This study was investigated to detect voids in nano-grout mixed with multi-walled carbon nanotube (MWCNT). Nano-grout specimens were fabricated with dimensions of ø100×200 mm. Test parameters were filling rate of grout and MWCNT concentrations. Heating experiment and magnetic field measurement were conducted to compare the temperature variations and magnetic field strength. As a result, 1.0wt% MWCNT nano-grout mixed has the largest temperature variations and magnetic field strength. The temperature variations and magnetic field strength decreased as the concentrations of MWCNT decreased. This study predicts that detecting voids in nano-grout mixed with MWCNT was possible by measuring the temperature variations and magnetic field strength.

Mechanical, physical, and thermal properties of the particle-blended epoxy adhesive for composite repair application

abst. 1148
Repository

Lai, Wei Liang (lai_weiliang@hotmail.com), Newcastle University, Singapore
Saeedipour, Hamid (hamid_saeedipour@rp.edu.sg), Republic Polytechnic, Singapore
Goh, Kheng Lim (kheng-lim.goh@ncl.ac.uk), Newcastle University, Singapore

Purpose: Adhesive is a key component for succeeding in repairing impact damaged fibre reinforced composite structures, by introducing the adhesive into all cracks to form a new matrix phase in the composite structures. Here, we investigated the mechanical, physical, and thermal properties of the epoxy adhesive for repair application. Materials: Two commercial types of epoxy adhesives (namely EpoTek 301 and NanoForce E100) were used. EpoTek 301 is a bisphenol A diglycidyl ether resin, while NanoForce E100 is a bisphenol A/F epichlorohydrin that was blended with CNTs by the manufacturer. For adhesive with nanoparticles, a mass concentration of 1, 3, 5 and 9 % of halloysite nanotubes (HNT) and 1 % of multi-walled carbon nanotubes (MWCNT) were blended into the EpoTek 301. Methods: For mechanical properties, the micro-mechanical tensile test and lap shear test were performed. The micro-mechanical tensile test was used to assess the adhesive tensile strength that were formed in the microcracks after repair, and the lap shear test was used to assess the adhesion strength of the adhesive to the composite laminates. For physical properties, the contact angle measurement and rheological test were performed. The contact angle measurement was used to assess the adhesive wettability to the composite laminate, and the rheological test was used to assess the adhesive viscosity at different shear rate for flowability in cracks of damaged laminates. For thermal properties, the adhesive thermal stability was assessed using thermogravimetric analysis (TGA) method, and the differential scanning calorimetry (DSC) analyser was used to derive the activation energy (Kissinger's method) for curing of adhesive mixture. Results: The micro-mechanical tensile test showed that the neat epoxy and epoxy with 1 wt% HNTs resulted in the highest magnitude of tensile strength (89 MPa). No trend of the adhesive strength in relation to the HNT concentration were observed, however, adding more than 1 wt% HNT in adhesive deteriorates the tensile strength by about 50%. Also, adding MWCNTs into the neat epoxy adhesive does not enhance the adhesive strength. The lap shear test showed that the adhesion strength were not enhanced with the presence of nanoparticles blended in adhesive. Furthermore, the adhesion strength may be compromised due to particles agglomeration that degraded the interface between adhesive and nanoparticles. The contact angle measurement showed that the adhesive droplets with 3 wt% HNTs, or lower, did not enhance the wetting properties as compared to the neat epoxy adhesive. The adhesive

with surfactant-treated CNTs shows enhanced wettability, mainly due to the reduction of Van der Waals attraction between the treated nanotubes in the epoxy adhesive. The rheological test showed that the adhesive viscosity increased with increasing nanoparticles concentration. All adhesive types revealed shear thinning behaviour where the adhesive viscosity decreased when the shear rate increased. The TGA showed that all adhesive blends were thermally stable from room temperature to approximately 320oC. Thereafter, the adhesive degraded until char residue were obtained. The mass of char residue increased with increasing nanoparticles concentration in adhesive. The DSC showed that the duration to reach the adhesive exothermic peak decreases with increasing temperature ramp rate. The Kissinger's activation energy showed that the neat epoxy adhesive and adhesive with 1 wt% untreated MWCNTs resulted in the highest magnitude of 64 kJ/mol K. Furthermore, the adhesive with HNTs exhibited lower activation energy than the neat epoxy adhesive. Conclusion: The findings concluded that, apart of rheological properties, the mechanical, physical, and thermal properties of different adhesive blends showed no appreciable difference between the neat epoxy adhesive and adhesive with less than 5 wt% HNTs. For rheological properties, the adhesive with CNTs resulted in the highest viscosity as compared to neat epoxy adhesive and adhesive with HNTs, which may cause poor adhesive infiltration into cracks of damaged laminates. Here, we prudently select three different adhesive blends, namely neat epoxy adhesive, adhesive with 1 wt% HNT (E1HNT), and NanoForce E100 for the composite repair application. The neat epoxy adhesive was selected due to its high micromechanical tensile strength and low viscosity, while E1HNTs and NanoForce E100 were selected due to its low viscosity as compared to the different adhesive blends with nanoparticles.

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abst. 1160
Virtual Room 1
Thursday
July 21
15h10

Trial of a spinning method to control the cross-sectional shape and investigation of dimensional effects of carbon nanotube yarns

Tateiwa, Rina (tateiwarina@akane.waseda.jp), Waseda university, Japan
Atsushi, Murata (a24penchan@fuji.waseda.jp), Narita International airport corporation (present), Waseda university (former), Japan
Kawada, Hiroyuki (kawada@waseda.jp), Waseda university, Japan
Hosoi, Atsushi (hosoi@waseda.jp), Waseda university, Japan

In recent years, there has been a demand for miniaturization and weight reduction in electronic devices and transportation equipment, as well as for lighter wiring materials and finer circuits. .Carbon nanotubes (CNTs) have been attracting attention as a new wiring material that can meet the needs for convenience, economy, and energy conservation. Individual CNTs have superior electrical properties compared to copper, which is currently used as a major wiring material. However, the maximum length of a single CNT that has been achieved is a few centimeters, and further macro scaling is necessary for industrial use. Therefore, attempts are being made to create a long structure by spinning individual CNTs into a thread. In this study, in order to explore the possibility of using dry-spun CNT yarns as electric wires, we attempted to control the cross-sectional shape of CNT yarns and investigated the size effect of conductivity. The dry spinning method is advantageous in terms of industrial production because it enables spinning without the use of hazardous chemicals or complicated equipment. In previous studies, it was reported that the cross-section of CNT yarn was deformed during the doping process. Therefore, as an approach to controlling the cross-sectional shape, we devised an array arrangement during spinning. As a result, we were able to suppress the deformation of the cross-section during doping treatment with iodine monochloride by dividing the web width and spinning from arrays placed at multiple locations. This result may be useful for the industrial production of CNT yarns, because the technique to suppress the cross-sectional deformation is considered to be necessary for the production of homogeneous CNT yarns. The relationship between the diameter and conductivity of CNT yarns has not been investigated before, so it was investigated in this study. As an approach to investigate the dimensional dependence of conductivity, we investigated in this study was to compare the conductivity between two types of CNT yarns with diameters of around 25[U+339B] and 33[U+339B]. The results showed that the conductivity of the finer yarn was higher than that of the thicker yarn at the similar apparent density. Specifically, the average diameter, average apparent density, and average conductivity were 26.3 mm, 0.309 g/cm3, and 3.16×104 S/m for the fine yarn and 38.6 mm, 0.284 g/cm3, and 2.20×104 S/m for the large diameter yarn, respectively. In other words, the average apparent density

of the fine yarns was only 8.8% higher, while the average conductivity was 43.6% higher. This trend was also maintained when the yarns were treated with polyacrylic acid or iodine monochloride. These results indicate that the thicker diameter of CNT yarns leads to a decrease in conductivity, and it is necessary to take measures to prevent this from happening when considering the industrial use of CNT yarns.

Effects of Heat Treatment and MWCNTs on Scratch Resistance of the Epoxy Resin doped with TiO2

abst. 1369
Poster

Mucha, Mateusz (m.mucha@law.mil.pl), Polish Air Force University, Poland
Duda, Jarosław (j.duda4400@wsosp.edu.pl), 41 Baza Lotnictwa Szkolnego, Poland
Zwarycz, Dominik (d.zwarycz4438@wsosp.edu.pl), 41 Baza Lotnictwa Szkolnego, Poland
Szczepaniak, Robert (r.szczepaniak@law.mil.pl), Polish Air Force University, Poland
Krzyzak, Aneta (a.krzyzak@law.mil.pl), Polish Air Force University, Poland
Kościński, Mikołaj (mikolaj.koscinski@amu.edu.pl), NanoBioMedical Centre at Adam Mickiewicz University and Poznań University of Life Sciences, Poland
Sterzynski, Tomasz (tomasz.sterzynski@put.poznan.pl), Poznan University of Technology, Poland
Sałaciński, Michał (michal.salacinski@itwl.pl), Air Force Institute of Technology, Poland

In our previous research, we have investigated the effects of heat treatment and MWCNTs (Multi Walled Carbon Nanotubes) on selected mechanical properties of the EP (epoxy resin) doped with titanium dioxide (TiO2) powder. The methods included determination of tensile (ISO-527), flexural (ISO-178) and compressive (ISO-604) properties as well as DMA (Dynamic Mechanical Analysis) in the temperature range from -70.0 to 120.0 °C. Moreover, the Raman spectroscopic characterization of the MWCNT powder was carried out. The aim of this paper is to is to extend the study of the EP/TiO2/MWCNTs nanocomposite. In order to prepare the samples, the MGS L285 epoxy resin was doped with TiO2 (5.0 and 20.0 wt.%) and MWCNTs (0.0, 0.5, 1.0 and 2.0 wt.%). The subsequent steps included mechanical mixing, hardener addition, bubble removal in the vacuum chamber, casting to silicone molds and heat treatment for 15 hours (at 50, 60 and 80 °C or ambient temperature for reference). The scratch testing was applied by means of the Bruker UMT Tribolab. The scratch topography was determined by the RTF MicroProf 100 optical profilometer. Moreover, Shore D hardness measurements, Charpy impact testing, SEM (Scanning Electron Microscopy) imaging and electrical conductivity measurements were carried out. Additionally, the properties of MWCNTs were determined in the TEM (Transmission Electron Microscopy). The study provided new insight into the effects of heat treatment and MWCNT on the TiO2/epoxy composite with the selected concentrations of titanium dioxide.

Natural Fibre Composites

abst. 1054
Room B035
Tuesday
July 19
12h10

On the buckling behavior of nonlinear biodegradable composite columns

WANG, LIU JIAO (lwang@pa.uc3m.es), Department of Continuum Mechanics and Structural Analysis. Universidad Carlos III de Madrid, SPAIN
SANTIUSTE ROMERO, CARLOS (csantius@ing.uc3m.es), Department of Continuum Mechanics and Structural Analysis. Universidad Carlos III de Madrid, SPAIN

There are no studies in the open literature about an effective analytical formulation to predict the critical buckling load of flax fiber reinforced PLA biocomposite columns. Comprehensive studies are necessary for this type of biocomposite as its application in the industrial field seems to grow in recent years. Therefore, the present work aims to prove the accuracy of prediction of the critical buckling load using an equation developed from the modified Ludwick non-linear elastic constitutive law. For this objective, comparative analyses were carried out through experimental and finite element approaches. First, flax/PLA specimens were manufactured using compression molding method. Specimens with different geometries were subjected to buckling tests to obtain the experimental critical load as a function of the geometric parameters. A numerical model was developed using the ABAQUS/Standard and it was validated with the experimental test data. In this process, a non-linear elastic model was included since the constitutive response of natural fiber reinforced polymer composite materials showed non-linear behavior. Finally, the theoretical and numerical predictions were compared with the experimental values. Results show that the average error of predictions from the FE method is 7.49%, and the average error of the theoretical prediction for the critical buckling load of flax/PLA is 4.05%. As a conclusion of this part of the study, both predictions of the critical buckling load of flax/PLA are acceptable. Additionally, a parametric study was developed to analyze the influence of the main geometric parameters and the elastic properties of the material. ***[Liu Jiao Wang is one of the Winner of the Ian Marshall Award for Best Student Paper]***

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abst. 1194
Virtual Room 1
Wednesday
July 20
15h10

Assessment of innovative bio-composite materials by experimental tests

Magagnini, Erica (e.magagnini@staff.univpm.it), Università Politecnica delle Marche, Italy
Bettucci, Elisa (eli_bt@hotmail.it), Università Politecnica delle Marche, Italy
Khatir, Abdelwahhab (a.khatir@pm.univpm.it), Università Politecnica delle Marche, Italy
Khatir, Samir (samir.khatir@ugent.be), Ghent University, Belgium

Nowadays, the current issues of sustainable development require a reflection on the need to implement strategies aimed at reducing the consumption of raw materials and energy by saving natural resources. The development of innovative and ecologically sustainable techniques in the field of civil engineering is one of the duties appointed to structural engineering. From this point of view, the development of composite material made with natural fibre instead of conventional synthetic fibres has become a crucial issue. Natural Fibre Reinforced Composite (NFRC) materials are gaining popularity in a multitude of sectors due to their interesting specific mechanical properties and low environmental effect, making them a viable and environmentally acceptable alternative to composites produced from synthetic polymers. The current research work shows an experimental approach to assess the mechanical properties of NFRC and FRP materials. Static tests together with non-destructive testing (NDT) method based on vibration analysis are conducted to characterize the behaviour of wood fibre-epoxy plates made by date palm petiole particles. In addition, the fatigue response of composites made with different types of fibres has been investigated with the aim to monitor and assess the damage mechanisms developed in the materials. Results of the experimental campaign are given and a discussion on the mechanical parameters of NFRP and FRP materials is shown.

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abst. 1205
Virtual Room 1
Wednesday
July 20
15h30

Numbers don't lie: Does the new sustainability agenda require a switch to biocomposites in the design of marine composite structures?

Proud, William (will.proud@bristol.ac.uk), Bristol Composites Institute - University of Bristol, United Kingdom
Trask, Richard (r.s.trask@bristol.ac.uk), Bristol Composites Institute - University of Bristol, United Kingdom
Hamerton, Ian (ian.hamerton@bristol.ac.uk), Bristol Composites Institute - University of Bristol, United Kingdom
Longana, Marco (m.l.longana@bristol.ac.uk), Bristol Composites Institute - University of Bristol, United Kingdom

A driving factor in many design decisions being made within the engineering industry is the need to meet legislated environmental targets. Within the marine industry, fibre reinforced polymer composites (FRPCs) used in service have traditionally comprised glass fibre reinforcement with an epoxy matrix. Biocomposites, comprised of a combination of bio-fibres and bio-resins have begun to see uptake in the marine industry. This work explores the implications of replacing synthetic with bio constituents in FRPCs by applying a Life Cycle Engineering (LCE) framework to the design of a marine structural component. Assessing the modified Trible Bottom Line (mTBL) of economic, environmental and technical factors can be achieved through the Life Cycle Engineering (LCE) design philosophy. LCE assesses the performance of a design or re-design over the three phases of a product/goods' life cycle; production, use and end of life. Considering the entire life cycle in the design phase enables the investigation of trade-offs between mTBL factors. A validated Particle Swarm Multiple Object Optimisation Algorithm (PSMOOA) is developed to implement the LCE design process. ABAQUS, analytical formulae and GaBi industrial software are incorporated in a python wrapper script that combines the PSMOOA. To generate data that will be used in the PSMOOA, an coupon level assessment is undertaken. Tensile and shear coupon tests are conducted to generate a mechanical performance database. Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) analyses are conducted to generate environmental and economic data respectively. Environmental tests are undertaken to explore the relative affect of the marine environment on the composites performance. Preliminary mechanical data indicates that for approximately the same areal weight, the glass and basalt fibres tested are superior to flax. Environmentally the recycling method and parameters such as electricity country location are found to have a significant impact on the presented outcome. Recycling of thermoplastic FRPs using dissolution is found to be more costly environmentally and economically relative to mechanical recycling methods for thermoset FRPs.

Can the recycling problem of waste printed circuit boards be solved with plant-based fiber-reinforced composites?

abst. 1283
Room B035
Tuesday
July 19
12h30

Genc, Garip (ggenc@marmara.edu.tr), Marmara University, Institute of Science and Tech., Mechatronics Engineering, Türkiye
Kesen, Ugur (ukesen@marmara.edu.tr), Marmara University, Institute of Science and Tech., Mechatronics Engineering, Türkiye

Laminates of conventional printed circuit boards (PCBs) are composites produced using epoxy resin and glass fiber. The main problem with such cards is that the recycling process is too expensive and needs a long time. Whether plant-based fiber-reinforced composites (Bio-PCB) will be a solution to this problem is an important research topic. Therefore, it is necessary to examine many features of such new cards and compare their performance. For this purpose, Luffa fiber-reinforced PCB (Luffa-PCB) was produced in this study. Here, epoxy is used as the matrix, just like in FR2 type PCBs. The performance comparison of both types of PCBs was made by examining the frequency response with an active filter circuit. In addition, the effects of the circuit elements on the PCBs on the filter frequency are also compared. According to the results obtained, it has been determined that Luffa-PCB has sufficient properties to be an alternative to FR2 type PCBs. In conclusion, although, for limited applications, these results are considered to be very promising for solving the recycling problem of e-waste PCB boards.

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abst. 1315
Poster

Dissolution of a commercial regenerated cellulose fibre (Cordenka) in the ionic liquid 1-ethyl-3-methylimidazolium acetate studied using time-temperature superposition

Alanazi, Maer (pymha@leeds.ac.uk), university of Leeds, United Kingdom
Ries, Michael (M.E.Ries@leeds.ac.uk), university of Leeds, united Kingdom
Hine, Peter (P.J.Hine@leeds.ac.uk), university of Leeds, united Kingdom

Wide-angle X-ray diffraction (WAXS) and mechanical testing techniques are used to track the dissolution of regenerated commercial cellulose fibre (Cordenka) in the ionic liquid 1-ethyl-3-methylimidazolium acetate [C2mim]+ [OAc]- for different times and temperatures. In the dissolution process, the oriented cellulose II crystals in the regenerated cellulose fibres dissolve and then reform into randomly oriented crystals to form a matrix phase, and this change in orientation allows us to follow the dissolution process using WAXS, and hence determine the dissolved matrix volume fraction vm. The change in the average molecular orientation P2 determined from an azimuthal () X-ray scan, allows the growth of vm to be calculated against time and temperature. The growth of vm was found to follow time temperature superposition, with an Arrhenius behaviour, giving a value for the activation energy of Ea= 149 $\pm$ 4 kJ/mol. Young's modulus was measured on all the resulting composite fibres. The fall of Young's modulus with dissolution time and temperature was also found to follow time-temperature superposition, with an Arrhenius behaviour giving a value for Ea= 198$\pm$ 30 kJ/mol. The Young's Modulus results plotted against vm determined from the WAXS measurements (Azimuthal scan) fitted well to the parallel Rule of Mixtures, based on the original unprocessed fibres Young's modulus (found using an extrapolation technique) and the measured modulus of a dissolved and coagulated 'matrix' film.

Non-destructive Inspection Techniques for Composite Materials and Structures

Modeling of nanoindentation experiments of thin ceramic coatings

abst. 1085
Repository

Aizikovich, Sergei (saizikovich@gmail.com), Don State Technical University, Russia
Vasiliev, Andrey (andre.vasiliev@gmail.com), Don State Technical University, Russia
Sadyrin, Evgeniy (owlsquall@gmail.com), Don State Technical University, Russia

Ceramic coatings of different thicknesses are deposed by a magnetron sputtering method using VSM100 unit (Aktan Vakuum, Russia). Series of nanoindentation experiments are made for a wide range of applied indentation force using the Nanotest 600 Platform 3 unit (Micro Materials, UK). The Oliver – Pharr approach is used to obtain reduced elastic modulus of the coatings. The disadvantage of this approach is that it does not take into account the presence of a deformable substrate, which can lead to an error in determining Young's modulus, especially for thin coatings. An advanced approach taking into account both coating and substrate deformation is also used to describe the experiments. This approach is based on a solution of the axisymmetric contact problem on indentation of a coated half-space. Solution of the contact problem is constructed in an approximated analytical form convenient for engineering applications. Indentation stiffness is constructed for a coating-substrate systems used in the experimental study. Good agreement of the theoretical and experimental data is observed. An effect of the coating thickness on the experimental data is analyzed. This work was supported by the Government of the Russian Federation (grant No. 14.Z50.31.0046).

Mathematical approach of the load estimation applied on the tooth fissure

abst. 1093
Repository

Zelentsov Vladimir (vbzelen@gmail.com), Don State Technical University, Research and Education Center "Materials", Russia
Sadyrin Evgeniy (owlsquall@gmail.com), Don State Technical University, Research and Education Center "Materials", Russia
Swain Michael (michael.swain@sydney.edu.au), The University of Sydney, Biomaterials Science Unit, Australia
Lapina Polina (polina_azarova86@mail.ru), Don State Technical University, Research and Education Center "Materials", Russia
Aizikovich Sergei (saizikovich@gmail.com), Don State Technical University, Research and Education Center "Materials", Russia

The occlusal surface of molars and premolars has a certain number of wedge-shaped notches, called fissures. Apex of the fissure is a natural stress concentrator. Microtomographic (micro-CT) studies of the enamel showed that in the vicinity of fissure apex, areas with a low mineral density are formed. To determine the degree of stress concentration at the apex of the fissure, the problem of the theory of elasticity about the stress-strain state of enamel with a wedge-shaped notch is considered. The study of stresses in the vicinity of the apex of the fissure makes it possible to construct the boundaries of the areas of virtual destruction of the enamel. Comparison of the sizes and locations of areas with a low density of enamel mineral content, obtained using microtomography, with the sizes and locations of areas of virtual destruction of enamel, obtained by theoretical means, made it possible to establish their approximate congruence. The congruence of these areas made it possible to theoretically recreate the nature and magnitude of the force load on the lateral surface of the fissure, which contributes to the formation of areas of reduced enamel mineral density. At the same time, the following were determined: the critical values of the bite force and the force of food action on the lateral surfaces of the fissures, the critical angles of the fissure at a given bite force, the influence of the location of food along the depth of the fissure, and the critical values of food adhesion on the lateral surface of the fissure. The developed technique can be used in practical dentistry to predict the strength properties of the occlusal surface of teeth and dental implant crowns. This work was supported by the Government of the Russian Federation (grant No. 14.Z50.31.0046).

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abst. 1094
Room B032
Wednesday
July 20
11h50

Non-destructive inspection of military designated composite materials with the use of infrared and Terahertz imaging

Strąg, Martyna (stragm@witu.mil.pl), Military Institute of Armament Technology, Poland
Hłosta, Paweł (piko@piko-projekt.pl), Military Institute of Armament Technology, Poland
Świderski, Waldemar (swiderskiw@witu.mil.pl), Military Institute of Armament Technology, Poland

Composites represent a wide group of materials with special properties which are obtained by combining various components which characteristics differ when they act as individual. They exhibit high mechanical strength which, in combination with low mass, makes them great construction materials. Therefore, they found applications in many fields such as e.g., aerospace, automotive, medicine, and military. Composites are sensitive to defects arising both during the manufacturing and the use. The latter is connected with large stresses for which composites may be exposed during their work and they include among others high humidity, aggressive chemicals, and physical attacks. Such factors may lead to the catastrophic failure of the constructions, so it is highly important to resolve methods allowing for their non-destructive (NDT) inspection during their lifetime. One of the most effective and widely used method of NDT is infrared thermography. It allows for detection of composites' defects such as delamination, voids, air bubbles or uneven distribution or direction of the reinforcing fibers. Typically, tested composites samples require external heating or cooling source to expose the hidden defects which usually have similar temperature as the surroundings. In recent years, the studies focused on NDT are heading towards imaging with the use of Terahertz (THz) waves. It relates to the unique capabilities of THz allowing for contactless inspection of non-metallic composites and for detection of defects in materials with low THz absorption like dielectrics such as plastics, ceramics, and certain composites. On the other hand, it cannot penetrate through water, metals, and other conducting materials. THz radiation is non-ionizing what increases it attractiveness and potential in biological applications. In the frame of this work the comparison results from Terahertz and IR imaging for non-destructive testing of non-metallic military designated composites are presented. The research was carried out by both transmission and reflection mode. Advantages and limitations of these methods in non-invasive inspection of composites are discussed. ***[Martyna Strąg is one of the Winner of the Ian Marshall Award for Best Student Paper]***

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abst. 1172
Virtual Room 2
Thursday
July 21
10h20

Non-destructive inspection of internal defects of the polymer tube using pulsed Terahertz waves based on generative adversarial networks

Kim, Sang-Il (sangilkim01@gmail.com), Department of Mechanical Convergence Engineering, Hanyang University, 222, Wangsimni-ro, Seongdong-gu, Seoul, Republic of Korea, Republic of Korea, KOR
Park, Dong-Woon (dongwoon902@gmail.com), Department of Mechanical Convergence Engineering, Hanyang University, 222, Wangsimni-ro, Seongdong-gu, Seoul, Republic of Korea, Republic of Korea, KOR
Kim, Heon-Su (khsu0212@gmail.com), Department of Mechanical Convergence Engineering, Hanyang University, 222, Wangsimni-ro, Seongdong-gu, Seoul, Republic of Korea, Republic of Korea, KOR
Kim, Hak-Sung (kima@hanyang.ac.kr), Department of Mechanical Convergence Engineering, Hanyang University, 222, Wangsimni-ro, Seongdong-gu, Seoul, Republic of Korea,

Polymer tubes have been used for transporting fluids in chemical, oil, and gas industries due to their lightweight and chemical resistance characteristics. However, if the polymer tubes are damaged during operation, they pose a risk to the facility in industrial environments. Therefore, detecting the defects of the polymer tubes is necessary during the process repair. In particular, the internal defects are difficult to be checked from the outside. In addition, it is more difficult to predict the location or type of defects in the polymer tube, it is important to compare the normal state with the current state to inspect the defect. Recently, abnormal region detection models were developed to detect defect states during the process automatically. The abnormal region detection with generative adversarial networks model trains only normal features. As a result, the model can distinguish abnormalities in the data by comparing the trained normal features. For training the GAN model, training data should be generated using a

non-destructive evaluation (NDE) method that can inspect the inside of the specimen. Among the NDE methods, ultrasonic and X-ray inspection methods have been widely used to detect the internal defects due to their high transmittance. On the other hand, these methods have some limitations in being adapted in the industry; the ultrasonic method requires a medium such as water, which can contaminate the sample. The X-ray method generates radiation harmful to the human body [1]. For these reasons, in this study, the terahertz (THz) inspection method was used to inspect the internal defects in the polymer tubes. The THz waves in frequency range of 100 GHz to 30 THz can penetrate non-metallic materials without any medium [2]. Furthermore, since the THz waves have low energy, the inspection process is safe for the human body. These features of THz waves can compensate for the disadvantages of the traditional NDE methods. The defects in the polymer tubes were analyzed using a terahertz time-domain spectroscopy (THz-TDS) system with the GAN model. The temporal THz data of normal and defective polymer tubes were obtained from the transmission mode of the THz-TDS system. Then, images of the polymer tubes were created by extracting maximum amplitudes of the temporal THz data. The images of the normal polymer tubes were trained through the GAN model to learn the features of the normal polymer tubes. After the training, the corresponding normal images with the THz images of the normal and defective polymer tubes were generated by the GAN model. Then, the abnormality rates were calculated from the differences between the generated and real images of polymer tubes. From the distribution of the abnormality rates, the THz images of the normal and defective polymer tubes can be distinguished within 90% accuracy. Acknowledgments: This research was also supported by a National Research Foundation of Korea (NRF) grant funded by the Korean Government (MEST) (2021M2E6A1084690). This work was also supported by Korea Institute of Energy Technology Evaluation and Planning(KETEP) grant funded by the Korea government(MOTIE) [20202020800360, Innovative Energy Remodeling Total Technologies(MV, Design, Package Solutions, and Testing Verifications Technologies) for the Aging Public Buildings]. Reference: [1] Seo, Hogeon, Kyoungjun Lee, and Kyung-Young Jhang. "In-line ultrasonic monitoring for sediments stuck on inner wall of a polyvinyl chloride pipe." The Scientific World Journal 2014 (2014). [2] Ryu C-H, Park S-H, Kim D-H, Jhang K-Y, Kim H-SJCS. Nondestructive evaluation of hidden multi-delamination in a glass-fiber-reinforced plastic composite using terahertz spectroscopy. 156, 338-347 (2016)

Optimal shunted damping configurations for noise reduction in laminated composite sandwich panels - Multi-modal damping

abst. 1260
Room B032
Wednesday
July 20
12h10

Cotrim, Bruno Ribeiro (bruno.ribeiro.cotrim@live.com.pt), IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Portugal, Portugal
Araújo, Aurélio Lima (aurelio.araujo@tecnico.ulisboa.pt), IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Portugal, Portugal
Madeira, José Firmino Aguilar (aguilarmadeira@tecnico.ulisboa.pt), IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Portugal; ADM, ISEL, Instituto Politécnico de Lisboa, Portugal, Portugal

The use of composite materials in the automotive and aerospace industries has seen growth due to their good mechanical properties combined with their low weight when compared to the metals traditionally used. This weight reduction comes, however, at the cost of worse vibrational and acoustic performances. The usage of sandwich structures with a viscoelastic core can be one solution to this problem, where the viscoelastic core is responsible for noise attenuation at high frequencies. These structures are many times combined with piezoelectric materials with shunt circuits, that have a high loss factor at low frequencies. In this work, a multi-objective optimization approach was applied to the vibroacoustic problem for the first five modes in sandwich panels using piezoelectric elements for passive energy dissipation. The utilized sandwich panel and piezoelectric materials will be presented, which were implemented in an in-house finite element code, then verified using the commercial software ANSYS. The radiated noise was evaluated with the radiated sound power, computed using Rayleigh's integral method. A multi-objective optimization problem with 7 objectives is then presented, which aimed to obtain the best piezoelectric distribution and its respective resistive circuit, while minimizing the added mass, the number of equipotential zones and the total radiated sound power for each of the first five modes. The algorithm used was Direct MultiSearch (DMS). At last, a comparison between

the calibration methods for the electrical circuits existing in the literature and the solutions obtained in the optimization problem was made.

Optimization techniques and methods

Reduction of free-edge effects around a hole of a composite plate using a numerical layup optimization

abst. 1050
Room B032
Wednesday
July 20
17h10

Kharghani, Navid (navid.kharghani@klub.tu-darmstadt.de), Institute for Lightweight Construction and Design, Department of Mechanical Engineering, Technische Universität Darmstadt, Germany
Mittelstedt, Christian (christian.mittelstedt@klub.tu-darmstadt.de), Institute for Lightweight Construction and Design, Department of Mechanical Engineering, Technische Universität Darmstadt, Germany

In a wide variety of applications, it is necessary to drill holes in laminates consisting of either plies of fiber-reinforced plastics (FRPs) or other materials. The reasons can be weight optimization or connecting the structure to the equipment such as cut-outs or holes in wing spar and cover panels to access to hydraulic system for maintainability. However, these holes redistribute the membrane stresses in the plates and may remarkably reduce their stability. In this regard, stress concentration phenomena play a significant role. One of the most well-known problems in this area is called "free-edge effect". It occurs as the result of mismatch of the mechanical properties between two adjacent dissimilar laminate layers. The stacking sequence has a great influence on the performance of composite structures especially when it comes to stress concentration effects. In the current research, various orientation angles and layups for a composite plate with a central hole are investigated and the optimized layup is determined for the desired thickness. The objective of the optimization is the minimization of the interlaminar peeling stress around the hole. Failure strength around the hole is the basis of the constraint incorporating Hashin's failure criteria for each lamina individually. For this purpose a two-step analysis is carried out: Primarily a finite element analysis is performed using ABAQUS to determine the constraint for orientation angles. Then, the pattern search method is utilized to obtain the optimized layup using the interaction of MATLAB and ABAQUS software. Moreover, a sensitivity analysis is carried out to determine the effect of the material properties, the size of the hole, and the initial guess applied for the pattern search solution upon the optimal layup sequence.

Design optimization of composite shaft subjected to torsional loading using Artificial Neural Network modeling based on Genetic Algorithm

abst. 1083
Virtual Room 1
Tuesday
July 19
16h30

Nair, Ajeesh Suresh (ajeeshsuresh.nair@concordia.ca), Concordia University, Canada
Ganesan, Rajamohan (r.ganesan@concordia.ca), Concordia University, Canada

Tubes and shafts made with polymer-matrix fiber-reinforced composite materials are widely used in automobile, mechanical, and aerospace engineering applications due to their fatigue-resistant, corrosion-resistant, and high strength-to-weight ratio characteristics. Shafts are preferred over tubes for engineering applications where torsional loading is predominant. The First-Ply Failure (FPF) of the composite shaft is an important design consideration. In the present work, the failure behavior of uniform-diameter composite shaft subjected to torsional loading is determined considering the first-ply failure characteristics. The first-ply failure of the composite shaft is determined based on the Classical Laminate Theory (CLT) and 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 uniform-diameter composite shaft developed using the commercial software ANSYS®. Seeking the optimal design of the composite shaft is a major design requirement in weight-saving and high-performance engineering applications. Genetic Algorithm (GA) is a robust and efficient method that is being used for optimization in a wide range of practical engineering problems. An efficient methodology based on the Artificial Neural Network (ANN) modeling, Monte-Carlo Simulation (MSC) method, and Genetic Algorithm for the design optimization of composite components is developed and presented in this work. The stacking sequence of a uniform-diameter composite shaft made of a Carbon Fiber Reinforced Polymer (CFRP) composite material, subjected to torsional loading is optimized for the maximum First-Ply Failure (FPF) strength, based on this methodology.

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abst. 1326
Virtual Room 1
Tuesday
July 19
15h50

OPTIMIZATION OF GREEN COMPOSITE LAMINATES UNDER IMPACT

Giammaria, Valentina (valentina.giammaria@unicam.it), School of Science and Technology, Mathematics division, University of Camerino, Via Madonna delle Carceri 9, 62032 Camerino, Italy
Del Bianco, Giulia (giulia.delbianco@unicam.it), School of Science and Technology, Mathematics division, University of Camerino, Via Madonna delle Carceri 9, 62032 Camerino, Italy
Raponi, Elena (elena.raponi@tum.de), School of Engineering and Design, Technical University of Munich, Arcisstr. 21, 80333 Munich, Germany
Boria, Simonetta (simonetta.boria@unicam.it), School of Science and Technology, Mathematics division, University of Camerino, Via Madonna delle Carceri 9, 62032 Camerino, Italy
Duddeck, Fabian (duddeck@tum.de), School of Engineering and Design, Technical University of Munich, Arcisstr. 21, 80333 Munich, Germany

Since natural fibers have great potential as an alternative to synthetic fibers when the components are impacted at low energies, their mechanical properties under different types of loading must be investigated. In this study, the behavior of flax and hemp/epoxy resin composite laminates under low-velocity impact conditions is investigated. Starting from an experimental campaign, finite element models are created and solved using the nonlinear explicit dynamic solver LS-DYNA. Thin shell elements with tiebreak contacts and solid elements with cohesive interfaces are analyzed to investigate the impact and post-impact failure mechanisms. It is well known that in the definition of these models, many parameters of the composite material cards are determined by experimental tests, while this is not the case for non-physical parameters. Since the trial-and-error method is very time-consuming, we present an optimization procedure aimed at identifying relevant parameters of the numerical model that allows to (1) predict the experimental force-displacement trend as accurately as possible and (2) reproduce numerically the damage mechanisms. Each step of the optimization [U+FB02]ow is performed using the external optimization tool LS-OPT, where the Dynamic Time Warping (DTW) is used as similarity measure to efficiently handle noise and hysteresis. For this purpose, a sequential optimization based on surrogate modeling techniques is used. The obtained results show that the optimization strategy presented here is an effective technique to identify the material parameters of the specific numerical models and to characterize the studied composites in view of future applications.

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abst. 1356
Virtual Room 1
Tuesday
July 19
16h10

Multi-scale topology optimization of composite beams accounting for loading uncertainty

Bruggi, Matteo (matteo.bruggi@polimi.it), Politecnico di Milano, Department of Civil and Environmental Engineering, Italy
Ismail, Hussein (hussein.ismail@emk.bme.hu), Budapest University of Technology and Economics, Department of Structural Mechanics, Hungary
Lógó, János (logo.janos@emk.bme.hu), Budapest University of Technology and Economics, Department of Structural Mechanics, Hungary

Topology optimization sketches lightweight components by searching the design domain for the distribution of material that minimizes a prescribed objective function given a set of constraints. In a classical topology optimization problem, the constitutive properties of the material to be distributed are scaled by the point-wise density filed, whose values range between 0 and 1. A strong penalization of the intermediate densities is generally implemented to achieve optimal layouts made of void and solid material. Intermediate values of the density have no physical meaning unless composite materials are allowed within the optimization. Indeed, periodic cells can be graded at the meso-scale to match the homogenized mechanical properties at the macro-scale using multi-scale optimization. In this contribution, a novel approach based on multi-scale topology optimization is proposed to design lightweight components that are endowed with a honeycomb-like microstructure that can be easily graded in the optimization process and then exported as a geometry ready for manufacturing, using e.g. additive manufacturing. Instead of working with a conventional volume-constrained minimum compliance problem, a displacement-constrained minimum volume problem is formulated with the main aim of controlling pointwise the displacement field. This is done in an efficient way by combining sequential

convex programming and the augmented Lagrangian method. It is assumed that the applied loads are affected by uncertainties in their magnitude, such that their joint normal distribution function, mean values, and covariances are known. The automatic generation of stiff layouts under the effect of loads with uncertain amplitude is tackled embedding the minimum weight formulation with an equivalent determinist constraint. A peculiar feature of the proposed formulation is that it accounts also for an enforcement governing the minimum amount of graded porous material to be distributed in addition to the void phase and the solid one. Numerical simulations are performed considering the lightweight design of plane components. Enforcing a minimum amount of graded material, layouts recalling sandwich structures may arise as optimal solutions. It is found that regions of solid material often lie along the perimeter of an inner core of graded porous phase. Such kind of layouts are inherently robust to loading uncertainty. An extension of the proposed formulation is proposed to tackle the optimal design of I-beams using a simplified two-dimensional modelling. The optimal shape of solid flanges is given in conjunction with the lightweight topology of a composite web to provide optimal solution for structural elements subjected to uniaxial bending.

Porous and cellular materials

abst. 1139
Room B035
Wednesday
July 20
11h30

Predicting Elastic Properties of Composite Metal Foams using 3D Finite Element Method

M. Keleshteri, Mohammad (m.keleshteri@ubc.ca), The University of British Columbia, Canada
Jelovica, Jasmin (jjelovica@mech.ubc.ca), The University of British Columbia, Canada

Composite metal foams (CMFs) are a new class of closed-cells porous materials that can be produced by distributing metallic spheres in a metallic matrix using casting or powder metallurgy techniques. CMFs offer better mechanical performance in compression to the conventional porous materials due to the uniform shape and even distribution of voids. To evaluate elastic properties of CMFs, the conventional theoretical approaches for periodic models are not a good candidate due to the random distribution of voids in these materials. Thus, in this paper, first a three dimensional CMF model is developed which is then used for finite element analysis to predict elastic properties, including Young's modulus, Poisson's ratio and shear modulus of composite metal foams. Aluminum and steel spheres within steel matrix are considered, known as Al-Steel and Steel-Steel CMFs, respectively. Comparing our predictions for elastic properties from the numerical finite element model against experimental results show a very good agreement. Finally, a theoretical formulations have been developed to evaluate the Young's modulus and Poisson's ratio of the composite metal foams based on the elastic properties of the parent material and density of the foam. These elastic properties formulations are helpful when response of CMF structures are of interest.

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abst. 1317
Room B035
Wednesday
July 20
11h50

Characterization of the foaming behavior of glass fiber reinforced polypropylene under varying manufacturing parameters

Alessandra, Kummerow (a.kummerow@tu-braunschweig.de), Technische Universität Braunschweig, Institute of Joining and Welding, Germany
Sven, Hartwig (s.hartwig@tu-braunschweig.de), Technische Universität Braunschweig, Institute of Joining and Welding, Germany

Multifunctional sandwich structures are characterized by their ability to absorb high mechanical loads in relation to their weight per unit area. Current processes for manufacturing sandwich structures are limited, as the face sheets and core materials are produced and joined in a multi-step, complex process. To reduce production costs, various processes have been developed based on injection molding of thermoplastics. The focus of development is primarily on foamed thermoplastics as core materials, which is why the foam process is becoming increasingly important. Thermoplastic foam injection molding differs from conventional injection molding in the addition of a blowing agent to the granules. A distinction is made between chemical and physical blowing agents, which cause different foaming processes. In the chemical foam molding, chemical blowing agents are added to the granules. During the melting process of the granules, these blowing agents decompose and release blowing gases, which then dissolve in the polymer melt. Physical foaming relies on direct loading of the polymer melt with the necessary blowing gas, i.e. no decomposition reaction takes place in the polymer melt. A major challenge in thermoplastic foam injection molding is the integral structure of the foam, i.e. the formation of a compact top layer and a porous foamed core. Unlike classic sandwich structures, in which the top layer and the core are made of different materials, this sandwich structure consists of the same material for the top layer and the core. Therefore, this is a special feature in the characterization, since the behavior of the compact top layer and the foamed core made of the same material differ significantly from each other, making an overall consideration of the structure more difficult. For this paper, foam sheets are manufactured using a novel physical thermoplastic foam injection process and analyzed in terms of their macroscopic and microscopic characteristics. Here, the manufacturing parameters, e.g. the melting temperature, for producing the foam specimens are varied in order to evaluate the influences on the foam behavior. The analysis is carried out over the entire length of the foam sheets by defining specific specimen areas distributed over the sheet in order to detect possible fluctuations between the gate and the end of the foam sheets. This procedure is necessary to be able to evaluate the following mechanical characterization of cut-out test specimens. For the microscopic analysis of the foam structure, polished specimens are prepared and examined under different microscopes. Furthermore, investigations with μ-computed tomography are carried out to determine the porosity of the foam. The mechanical characterization is performed by means of tensile, compression and bending tests on suitable test specimens.

Development and characterization of in-situ sandwich panels with aluminum alloy foam core

abst. 1337
Room B035
Wednesday
July 20
12h10

Caldeira, Ana Sofia (sofiacaldeira@live.ua.pt), Department of Mechanical Engineering, Centre for Mechanical Technology and Automation (TEMA), University of Aveiro, Portugal
Vesenjak, Matej (matej.vesenjak@um.si), Faculty of Mechanical Engineering, University of Maribor, Slovenia
Carneiro, Vitor H. (vitorhcarneiro@hotmail.com), Department of Mechanical Engineering, CMEMS, University of Minho, Portugal
Krstulović-Opara, Lovre (Lovre.Krstulović-Opara@fesb.hr), Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split, Croatia
Duarte, Isabel (isabel.duarte@ua.pt), Department of Mechanical Engineering, Centre for Mechanical Technology and Automation (TEMA), University of Aveiro, Portugal

The aluminum alloy foams have been explored to be used in energy absorption applications that require lightweight structures with high strength-to-weight and stiffness-to-weight ratios, high impact energy absorbing capacity, and good damping of noise and vibration. The metal foams are usually applied as core and/or as filler of sandwich panels and thin-walled structures. The purpose of this paper is to develop in-situ sandwich panels consisting of a highly porous aluminum foam core and aluminum alloy face sheets manufactured by the powder metallurgy method in which the face sheets are bonded to the foam core during the foam formation. The samples are geometrically analyzed in 2D and 3D using X-ray microcomputed tomography to extract morphological and topological properties of the foam core, the face sheets, and the bonding between them. The mechanical and acoustic properties of in-situ sandwich panels are evaluated.

Development and characterization of aluminum alloy foam – cork hybrid structures

abst. 1338
Room B035
Wednesday
July 20
12h30

Sousa, João D. P. (joaoduarteps@ua.pt), Department of Mechanical Engineering, Centre for Mechanical Technology and Automation (TEMA), University of Aveiro, Portugal
Pinto, Susana C. (scpinto@ua.pt), Department of Mechanical Engineering, Centre for Mechanical Technology and Automation (TEMA), University of Aveiro, Portugal
Vesenjak, Matej (matej.vesenjak@um.si), Faculty of Mechanical Engineering, University of Maribor, Portugal
Krstulović-Opara, Lovre (Lovre.Krstulovic-Opara@fesb.hr), Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split, Croatia
Carneiro, Vitor H. (vitorhcarneiro@hotmail.com), Department of Mechanical Engineering, CMEMS, University of Minho, Portugal
Marques, Paula A.P. (paulam@ua.pt), Department of Mechanical Engineering, Centre for Mechanical Technology and Automation (TEMA), University of Aveiro, Portugal
Duarte, Isabel (isabel.duarte@ua.pt), Department of Mechanical Engineering, Centre for Mechanical Technology and Automation (TEMA), University of Aveiro, Portugal

Cellular solids and porous materials have been considered as one of the most suitable lightweight multifunctional materials for a wide range of commercial and industrial applications, e.g. in medicine, military. Their use contributes to an immediate and significant weight reduction and material savings of the components but also to multifunctionality due to their 3D cellular structures (open-cells or closed-cells). Herein, hybrid structures based on cellular materials are developed and studied by combining

open-cell aluminum foam with cork. These hybrid structures were prepared by infiltrating a mixture containing polymer-coated cork powders into the open-cell foam. The samples are geometrically analyzed using X-ray microcomputed tomography to extract morphological and topological properties of the voids and the solid phase. The mechanical, thermal, acoustic, and fire retardancy properties of these aluminum foam-cork hybrid structures are evaluated and compared with their individual components (open-cell aluminum alloy foam and agglomerated cork).

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abst. 1339
Room B035
Wednesday
July 20
12h50

Mechanical properties of the aluminum foam-filled tubes

Duarte, Isabel (isabel.duarte@ua.pt), Department of Mechanical Engineering, Centre for Mechanical Technology and Automation (TEMA), University of Aveiro, Portugal
Vesenjak, Matej (matej.vesenjak@um.si), Faculty of Mechanical Engineering, University of Maribor, Slovenia
Krstulović-Opara, Lovre (Lovre.Krstulovic-Opara@fesb.hr), Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split, Croácia

The research focuses on lightweight structures filled with cellular (porous) metals. Initially, their design and fabrication procedures are described. Aluminum alloy tubes of different shapes were filled (in-situ and ex-situ) with different aluminum alloy foams (e.g., open and closed-cell foams). They were subjected to mechanical loading in an extensive experimental testing program. Different types of loading (e.g., compression, bending) and velocity (e.g., quasi-static, dynamic) were considered. The deformation response, including the collapse mechanism of the foam-filled structures, has been analyzed in detail. The mechanical properties, energy absorption capacity, and strain rate sensitivity were also evaluated. It was found that the lightweight aluminum foam-filled tubes offer a stable crush performance and that their mechanical properties and deformation mechanism can be tuned for specific applications.

Prediction of temperature regimes in pultrusion of thermoplastic laminates.

abst. 1324
Repository

Minchenkov Kirill (kirill.minchenkov@skoltech.ru), Skolkovo Institute of Science and Technology, Russia
Safonov Alexander (a.safonov@skoltech.ru), Skolkovo Institute of Science and Technology, Russia
Gusev Sergei (), Skolkovo Institute of Science and Technology, Russia
Rubtcov Maxim (), Skolkovo Institute of Science and Technology, Russia
Akhatov Iskander (), Skolkovo Institute of Science and Technology, Russia

The main problem of thermoplastic pultrusion is high viscosity resins, which negatively affect filament impregnation. Usage of pre-consolidated tapes (PCT) as raw materials allows avoiding poor impregnation. The main task of thermoplastic pultrusion with pre-impregnated tapes is to consolidate all tapes. In order to soften the matrix and paste together the tapes into a single material, it is necessary to heat them. The objective of this work is to determine the required pultrusion temperature for the consolidation of tapes made of fiberglass and polypropylene. Four flat profiles were manufactured on pultrusion machine Pultrex Px500-6T (Pultrex, UK) with pulling speeds 0.2, 0.4, 0.6, 0.8 m/min. PCTs made of fiberglass and polypropylene were used as raw materials. The temperature inside the profile was recorded by bare thermocouples during the process. To assess the properties of materials, mechanical tests were carried out according to ISO and ASTM standards. The morphology of the profile cross-section was estimated using a microscope. 3D Finite element model was developed for temperature distribution analysis. Experimental and simulated data were validated. Mechanical tests results showed that strength decreases with the increasing pulling speed. Microstructure analysis demonstrated that the profile made at a pulling speed of 0.2 m/min is completely consolidated. Also, it was observed areas of unconsolidated tapes in profiles, which were made at higher pulling speeds. It was observed that only one profile, which was made at a pulling speed of 0.2 m/min was heated higher Vicat softening temperature (VST A/50), which equals 130 [U+2103] for Moplen RP348U polypropylene. The others profiles were not heated to this temperature. Thus, it was concluded that the VST is the minimum required temperature for the production of a profile from thermoplastic tapes. Tapes do not consolidate inside the profile at temperatures below VST.

Smart Composites

abst. 1001
Repository

Flutter analysis of damaged composite plates under hygro-thermal environment and its passive control using piezoelectric patches

Kuriakose, Vinu M (vinukuriakose@sastra.ac.in), SASTRA Deemed to be University, India
Sreehari VM (sreehari_vm@mech.sastra.edu), SASTRA Deemed to be University, India

Influence of hygro-thermal conditions on passive flutter control of damaged composite plates with piezoelectric patches are investigated in this work. Mathematical model is developed for damaged composite plate with piezoelectric patches under hygro-thermal conditions by finite element method. Internal flaws are incorporated in composite plate based on anisotropic damage modeling concept. Present finite element formulation is coded in Matlab environment. The flutter velocity and flutter frequency values for damaged composite plates are obtained at different hygro-thermal conditions. Deterioration in the flutter characteristics are observed due to the presence of internal flaw in composite plates. PZT patches are bonded on the surface of the composite plate and studies are carried out with different input voltages. The enhancement in flutter characteristics of a damaged composite plate by employing PZT patches is presented for varying hygro-thermal conditions.

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abst. 1020
Repository

Thermo-structural analysis of smart composite plates having internal flaw

Vinu M Kuriakose (vinukuriakose@sastra.ac.in), SASTRA Deemed to be University, India
Sreehari VM (sreehari_vm@mech.sastra.edu), SASTRA Deemed to be University, India

Aerospace researches and industries demands light weight structures. Reduction in thickness of aerospace structures for making it light weight results in making it more flexible. Minor damages create serious reductions in natural frequency. Thermal environment also vary the mechanical properties of structure. Once internal flaws and thermal environment acts together in a structure, it will reflect a severe reduction in the vibration characteristics of a composite structure. In this present work, effect of thermal environment on dynamic behaviour of a smart composite plate having internal flaw is discussed. Anisotropic damage formulation is incorporated in the finite element formulation for structural dynamics of smart composite plate under thermal environment. Natural frequency values of smart composite plate with internal flaw for several parametric variations at different thermal environment are presented.

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abst. 1042
Repository

Reversible energy absorbing behaviors of shape-memory thin-walled structures

Jin Wang (jin.wang@csu.edu.cn), Central South University, China
Guangyu Sun (sgy0514@csu.edu.cn), Central South University, China
Kui Wang (kui.wang@csu.edu.cn), Central South University, China
Song Yao (song_yao@csu.edu.cn), Central South University, China
Yong Peng (yong_peng@csu.edu.cn), Central South University, China

In this work, a shape-memory circular thin-walled structure was proposed. The structure was processed based on the 3D printing technique of fused deposition molding. The polylactic acid/thermoplastic polyurethane elastomer copolymer was used as the shape-memory material. After the progressive folding during the quasi-static compression (2 mm/min), it was observed that the successful recovering behaviors triggered by heating (water at 45 [U+2103]). Focusing on the reversible energy absorption, the compressive force responses were investigated under different cyclic numbers and ambient temperatures. With increasing loading cycles, the specific energy absorption showed a first decreasing tendency but the gradually convergence. The crushing force efficiency increased due to the rapid decrease of the peak crushing force. At the ambient temperatures of 20 [U+2103] and 40 [U+2103], the shape-memory circular thin-walled structure presented the progressive collapse mode during compression, while overall

fracture failure happened due to the cold brittleness of the shape-memory polymer at the ambient temperatures of 0[U+2103], 20[U+2103], and 40[U+2103]. The study offered new insights on designing 3D printed thin-walled structures that could show reversible energy absorbing ability.

Effective magneto-elastic coupling in magnetostrictive Terfenol-D composites

abst. 1067
Repository

Lin, Yin-Zhao (n16084365@gs.ncku.edu.tw), National Cheng Kung University, Taiwan
Lin, Chien-hong (clin@gs.ncku.edu.tw), National Cheng Kung University, Taiwan

Two micromechanical formulations are established for analysis of nonlinear magnetoelectric coupling in composite materials with 1-3, 0-3 and 2-2 connectivities. The studied two-phase composites are constructed by magnetostrictive and piezoelectric phases that exhibit significant material nonlinearity when each or all of them are subjected to large driving magnetic or electric fields. The simplified unit-cell model is first formulated followed by a reformulation of the Mori-Tanaka model so that a comparison can be made between two micromechanics models in terms of their mathematical structures and micromechanical predictions. In order to analyze the nonlinear composites, a secant linearization is employed for each constituent, concentration-factor tensors are introduced for bridging microscopic and macroscopic behaviors, and residual vectors are defined for quantitation of the errors resulted from the linearization process. Micromechanical simulations show that 1) magnetoelectric coupling can be modulated by the composite connectivity and constituent proportion, and 2) the field-dependent magnetoelectric responses leads to significant difference between linear and nonlinear predictions.

Experimental verification of smart structures composed of PVDF ribbon grid sensor embedded carbon/epoxy fabric prepregs

abst. 1214
Repository

Jia-le Che (810146284@qq.com), School of Mechanical Engineering Chung-Ang University, Korean
In-Jun Jung (zxcv1726@cau.ac.kr;), School of Mechanical Engineering Chung-Ang University, Korean
Seung-Hwan Chang (phigs4@cau.ac.kr), School of Mechanical Engineering Chung-Ang University, Korean

The hinge joint between warp and weft yarns of the carbon/epoxy fabric prepregs they have good drapability to fabricate complex shaped structures. However, due to its brittleness, carbon/epoxy composite structures are it is susceptible to impact loads. Therefore, there is a need for efficient real-time structural health monitoring technology dedicated to structural integrity. The impact characteristics of non-sheared and sheared woven fabric composite structures were investigated by performing failure characterizations and estimating impact locations utilizing several signal processing techniques. To do this, polyvinylidene difluoride ribbon sensors (PVDF) were embedded in carbon/epoxy fabric prepregs as a result, the smart structure which monitors structural integrity under various impact loads was constructed. When woven fabric composite structures undergo large shear deformation, the fiber orientation is changed and the micro-structures like tows deforms too. This deformation will affect not only the composite structures but also the performance of polyvinylidene difluoride ribbon sensors. To evaluate the performance of the smart structure under large shear deformation, a composite egg-box structure made of carbon/epoxy fabric prepregs was prepared, and an impact experiment was carried out. Failure characterizations and impact localizations for the specimens were carried out by using a discrete wavelet transform and Bayesian regularized artificial neural network model. Through experiments and data analysis, the feasibility of smart structures composed of polyvinylidene difluoride ribbon sensors (PVDF) embedded carbon/epoxy fabric prepregs in 3D structures with large shear deformation was proved. At the same time, the impact performance of the composite egg-box structure was experimentally evaluated.

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abst. 1103
Virtual Room 1
Wednesday
July 20
09h40

Approximate local postbuckling analysis of composite panels braced with omega-stringers

Schilling, Jakob C. (jakob.schilling@klub.tu-darmstadt.de), Technical University of Darmstadt, Institute for Lightweight Construction and Design, Germany
Mittelstedt, Christian (), Technical University of Darmstadt, Institute for Lightweight Construction and Design, Germany

For thin-walled structures such as omega-stringer-stiffened panels, the stability behavior is critical in the design. This type of stiffened panel made of composite material is used in the aerospace and shipbuilding industry. To utilize the full lightweight potential, the analysis of the postbuckling behavior is particularly interesting. A locally postbuckled panel is still able to carry increasing loads without immediate failure. To find optimized designs, highly computationally efficient analysis methods are necessary. Thus, a new closed-form analytical model for the local postbuckling of omega-stringer-stiffened composite panels is introduced that is derived based on energy methods. It allows to describe the stability behavior in relative closeness to the bifurcation point and models the deformation, load distributions, and characteristic quantities such as the effective width. The quality of the model is assed in comparison to finite element analyses. The novel computational model offers a highly efficient analysis tool for consideration in respect to preliminary design and optimization.

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abst. 1187
Repository

Experimental and numerical approach for predicting global buckling load of pressurized unstiffened cylindrical shells using vibration correlation technique

Jeon, Min-Hyeok (mhjeon5857@gmail.com), Chungnam National University, Republic of Korea
Kong, Seung-Taek (), Chungnam National University, Republic of Korea
Hyun-Jun Cho (), Chungnam National University, Republic of Korea
In-Gul Kim (), Chungnam National University, Republic of Korea
Chang-Hoon Sim (), Chungnam National University, Republic of Korea
Jae-Sang Park (), Chungnam National University, Republic of Korea
Joon-Tae Yoo (), Korea Aerospace Research Institute, Republic of Korea
Yeoung-Ha Yoon (), Korea Aerospace Research Institute, Republic of Korea

The cylindrical shells such as propellant tank in launch vehicle subjected to internal pressure and compressive load are very thin due to its lightweight design and those are extremely imperfection-sensitive. In the process of manufacturing or assembling, dents and curvature can be created. These geometric initial imperfections significantly decrease the global buckling load of the cylindrical shells than the buckling load calculated at the design stage. However, the internal pressure has an effect upon reducing the geometric imperfection, and improve the buckling stability. Buckling test of cylindrical shell can cause the permanent failure such as crack, plastic deformation or internal defect. Nevertheless, buckling test is essensial for validation of design and numerical models. Therefore, non-destructive method to predict the global buckling load of the propellant tank structure subjected to internal pressure and compressive load without damage should be evaluated. The global buckling load of imperfection-sensitive shell can be estimated using vibration correlation technique(VCT) which is non-destructive method. This novel empirical method uses the correlation between the compressive load and natural frequency of structure and has the the advantage of predicting the global buckling load from prebuckling stage without reaching buckling load of structure. In this study, the global buckling load of unstiffened cylindrical shells with initial imperfection subjected to internal pressure and compression load was predicted using VCT. The thin metal and composite unstiffened cylindrical shells with high radius-to-thickness ratio similar to that of propellant tank were used in vibration and buckling tests. In order to measure natural frequency, it is necessary to measure the response of exctied structure from excitation source. However, impact hammer or shaker may cause the damage of structure and the mass of the accelerometer can affect natural frequency of thin shell. For non-contact excitation, the speaker was

used to excite the structure. White noise and sweep-sine signal was generated to excite the cylindrical structure. However, since the frequency range of the cylindrical structure is relatively high, there is limit to generate high acoustic pressure and to measure low response. Instead of using the sophisticated and expensive equipment such as LDV(Laser doppler vibrometer), the PVDF sensor with light weight and excellent dynamic characteristics was used to measure response of structure in this study. The buckling and vibration test for the cylindrical shell without and with two different internal pressure were conducted. Natural frequencies were measured from vibration test at some interval load level during increasing compressive axial load. Estimated results using VCT were verified by measured buckling load. Before buckling test, geometric initial imperfection was measured by the measuring equipment consist of laser displacement sensor and rotary and linear stage. The finite element analysis of model with measured imperfection of cylindrical shells used in the test was performed. The global buckling load was predicted using VCT and the results were compared with the test results. The effect of improved buckling stability due to internal pressure and the radius to thickness ratio of structures on the prediction results using VCT were analyzed by test and numerical methods. The deviation of the estimated load using different load level was compared with measured buckling load and minimum applied compressive load level required to predict the global buckling load within allowable tolerance has proposed. It was verified that buckling performance and stability of the unstiffened cylindrical shells can be predicted non-destructively from vibration and compressive test in a prebuckling state within a low compressive load level. Operation of the tested structure after non-destructive test can be expected and this method can be used to verify instability point of reusable launch vehicles before the reuse of the structure.

Structural Health Monitoring

abst. 1072
Room B032
Thursday
July 21
15h10

Quantitative damage monitoring of composite structures under cyclic loading using thermography and image processing

Chen, Xiao (xiac@dtu.dk), Technical University of Denmark, Denmark
Sheiati, Shohreh (), ,

This study presents a method to quantitatively monitoring multiple sub-surface damages in large-scale composite structures when they are subject to cyclic loads. The damages generate thermal footprints due to material friction, allowing efficient detection using passive thermography. Image processing algorithms and thermodynamics principles are used to analyze the thermal images for automated damage localization and quantitative evaluation of damage growth and damage severity. The proposed method is demonstrated on a composite wind turbine in which artificial defects are introduced to trigger damage growth in various locations under cyclic loading. It shows that the developed method is able to not only locate multiple damage sites remotely but also evaluate each single damage in near real-time. This method can potentially lead to a remote and automated technique for quantitative structural health monitoring of large-scale structures with growing damages when they are under cyclic loads.

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abst. 1122
Room B032
Thursday
July 21
15h30

Damage Detection of Civil Structures using Artificial Neural Networks and Refined Component-Wise Finite Element Models

Enea, Marco (marco.enea@polito.it), Politecnico di Torino, Italy
Shen, Jiahui (jiahui.shen@polito.it), Politecnico di Torino, Italy
Pagani, Alfonso (alfonso.pagani@polito.it), Politecnico di Torino, Italy
Carrera, Erasmo (erasmo.carrera@polito.it), Politecnico di Torino, Italy

Civil infrastructures always meet the problem of material damage and deterioration during their service lives. Structural Health Monitoring (SHM) based on Artificial Neural Networks (ANNs) is a modern technology that has been widely applied to detect damages of civil structures in recent years. In this work, feedforward ANN and Convolutional Neural Network (CNN) are employed for vibration-based and image-based damage detection, respectively. The Component-Wise finite element method based on the Carrera Unified Formulation (CUF) is utilized for dynamic and static analysis of civil structures, which further helps in creating a dataset of damage scenarios and ensure the success of the ANN training process. Once the dynamic parameters or the image of displacement field from an unknown structure subjected to the same boundary condition is given, the corresponding trained ANNs can be able to detect damage locations and intensities of the structure accurately.

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abst. 1195
Room B032
Thursday
July 21
15h50

Piezoresistive Properties of MWCNT,CB,GNP/Epoxy Composites

Zehni, Ozan Can (ozan.zehni@postgrad.manchester.ac.uk), The University of Manchester, School of Materilas, The UK
Kinloch, Ian (Ian.Kinloch@manchester.ac.uk), The University of Manchester, The UK
Bissett, Mark (mark.bissett@manchester.ac.uk), The University of Manchester, The UK

The use of composite materials is increasing day by day due to their extraordinary mechanical properties in many areas such as aerospace, automotive and energy. However, composite materials also have some weak properties, such as electrical and thermal conductivity. Carbon-based nanomaterials are one of the most important candidates for the improvement of these properties due to their superior physical properties. The key point is to transfer the potential mechanical, thermal and electrical properties of the CBs, CNTs or GNPs to the polymer composite. The use of carbon-based nano-materials in composites not only increases the electrical and thermal properties but also brings piezoresistive properties to the material. GNP (Graphene Nano Platelet), MWCNT (Multi Walled Carbon Nano-Tube) and CB (Carbon

Black)/Epoxy composites have self-sensing features which makes it a promising candidate for Structural Health Monitoring applications with the enhanced electrical properties. Piezoelectric properties of carbon-nanomaterials have been investigated in many studies, in this study piezoelectric properties are explored under two different in-situ test configurations which are tensile and compression. This study aims to investigate the self-sensing and piezo resistive properties of GNP, MWCNT and CB/Epoxy with different particle contents for GNP (7, 9 and 11 wt. %), MWCNT (0.3, 0.5 and 0.7 wt. %) and CB (3,5,7 wt.%) and 3 roll milling method is used in the distribution of all test samples. As a result of the tests, it is observed that the piezo resistance properties of GNP, MWNCT and CB/Epoxy are different for various tensile tests. The GF (Gauge Factor) value is calculated far above the value of the commercial strain gauges for all samples. However, the GF is not constant unlike conventional strain gauges during tensile tests and different trends are calculated for each sample. Considering the results obtained during compression tests, more similar piezo resistance properties are obtained in contrast to the tensile test results and GF value varies for each sample during the test, as in the tensile test. Nevertheless, the repeatable GF values and trends are calculated for samples have same nanoparticle and weight ratio during the tests. Detailed observations and results will be presented at the conference.

Thermal problems on Composite structures

abst. 1034
Virtual Room 1
Wednesday
July 20
17h10

EXACT 3D COUPLED HYGRO-ELASTIC SHELL MODEL FOR MULTILAYERED STRUCTURES

Brischetto, Salvatore (salvatore.brischetto@polito.it), Politecnico di Torino, Department of Mechanical and Aerospace Engineering, Italy
Torre, Roberto (roberto.torre@polito.it), Politecnico di Torino, Department of Mechanical and Aerospace Engineering, Italy
Cesare, Domenico (domenico.cesare@studenti.polito.it), Politecnico di Torino, Department of Mechanical and Aerospace Engineering, Italy

The present exact 3D coupled hygro-elastic shell model is employed for the hygroscopic stress analysis of constant radii of curvature shells and plates in multi-layered configuration. The coupled hygro-elastic model combines the 3D elastic equilibrium equations and the 3D Fick diffusion equation in the same system. This system of partial differential equations in the z thickness coordinate is defined in an orthogonal mixed curvilinear coordinate system (a, b, z) for spherical shells, cylindrical shells and plates. A layer-wise approach for multi-layered structures and the exponential matrix method for the partial differential equation solution are here employed. Simply-supported boundary conditions and harmonic forms for displacements and moisture content are used. The moisture content is imposed in steady-state conditions at the external surfaces of the structures, and then it is easily introduced in the system of equations. Therefore, both displacements and moisture content are primary variables of the model; they are obtained directly from it without any external calculation tool. On the contrary, in un-coupled hygro-elastic models, the moisture content profile in steady-state conditions must be separately defined: it can be calculated from the 3D Fick diffusion equation, it can be evaluated from the 1D version of the Fick diffusion equation or it can be a priori assumed as linear through the thickness direction. The so-defined moisture content profile becomes a known term in the 3D differential equilibrium equations of the un-coupled model. The hygro-elastic stress analysis for plates and shells is proposed and discussed for several thickness ratios, geometries, lamination schemes, materials and moisture content values. The coupled hygro-elastic model gives the same results obtained via the un-coupled hygro-elastic model when the moisture content is externally calculated by separately solving the 3D Fick diffusion equation. In both cases, thickness and material layer effects are included. The un-coupled hygro-elastic model using the 1D Fick diffusion equation discards the thickness layer effect. The un-coupled hygro-elastic model using a priori linear assumed moisture content profile discards both thickness and material layer effects.

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abst. 1049
Virtual Room 1
Wednesday
July 20
17h30

Microstructure of epoxy resin composite modified with recycled fine aggregate

Krzywiński, Kamil (kamil.krzywinski@pwr.edu.pl), Wroclaw University of Science and Technology, Poland
Sadowski, Łukasz (lukasz.sadowski@pwr.edu.pl), Wroclaw University of Science and Technology, Poland
Krakowiak, Konrad (), University of Houston, United States of America

The phenomena of low thermal shock resistance occur in production and warehouse buildings and are crucial for composites with a large area (e.g. floors). The wear of floor can be occurred during spinning of the forklift wheel [1]. The loaded spinning wheel causes the failure of floor by friction force and by rapidly growing temperature in the floor structure. The coatings made of epoxy resin are especially sensitive to temperature changes even during curing time. The only way to enhance thermal properties of the polymer-cementitious floor composite is modification of the layer which has physical contact during loading. Previous studies [2] shows that modification of the epoxy resin with recycled fine aggregate sourced from building demolition could change its mechanical properties. Therefore, in this study the microstructure of the epoxy resins modified with recycled fine aggregate was analyzed in different temperatures. Acknowledgments: The authors received funding from a project supported by the National Centre of Science, Poland [Grant no. 2019/35/O/ST8/01546 "Multi-scale evaluation of

the effect of thermal shock on the properties of environmentally-friendly polymer-cement composites modified with recycled fine aggregates (POWER)"]. References: [1] Sadowski, Ł., Hoła, J., Żak, A., Chowaniec, A. (2020). Microstructural and mechanical assessment of the causes of failure of floors made of polyurethane-cement composites. Composite Structures, 238, 112002. [2] Krzywiński, K., Sadowski, Ł., Stefaniuk, D., Obrosov, A., Weiß, S. (2021). Engineering and manufacturing technology of green epoxy resin coatings modified with recycled fine

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Investigations of thermal-dynamic mechanical properties and the glass transition temperature of epoxy composites with silicon carbide (SiC) and tungsten carbide (WC) particles

abst. 1250
Poster

Kucharczyk, Wojciech (wojciech.kucharczyk@uthrad.pl), Kazimierz Pulaski University of Technology and Humanities in Radom, 29 Malczewskiego Str., 26-600 Radom, Faculty of Mechanical Engineering, Poland
Stawarz, Sylwester (stawarz@uthrad.pl), Kazimierz Pulaski University of Technology and Humanities in Radom, 29 Malczewskiego Str., 26-600 Radom, Faculty of Mechanical Engineering, Poland
Żurowski, Wojciech (wojciech.zurowski@uthrad.pl), Kazimierz Pulaski University of Technology and Humanities in Radom, 29 Malczewskiego Str., 26-600 Radom, Faculty of Mechanical Engineering, Poland
Bakar, Mohamed (m.bakar@uthrad.pl), Kazimierz Pulaski University of Technology and Humanities in Radom, 29 Malczewskiego Str., 26-600 Radom, Faculty of Chemical Engineering and Commodity Science, Poland
Opara, Tadeusz (t.opara@uthrad.pl), Kazimierz Pulaski University of Technology and Humanities in Radom, 29 Malczewskiego Str., 26-600 Radom, Faculty of Mechanical Engineering, Poland
Rucki, Mirosław (m.rucki@uthrad.pl), Kazimierz Pulaski University of Technology and Humanities in Radom, 29 Malczewskiego Str., 26-600 Radom, Faculty of Mechanical Engineering, Poland
Gevorkyan, Edwin (cermet-u@mail.com), Ukraine State University of Railway Transport, 7 Feuerbach Sq., 61010 Kharkiv, Wagon Engineering and Production Quality, Ukraine
Białkowska, Anita (a.bialkowska@uthrad.pl), Kazimierz Pulaski University of Technology and Humanities in Radom, 29 Malczewskiego Str., 26-600 Radom, Faculty of Chemical Engineering and Commodity Science, Poland

The thermal-dynamic mechanicals properties of two kinds of epoxy composites (based on resins Epidian 52 cured with triethylenetetraamine and Epidian 112 cured with polyaminoamide) modified with different contents of silicon carbide SiC and tungsten carbide WC particles (from 10% to 56% of each powder weight fraction into composite) were investigated in this study. Statistical methods for planning experiments were used, and regression equations of the components response functions were formulated. The effect of components on composites properties was established. Typical SEM structures of tested samples were shown. Dynamic mechanical analyzer measurements were carried out on an Instrument DMA SDTA861, Mettler Toledo. The samples were subjected to a sinusoidal stress amplitude, deformation amplitude and phase lag were determined as a function of temperature, frequency and force amplitude. The tests were performed by using the three-point bending mode and also the dual cantilever bending deformation mode in the temperature range from 20°C to 140°C, at heating rate 2°C/min with a maximum deformation to ± 0.6 mm, maximum amplitude of the force of 40 N and a frequency of 10 Hz. Polymer samples were tested for their viscoelastic response including complex modulus (M*), storage modulus (M'), loss modulus (M") and damping factor (tan) and evaluated for their dependence on the composite components. The glass transition temperature (Tg) was determined from the position of the maximum value of tan . The differences between the maximum values of the composite modules (M*) of individual composites, estimated in both bending modes, are very large. They range from 42 MPa (the dual cantilever bending mode, sample № 3 with 50% Epidian 112 cured with polyaminoamide + 10% SiC + 40% WC) to over 7000 MPa. In the three-point bending mode, the highest value of the complex modulus M* = 7043 MPa and a low maximum value of the damping factor tan = 0.39 were shown by the composite № 5 (30% Epidian 112 cured with polyaminoamide + 56% SiC + 14% WC). In the double cantilever bending mode, the highest value of the modulus M* (ie 6151 MPa) was shown by the composite № 6 (30% Epidian 52

cured with triethylenetetraamine + 56% SiC + 14% WC) with the factor of damping tan = 0.81 and Tg = 84°C. The glass transition temperature (Tg) reached values from about 47°C (sample № 5 - with tan = 0.39 in the dual cantilever mode) to above 97°C - 102°C with maximum tan = 0.58 - 0.63 in both test modes for sample № 2 (30% Epidian 52 cured with triethylenetetraamine + 14% SiC + 56% WC). The differences in the values of the glass transition temperature were very significant - over 50°C for tested composites. However, it was shown that, the higher the glass transition temperature, the greater the thermal stability of the material and the better its thermal-dynamic mechanical properties.
Keywords: epoxy composites, silicon carbide powder fillers, tungsten carbide powder fillers, thermo-dynamic mechanical analysis, viscoelastic modulus, glass transition temperature

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abst. 1284
Room B032
Wednesday
July 20
12h30

Ply-resolved quantification of thermal degradation on carbon fibre-reinforced polymers

Bibinger Johannes (Johannes.Bibinger@unibw.de), University of the Federal Armed Forces in Munich – Department of Aerospace Engineering, Germany
Eibl Sebastian (SebastianEibl@bundeswehr.org), Bundeswehr Research Institute for Materials, Fuels and Lubricants (WIWeB), Deutschland
Gudladt Hans-Joachim (Hans-joachim.Gudladt@unibw.de), University of the Federal Armed Forces in Munich – Department of Aerospace Engineering, Deutschland

The carbon fibre-reinforced polymer HexPly® 8552/IM7 consisting of 32 unidirectional plies is thermally irradiated from one side with an infrared lamp of a tube emitter at a heat flux of 50 W/cm2 under varying exposure time. These Panels are cut and defined plies are removed from the front and back sides to prepare specimens with different ply ranges. Non-destructive and destructive methods are used to characterize the damage mechanism as well as the mechanical properties depending on the ply position. In the case of one-sided thermal irradiation, a temperature and consequently a damage gradient occurs, which can be classified in maximum three sections. From no till minor thermal degradation, over structural damage and to depletion of the polymeric matrix. Due to this separation, the effect of the damage mechanism, comprising matrix degradation and structural damage, on the damage behavior as well as mechanical properties can be determined. This allows the introduction of damage models predicting residual strength. Thereby, the three-section model provides the best prediction quality due to the damage grad-based background.

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abst. 1305
Repository

A new combined asymptotic-tolerance model of thermoelasticity problems for thin biperiodic cylindrical shells

Tomczyk Barbara (barbara_tomczyk@sggw.edu.pl), Department of Mechanics and Building Structures, Faculty of Civil and Environmental Engineering, Warsaw University of Life Sciences, Poland
Bagdasaryan Vazgen (vazgen_bagdasaryan@sggw.edu.pl), Department of Mechanics and Building Structures, Faculty of Civil and Environmental Engineering, Warsaw University of Life Sciences, Poland
Gołąbczak Marcin (marcin.golabczak@p.lodz.pl), Institute of Machine Tools and Production Engineering, Faculty of Mechanical Engineering, Lodz University of Technology, Poland
Litawska Anna (a.litawska@gmail.com), Department of Structural Mechanics, Faculty of Civil Engineering, Architecture and Environmental Engineering, Lodz University of Technology, Poland

The objects of considerations are thin linearly thermoelastic 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 varying shell thickness and/or periodically varying inertial, elastic and thermal 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

contribution is to formulate and discuss a new averaged mathematical model for the analysis of selected dynamic thermoelasticity problems for the shells under consideration. This model will be derived applying the combined modelling procedure. The combined modelling includes both the asymptotic and the tolerance non-asymptotic modelling techniques, which are conjugated with themselves under special conditions. The tolerance modelling procedure is based on the concept of tolerance relations between points and real numbers related to the accuracy of the performed measurements and calculations. The starting equations are the well known governing equations of linear Kirchhoff-Love theory of thin elastic cylindrical shells combined with Duhamel-Neumann thermoelastic constitutive relations and coupled with the known linearized Fourier heat conduction equation in which the heat sources are neglected. For the micro-periodic shells under consideration, the starting equations mentioned above have highly oscillating, non-continuous and periodic coefficients. Contrary to the starting equations, governing equations of the combined asymptotic-tolerance model proposed here have constant coefficients depending also on a cell size. Hence, this model makes it possible to study the effect of a microstructure size on the global shell thermoelasticity (the length-scale effect). This effect plays an important role in many special dynamic thermoelasticity problems in micro-periodic structures. An important advantage of the combined model derived here is that it makes it possible to separate the macroscopic description of the modelling problem from its microscopic description.

Determination of heat deflection temperaturę under load (HDT) and Vicat softening temperature (VST) of powder composites used for ablative coatings

abst. 1319
Poster

Szczepaniak Robert (r.szczepaniak@law.mil.pl), Military University of Aviation, Poland
Sapinski Przemyslaw (p.sapinski@law.mil.pl), Military University of Aviation, Poland
Plonka Daniel (d.plonka4290@wsosp.edu.pl), Military University of Aviation, Poland
Krzyzak Aneta (a.krzyzak@law.mil.pl), Military University of Aviation, Poland
Kosicka Ewelina (e.kosicka@pollub.pl), Faculty of Mechanical Engineering, Lublin University of Technology, Poland

This paper presents the results of a study to determine the heat deflection temperature (HDT) and Vicat softening temperature (VST) of polymer matrix powder composites used for ablative shielding. This is an important issue due to the fact that during ablative tests the composite material is partially burnt (ablative layer) but also heated to a higher temperature in the remaining part, and this is associated with a change in visco-elastic properties, which depend on VST and HDT temperatures. Different mass percentages of powder modifiers (montmorillonite, halloysite, mullite, carbon nanotubes, silicon carbide, glass microballoons) were used and the type of matrix (LH 145 with H147 hardener, L285 MGS with H285 hardener, and Epidian 57 with Z-1 hardener) were changed in the present studies. In addition to observation of thermal properties that may change due to modification of the composition of the composites, the effect of conditioning of the samples on the test results was also studied. It was observed that pre-heating the composite at temperatures about 55°C increased the HDT and VST by about 20°C, as well as increased the composite hardness by about 3-7%.

Analysis of ablative properties of hybrid composite with fiber reinforcement and powder aerogel

abst. 1340
Poster

Szczepaniak Robert (r.szczepaniak@law.mil.pl), Military University of Aviation, Poland
Wróblewski Mikołaj (mikki841@gmail.com), 7th air squadron, Poland
Przybyłek Paweł (p.przybylek@law.mil.pl), Military University of Aviation, Poland
Krzyzak Aneta (a.krzyzak@law.mil.pl), Military University of Aviation, Poland
Komorek Andrzej (a.komorek@law.mil.pl), Military University of Aviation, Poland
Bąbel Robert (r.babel@law.mil.pl), Military University of Aviation, Poland

The publication presents the results of research on the effect of using powder aerogel in a hybrid composite consisting of a fiber composite from the front (about 3 mm) and a powder composite reinforced with aerogel in the further part of the sample (about 7 mm). The reinforcement in the fibrous composite uses carbon and aramid fabrics to prevent the material from eroding too quickly under the influence of heat flux. The L285 MGS epoxy resin with hardener H285 MGS (resin with aviation approval), characterized by low viscosity and good mechanical properties in the proportion by weight of mixing specified by the manufacturer, was used for the matrix of the composite samples. Additionally, the ablation properties were modified by the use of JIOS silica aerogel - AeroVa Aerogel. This additive is characterized by extremely low thermal conductivity (in the order of 0.0017 - 0.022 W / mK) and very low flammability. 14 samples were prepared, two in a series, which differed in the amount of aerogel reinforcement (from 0 to 6% airgel) in the reinforcement of the powder composite. The tests were carried out for 180 seconds of exposure to the hot gas stream at a temperature of about 1000°C. The temperature of the rear surface was measured using thermocouples and a thermal imaging camera. On the other hand, the temperature of the ablative surface was measured using a laser pyrometer. The analysis of ablative parameters such as ablation surface temperature, posterior surface temperature, the ablation weight loss, the rate of ablation was performed. The obtained results are presented in both tabular and graphic form.

Composite optimized design for fibre placement manufacturing and additive manufacturing

abst. 1082
Room B032
Wednesday
July 20
15h10

Van den Brink, Wouter (brinkw@nlr.nl), Royal NLR, Netherlands
Maas, Robert (Robert.Maas@nlr.nl), NLR, Netherlands

Fibre steering for Carbon Fibre Reinforced Plastic (CFRP) design in aerospace structures has been investigated for several decades. It has been shown by researchers (among which Gürdal et al.) that performance improvements using fibre steering technology, also known as variable stiffness designs, can be achieved and potentially be translated into structural weight reduction. Actual application of this technology however has been limited. In this paper the fibre steering designs for fibre placement manufacturing and the recent developments in composite additive manufacturing design in combination with topology optimization will be presented. Optimization of a thermoset composite space launcher structure part called the Engine Thrust Frame (ETF) has been performed and will be presented. The composite design optimization process using fibre steering optimization methods has been applied to the ETF with multiple loadcases. The approach uses in-loop finite element calculations and control points interpolation of the steered-ply orientation. This is followed by the translation to the actual fibre paths for AFP manufacturing using the in-house developed PathFinder tool. This design was manufactured in scale and tested. A similar approach that will be presented is on optimization of a thermoplastic composite aircraft horizontal stabilizer skin section with a length of 4.5 meters. The laminate locally respects previously certified laminate stacking definitions. Several design manufacturing constraints were applied to reduce the rework after the optimization process. The first constraint ensures that the fibre paths for the skin is continuous over the centre-box of the horizontal stabilizer. Another constraint restricts the first layer to be non-steered and an overall maximum steering radius of 1000 mm. With thermoplastic material the fibre steering in the first layer on the mould is not feasible because of the limited tack which limits the design. Recent work on the application of the same optimization approach towards composite additive manufacturing will be presented. This AM technology allows for steering of the fibre yarns with small radii and therefore increasing the design space compared to standard layups or fibre placement manufacturing. This gives interesting possibilities for further optimization of composite additive manufactured parts besides the afore mentioned fibre placement manufacturing designs. Keywords: composites, fibre steering, design optimization. REFERENCES: [1] Z. Gürdal,B.F. Tatting,C.K. Wu, "Variable stiffness composite panels : Effects of stiffness variation on the in-plane and buckling response," Composites Part A-applied Science and Manufacturing, vol. 39, p. 911, 2008.

Improved buckling performance of fibre-steered laminated plates with embedded pseudo-stiffeners

abst. 1089
Room B032
Wednesday
July 20
15h30

McInnes, Calum J. (calum.mcinnes@bristol.ac.uk), University of Bristol, United Kingdom
Pirrera, Alberto (), University of Bristol, United Kingdom
Kim, Byung Chul (), University of Bristol, United Kingdom
Groh, Rainer M.J. (), University of Bristol, United Kingdom

Tow-steered laminates, those in which the fibre angles vary spatially across a ply, have been investigated for improving structural performance under various loading conditions, such as buckling, bending and vibration. When steering tows by the Continuous Tow Shearing (CTS) process, the material is sheared in-plane along a curvilinear reference path. This in-plane shearing generates a non-linear orientation-thickness coupling which can be exploited in design of laminated structures. The thickness change generated by this mechanical coupling allows embedded stiffeners to be laminated into the structure. These embedded stiffeners are termed 'pseudo-stiffeners' and have been considered for reducing the imperfection sensitivity of a thin-walled CTS tow-steered cylinder [1]. However, the design and use of these pseudo-stiffeners to act as conventional stiffening features has not been investigated. Previous studies have steered tows continuously across a ply in a chosen direction. This continuous and global dependence of fibre angle on in-plane position has been a barrier for wider adoption of the tow steering

concept in industry as it requires specialised and new modelling approaches. For example, as the fibre angles varies continuously, it is not clear how is what the most optimal tow-steered reference paths are for a specific load case. In this work, the concept of 'local' tow steering is proposed, where tows are steered across a comparatively shorter length than conventionally defined. This 'local' steering approach in conjunction with the CTS process allows for pseudo-stiffeners to be embedded in a tow-steered laminated structure. Hence, instead of attempting to define a non-intuitive curvilinear reference path, one can instead define pseudo-stiffeners through definition of design parameters, such as pseudo-stiffener orientation, in-plane width, out-of-plane thickness and count. Hence, this work utilises the potential of pseudo-stiffener design to propose several novel tow-steered structures of improved structural performance than that possible with conventional straight fibre design. To quantify performance benefits of these pseudo-stiffeners on structures manufactured by the CTS process, a study into the potential improvements of buckling performance for laminated plates is conducted. Following a classic load case, a simply-supported CTS plate is analysed under uniaxial compression. The effects of pseudo-stiffeners, embedded by locally increasing the laminate thickness through tow steering, are directly compared in performance to an optimum straight fibre design. However, by embedding pseudo-stiffeners through shearing tows a mass increase is also generated. Hence, to allow for a fair comparison of performance between straight fibre and CTS plates, the mass of the tow-steered structure shall be conserved. Firstly, this work will embed pseudo-stiffeners into the optimum straight fibre design to explore the expected further increased structural performance that this design can achieve. Next, an investigation into other more novel designs will be considered. As laminated structures are comprised of multiple layers of material, a CTS laminate can be readily designed such that stacked plies of multiple different steering directions can embed grid-like stiffening patterns, e.g., ortho- and iso-grids. It is expected that these embedded stiffening patterns can allow for increased structural performance. REFERENCES: [1] Lincoln, R. L., Weaver, P. M., Pirrera, A., and Groh, R. M., "Imperfection-insensitive continuous tow-sheared cylinders," Composite Structures, Vol. 260, 2021, p. 113445. https://doi.org/10.1016/j.compstruct.2020.113445, URL https://doi.org/10.1016/j.compstruct.2020.113445.

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abst. 1156
Room B032
Wednesday
July 20
16h10

Evaluation of manufacturing defects in variable axial composites made by filament winding

Maciel, Maísa Milanez Ávila Dias (maisa.madm@usp.br), São Carlos School of Engineering, University of São Paulo (EESC - USP), Brazil
Guedes, Rui Miranda (rmguedes@fe.up.pt), , Faculty of Engineering of University of Porto (FEUP), Portugal
Tita, Volnei (voltita@sc.usp.br), São Carlos School of Engineering, University of São Paulo (EESC - USP), Brazil

Carbon fiber reinforced polymers (CFRP) are widely used for load-bearing structures, among which cylindrical shells, shafts, and pressure vessels are some of the most used primary structures for aerospace, marine, and energy industries. The most used manufacturing process for such structures is filament winding (FW), which is a well[U+2010]established process that yields high[U+2010]productivity rates, and high-quality shells. Exploiting the capabilities of modern manufacturing processes is essential to improve the mechanical performance of the final structure. Traditionally, CFRPs are manufactured as stacked unidirectional plies, which are rotated to present a quasi-isotropic behavior. But by varying the orientation of the fiber axes in the layer, such as placing the fiber in line with the main stress field directions, a significant improvement in maximum load can be achieved. Thus, Variable Axial Composites – VAC (known, sometimes, as variable[U+2010]stiffness laminates) have been investigated for flat laminates, however, less attention has been given to curved surfaces, especially closed cylindrical shells. VAC has mainly two types of imperfections arising from the processing methods, which are formed from the tow path manipulation between adjacent tows. These imperfections are fiber gaps and the overlapping of tows, which can be hotspots for damage nucleation. To safely use these materials in primary structures knowing the initiation and propagation of damage is crucial. Considering the scale of this problem, a microscale analysis using the Representative Volume Element (RVE) technique can bring great contributions. Since this analysis is very flexible and can be used as a framework to further investigate micro to macro-damage mechanisms in the future. A development of RVE determines largely the accuracy of the modeling of a heterogeneous material, which is a crucial step. Since few studies have investigated the actual size and distribution of gaps and/or overlaps in VAC for curved surfaces, the present, work aims to extend the knowledge of VAC at the micro-scale, evaluating the manufacturing defects in VAC made by filament winding (FW). Cylinders with VAC were produced by the FW technique using a KUKA KR 140 L100 robot in which the prepreg used was from TCR towpreg containing Toray T700-12K-50C filaments and UF3369 epoxy resin system. Samples of curved surfaces were obtained from the cylinders for micro-CT (Bruker SkyScan 1172) and microscopy analysis. These analyses allow the assessment of microstructure on the VAC, making it possible to evaluate the size, volume, and distribution of imperfections in samples, to be correlated to angle variation of tows. As it is known, this information leads to the development of more accurate RVEs models, which then can be analyzed by the Finite Element Method. Preliminary analyses of micro – CT were carried out due to the constituents of the samples, which are mostly carbon, making CT analysis very challenging. The preliminary scan results showed that a reasonable contrast between carbon fiber and epoxy resin, was fair, which is very important for the investigation in terms of manufacturing defects. But, unfortunately, the resolution of the images was insufficient to quantify each constituent properly. Therefore, additional CT analysis with increasing scan time and decreasing sample size will generate images with higher resolution. The distinction between resin pockets and surface porosity was another issue presented in the preliminary analysis. And, one way to solve this is by performing scans underwater. The preliminary results showed that the Micro-CT technique permits the obtainment of a 3D image of the investigated VAC, but further analyses are required. Also, microscopy analyses are necessary to validate the CT scans.

Design of variable stiffness composite plates using lamination parameter extrapolation and spectral-Chebyshev method

abst. 1242
Virtual Room 1
Thursday
July 21
13h10

Khandar Shahabad, Peiman (peiman@sabanciuniv.edu), Sabanci University, Turkey
Rafiei Anamagh, Mirmeysam (mirmeysam.anamagh1@sabanciuniv.edu), Sabanci University, Turkey
Serhat, Gokhan (serhat@is.mpg.de), Max planck institute, Germany
Basdogan,Ipek (ibasdogan@ku.edu.tr), Koc University, Turkey
Bediz,Bekir (bbediz@sabanciuniv.edu), Sabanci University, Turkey

Fiber-reinforced composites are widely used in various industries due to their remarkable advantages such as high stiffness and strength-to-weight ratios. The mechanical behavior of these materials directly depends on the fiber orientations and stacking sequence. Thus, these characteristics can be optimized to tailor the mechanical behavior of composite structures. Although straight fiber composites are traditionally used, the full potential of the fiber-reinforced composites can be exploited using curvilinear fibers. In this study, a new technique called the lamination parameter extrapolation method is presented to design symmetric and balanced variable stiffness composite panels. Lamination parameters are used to model varying stiffness properties in a compact form. In the proposed approach, two master points are considered to decrease the number of design variables. The locations of these points and two corresponding lamination parameters are used as design variables. The two-dimensional spectral-Chebyshev approach is used to solve the boundary value problem, while the first-order shear deformation theory is employed to express the deformation field. Then, discrete fiber orientations at each Gauss-Lobatto point are determined for the optimum lamination parameters and master points locations. Subsequently, considering manufacturing constraints, the continuous curvilinear fiber paths are calculated and plotted. The proposed method is utilized to maximize the fundamental natural frequency of composite panels. The obtained results are validated with those present in the literature, and it is shown that the optimum designs can be determined efficiently.

MULTI-STABILITY ANALYSIS OF FRP METAMATERIALS

abst. 1268
Room B032
Wednesday
July 20
15h50

Risso, Giada (grisso@ethz.ch), ETH Zürich, Switzerland
Ermanni, Paolo (permanni@ethz.ch), ETH Zürich, Switzerland

Multi-stable structures show high potential for use in shape adaptation. When designing lightweight shape adaptable structures, multi-stable components are favorable due to their ability to maintain multiple stable shapes without the need for a continuous power supply. In the last decades, intensive research has been conducted to investigate and model the stability behavior of unsymmetric laminated fiber-reinforced polymer (FRP) composites. Recently, the authors presented a novel manufacturing technique for the fabrication of multi-stable composite structures with complex 3D topologies. Such concept consists of combining thin FRP strips into flat periodic grid-like structures with pre-stretched membranes. Previous results demonstrated the potential of the novel FRP metamaterials. Differently from unsymmetric laminates-based concepts, FRP metamaterials show low coupling of the multi-stability property with the shell boundary conditions, and that the periodic extension of the concept is not only preserving the multi-stability but rather enhancing it. The present research illustrates and characterizes the multi-stability behavior of FRP metamaterials. Similar to the investigation performed on unsymmetric laminates, the snap-through buckling process between the stable states of several single cells made with different materials is numerically simulated and experimentally validated. The force-displacement curve is obtained experimentally with a tensile testing machine and a custom-designed testing rig, and the corresponding FE simulation is developed with the commercial software Abaqus. Results highlight that force-displacement curves depend on the material employed to manufacture the strips and that the multi-stability property depends on the level of anisotropy of the laminates employed. Highly anisotropic laminates strengthen the multi-stability while isotropic materials suppress it. To conclude, FRP metamaterials manufactured with highly anisotropic laminates are highly multi-stable. The investigation of the snap-through buckling behavior of the structures presented in this work is of value for the implementation of FRP metamaterials into real-world applications. The analysis of the critical loads manifests the feasibility of the presented multiple stable states for large shape adaptable mechanical metamaterials. Envisioned applications are reconfigurable solar arrays, antennas, soft robots, and adaptive building facades. ***[Giada Risso is one of the Winner of the Ian Marshall Award for Best Student Paper]***

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