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BOOK OF ABSTRACTS

Contents

1 Opening

A. J. M. Ferreira, Heng Hu (Chairs)

Welcome to the 2nd International Conference on Theoretical, Analytical and Computational Methods for Composite Materials and Composite Structures. The first event was organized in 2018 in Wuhan University. Given the current pandemic circumstances, this 2nd edition is organized online. Hopefully next events will be organized in the normal way, or at least in mixed mode (normal + online). We intend to share the latest state-of-the-art on research in composite materials and structures.

2 Damage Mechanics

Effect of Fiber Orientation on the Machinability of Ultrasonic Assisted Grinding of 2D-C/SiC Ceramic Matrix Composite

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The grinding mechanism of ceramic matrix composites is one of the most challenging problems in the current research, in order to reveal the mechanism of ultrasonic assisted grinding of ceramic matrix composites. This paper studies the effects of different grinding directions of 2D-C/SiC ceramic matrix composites on grinding force, surface roughness, and surface/subsurface microstructure morphology. In addition, the material removal mechanism is also analyzed. The study found that the main removal mechanisms of ultrasonic-assisted grinding and ordinary grinding are brittle removal, and the damage types of materials are matrix cracking, fiber fracture, fiber pull-out, interface peeling, and interface fracture. Grinding parameters and ultrasonic parameters have an important influence on the grinding force and surface roughness. Different grinding directions have different material removal mechanisms. Ultrasonic assisted grinding can effectively reduce the grinding force and obtain better surface quality. Based on the findings of this research, the grinding force and surface integrity of 2D-C/SiC ceramic matrix composites are predicted, which can provide certain guidance for the design and processing of this material.

On the imperfect interfaces in viscoelastic composite materials

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Nowadays, the modeling of imperfect interfaces in composite materials plays an essential role in me- chanical and civil engineering applications. Here, several physical phenomena are commonly studied such as adhesion, non-conforming contact, microcracks, friction, unilateral contact, among others. With this pur- pose, two main approaches are considered, namely the phenomenological and

the deductive. In the former, the authors assume the properties of the imperfect interfaces based on experimental observations; interface of spring type is an example in this case. On the other hand, the deductive method, which is founded on micromechanical concepts starts by considering an adhesive assembly of two bodies where the adhesive layer, also called interphase, is characterized by a low thickness. Because of this, it becomes problematic to address the heterogeneous problem by means of a finite element analysis. So that, the introduction of a dimensionless scaling parameter and the use of asymptotic homogenization techniques arise as a suitable alternative for the solution of the problem. In particular, the methodology consists in to replace the problem of the thin adhesive by a homogeneous problem wherein the small parameter is geometrically vanished in the limit theory and the mechanical properties of the new imperfect interfaces are derived from the mechanical and geometrical behavior of the original interphase. Additionally, several examples of man-made materials with practical purposes possess viscoelastic con- stituents. Others are found in nature such as biological tissues. The viscoelasticity involves both instant elastic and time-dependent viscous behavior. In particular, conventional adhesives such as water-based poly- mers generally exhibit viscoelastic properties, hence the importance of study these effects in the imperfect interfaces models. Based on the above considerations, the present work deals with the modeling of the imperfect interfaces for composites where the adhesive and some of the adherents exhibit viscoelastic effect. In particular, we use a deductive approach via the asymptotic homogenization theory to derive the viscoelastic imperfect interfaces from the viscoelastic behavior of the thin interphase. The main novelty of this study lies in taking into account the viscoelastic effects for the interphase material. The approach aims to generalize the results for elastic composite materials and to extend them to non-ageing viscoelastic ones. The work is divided into several steps. First, we consider a problem of composite body made by three deformable solids bonded together, i.e. two adherents in perfect contact with a viscoelastic interphase, and a classical rescaling technique is introduced. Then, the viscoelastic imperfect interface conditions are derived by means of the classical scheme of matched asymptotic expansion method. Finally, we solve a numerical example to show the potential of the model.

Keywords: Multi-scale modeling; imperfect interface; viscoelastic interphase; asymptotic homogenization method
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Damage evolutions and interactions of composite materials and structures under static and cyclic loading

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Damage tolerance (DT) analysis and computational methods for composite materials and structures are fundamentally different compared for traditional metals which are based on macroscopic crack initiation and propagation. Damage tolerance assessment for composite structures, such as the FAR 25 and CS-25 airworthiness regulations, are based on static strength with damage evolution influenced with cyclic loading. The characteristics of damage evolution of composite materials and structures and damage interaction under static and cyclic loading are investigated in this paper with theoretical and computational analysis based on experimental observations to explore the different damage mechanisms and their interactions. It is revealed that the damage evolution in composite laminates,

especially damage initiation and growth at interface, under simple static loading can be described by the cohesive zone model with a mixed-mode traction separation damage law. The damage initiation is based on the maximum values of interfacial strength of composite materials and damage growth is controlled by the fracture toughness under static loading. However, damage initiation and damage growth under cyclic loading can be occurred below the maximum values of interfacial strength and fracture toughness respectively defined in the cohesive zone model under simple static loading. This is attributed to different damage initiation and damage growth mechanisms under simple static and cyclic loadings. Furthermore, sophisticated interactions are observed among the damage evolutions in the sequential static and cyclic loadings, and this must be considered for damage tolerance analysis of composite structures under in-service loading spectrum in the engineering applications.

3 Auxetic materials

In-plane compression behaviors of the auxetic star honeycomb: Experiment and numerical simulation

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Star honeycombs with negative Poisson's ratio (NPR) have extensive prospects in engineering applications due to the excellent crashworthiness. This study aims to reveal the in-plane compression behaviors of star honeycombs under quasi-static loading. Two kinds of star honeycombs with different cell-wall angles were fabricated by additive manufacturing technology for in-plane compression tests. The experiment results show that the cell-wall angle has no obvious effect on the deformation modes, whereas the small cell-wall angle can improve the energy absorption capacity of star honeycombs. In addition, the unilateral horizontal maximum strain (UHMS) is proposed to evaluate the deformation stability of the honeycomb. Subsequently, numerical simulations are conducted to further investigate the influences of macro and micro geometric parameters on the in-plane compression behaviors of star honeycombs. The results show that reducing the orthogonal array ratio and length of the ligament can significantly enhance the deformation stability and energy absorption capacity. Moreover, according to the deformation mechanisms of a typical cell, a theoretical model is established to predict the plateau stress of star honeycombs under quasi-static loading. The theoretical results are in good agreement with the simulation results. Finally, three kinds of improved star honeycombs (ISH) are constructed by adjusting the ligament length, which improved the SEA by 30% compared to the classic star honeycomb. Besides, the ISH-II exhibits a stable deformation mode with a significant NPR effect. The results of this paper are expected to provide references for designing and optimizing the star honeycomb structure.
Keywords: negative Poisson's ratio, star honeycomb, deformation mode, plateau stress, crashworthiness.

Bi-material negative stiffness honeycombs for reusable energy trapping

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Negative stiffness honeycombs (NSHs) have good reusability and low rebound characteristics, thus have great application potential in the field of energy absorption and buffering. However, to ensure that the NSH does not fail during deformation, a small cellular wall thickness of the NSH is required, which results in poor structural mechanical performance and low specific energy absorption. To obtain better mechanical properties and higher specific energy absorption, a bi-material negative stiffness honeycomb (BNSHs) is proposed and investigated in this work. The stress-distribution in the cross-section of the NSH is analyzed, based on which a bi-material design scheme is proposed. BNSHs with different structural parameters are fabricated by combining the assembly-bonding process and additive manufacturing technology. A loading-unloading experiment is conducted under a displacement-controlled compression load. The deformation of the BNSH is also simulated by a finite element method. Mover, impact experiment is also carried out to investigate the buffer characteristics of the BNSH. The results show that the BNSH has good reusability and its specific energy absorption is much higher than that of NSH composed of a single material. This work also provides an inspiration for design other reusable materials using the concepts of composite materials.

4 Plates and Shells

A data-driven method based on artificial neural network for composite structures

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This paper aims to propose a data-driven method based on artificial neural network (ANN) for composite structures and materials. It consists of three steps: (1) sample database acquisition, (2) database expansion based on ANN, and (3) data-driven. Firstly, the sample database containing stress and strain is established by FE2 or other methods such as experimental methods. Secondly, ANN is used to expand the sample database. Finally, data-driven is used to analyze the macroscopic problem. The main idea is to expand the database by ANN. The databases established by different methods are directly compared and then used for data-driven, whose results will be compared. Compared to other numerical or experimental methods to establish the database, the proposed method improves significantly the efficiency of establishing the database while ensuring the accuracy. In addition, the proposed method can also be used to deal with noise data. This work provides a reliable method to expand the database, which helps to improve the efficiency of data-driven.
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A novel data-driven computing algorithm for strong nonlinear response simulation of thin-walled composite structures

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This work aims to propose a novel data-driven computing algorithm for strong nonlinear response simulation of thin-walled composite structures. The specificity of the present work lies in the using of model reduction and directly embedding the generalized stress and strain data (normal strain, curvature, normal force, bending moment, etc.) into mechanical simulations. Towards this end, the buckling and post-buckling analyses of composite beam are carried out to demonstrate the efficiency and accuracy of the proposed scheme. It consists of two main steps: the first step is to construct the generalized stress and strain data, namely the structural genome database, by using tension and bending experiments; the next step is to conduct the buckling and post-buckling analysis of the composite beam by using the proposed data-driven approach, in which Newton-Raphson method is utilized for the nonlinear iterative process. It is found that the proposed algorithm permits to efficiently trace the strong nonlinear equilibrium path. Last but not least, the combination of traditional structural analysis and data-driven technique has great potential in engineering design and optimization of thin-walled composite structures.
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Multiscale simulation of composite plates by Structural-Genome-Driven method

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This article applies Structural-Genome-Driven method to carry out multiscale simulations of composite plates. Firstly, the generalized strain and stress are adopted to construct the penalty function

of data-driven framework of plate. Secondly, the multi-level finite element method (FE2) is applied to construct the structural genome database of the composite plate. The database not only stores the generalized strain and stress at the macroscopic scale, but also retains the corresponding microscopic deformation. Finally, the based on the database, the data-driven computing method is adopted to carry out the multiscale analysis of composite plates. The results are in good agreement with those obtained by the FE2 method. For composite plates with hybrid reinforcement, even if the deformation of the Representative Volume Element (RVE) at the microscopic scale has entered the material nonlinear stage, the SGD of plate can also describe its mechanical behavior well.
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Numerical simulation of multi-stability in laminated shell structures

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This paper aims to propose an efficient and reliable approach for multi-stability analysis of composite shell structures. Towards this end, efforts are made in four aspects: (1) the shell model, (2) nonlinear solver, (3) detection of critical points and (4) identification of stable states. Firstly, by introducing an extra linear strain into a 6-parameter shell formulation, an equivalent single layer shell model is established, which accounts for large deformations and enables convenient usage of complete three-dimensional (3D) constitutive laws without condensation. Secondly, a power-series based continuation algorithm, i.e., Asymptotic Numerical Method (ANM) is utilized to efficiently trace the complex equilibrium paths. Furthermore, a bifurcation indicator integrated with the ANM is used to accurately detect the evolution of critical points and the corresponding buckling modes. Finally, the nature eigenfrequency is adopted as a criterion to identify the stable/unstable states of a shell at any load level. The approach is applied to investigate several multi-stability problems in cylindrical laminated shells. Good agreement is observed even in an "extreme" experimental case where the multi- stability is highly sensitive, and it is found that the precise approximation of the strain energy is crucial for accurate prediction of shell stability. This study is believed to provide a powerful alternative to other methods for the stability analysis and the design of advanced composite shell structures.
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Finite element model for carbon nanotube-reinforced and functionally graded multilayer graphene nanoplatelet-reinforced composite beams

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This paper investigates bending, vibration and buckling analysis of carbon nanotube-reinforced composite (CNTRC) and functionally graded multilayer graphene nanoplatelet-reinforced composite (GPLRC) beams. Both normal and shear effects are included in the formulation of the governing equations of motion of the beams. Finite element model is employed to determine displacements, critical buckling loads and natural frequencies of the beams with different boundary conditions. Several important factors in parametric studies including distribution pattern (U, X, O, A-beams), and volume fraction of CNTs, GPL weight fraction, slenderness ratio, boundary condition, etc. are investigated. Some new results are presented and discussed in details for further development and validation.

Keywords: CNTRC; GPLRC; FEM; bending; vibration; buckling

Numerical Crashworthiness investigations of a Full-Scale Composite Fuselage Section

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To apply a new material model developed and validated for plain weave fabric CFRP composites usually used in stanchions in sub-cargo section in aircrafts. This work deals with the development of numerical model of fuselage section of commercial aircraft, based on the pure explicit finite element method FEM within Abaqus/Explicit commercial code. The aim of this work is the evaluation of the energy absorption capabilities of a full-scale composite fuselage section including sub-cargo stanchions, Drop tests were carried out from a free fall height of about 5 m and impact velocity of about 6 ms. To asses the prediction efficiency of the proposed numerical modeling procedure, a comparison with literature existed experimental results was performed. We demonstrate the efficiency of the proposed methodology to well capture crash damage mechanisms compared to experimental results
Keywords: Crashworthiness, fuselage section, Finite Element Method (FEM), Stanchions, Energy Absorption.

Prediction of the effective modulus and strength of Tow Based Discontinuous Fiber Composites using meso-scale Finite Element models

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Compression molded Tow Based Discontinuous Composites (TBDC) materials made from chopped Carbon Fiber Reinforced Polymer (CFRP) tows are a type of material system that can be manufactured in complex three dimensional geometries, providing an alternative to the use of metallic materials for secondary and even primary structure. While TBDC materials are finding use in both aerospace and automotive structural applications, the inherent variability of the effective stiffness and strength of laminate creates challenges in substantiating the strength of the part or ensuring that optimal weights have been achieved. In the manufacturing of TBDC's the individual chopped CFRP tows

are either directly placed into the mold or are first pre-consolidated into mats and then placed in the mold, and subjected to heat and temperature allowing the tows to flow as viscous fluid, filling the cavities of the mold. In the laminate, the chopped tows rise and fall over one another to different extents during the compression molding process, creating resin rich regions and variable local laminate definitions. These resin rich regions have been shown to act as locations where damage may initiate as they act as internal stress concentrations. The effective elastic properties of TBDC's are often approximated as being equivalent to that of a Quasi-Isotropic laminate, however the approximation does not adequately approximate the strength properties. Previous works have demonstrated various idealizations ranging from stochastic quasi-isotropic analogies of the laminate to detailed solid element Finite Element Solutions using a commercially available tool to idealize the mesostructure. While these methods have been shown to approximate the effective axial modulus of TBDC materials, simulating the failure has proved to remain a challenge, as these methods fail to physically represent the mesostructure of the laminate.

A Random Sequential Addition Representative Volume Element (RVE) generation algorithm has been developed that considers the mesostructural morphology of TBDC's using a non-conforming voxel based mesh framework. The goal of the framework is to provide an adequate means for simulating the stiffness and strength of TBDC composites while providing detailed mesoscopic definitions to enable the study the effects of different mesostructural details on the properties of the laminate. The heterogeneous mesostructure includes varying local lay-ups, resin rich zones and out of plane tortuosity of the tows. The objective of this work is use the methodology to determine the effective stiffness and un-notched failure strength for TBDC laminated subjected to uniaxial loading. The commercial finite element solver Abaqus is used to perform the simulations, using the native Progressive Failure Analysis methods for composite materials in the solver. The calculated effective modulus and failure strengths of the virtual coupons are then compared to reported value in the available literature.

Nonlinear response of functionally graded cylindrical microshells conveying steady viscous fluid

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Nonlinear dynamic response analysis and free vibration of functionally graded (FG) cylindrical microshells with internal fluid flow are investigated based on the linearized potential flow theory and shear deformation shell theory. The size effects are considered by modified couple stress theory. The steady viscous forces of fluid flow are added to the inviscid and incompressible microshell-fluid coupled system using time-mean Navier–Stokes equations. The nonlinear partial differential equations of microshell-fluid system are derived by Hamilton's principle, and the reduced nonlinear ordinary differential equations are obtained using Galerkin's method and the static condensation method. Then, some numerical examples are presented to investigate the effects of fluid velocity, fluid viscosity, scale parameters, material properties and axial loads on the natural frequencies, nonlinear dynamic response and critical flow velocities. Comparisons with the corresponding inviscid case and previously literatures are also here discussed.

Rotordynamic Analysis of Tapered Composite Driveshaft Based on the Finite Element Formulation including Shear Deformation Effects

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In this paper, the rotordynamic response of a rotating tapered driveshaft made of laminated composite material is investigated. In the tapered shaft, shown in Figure below, the inner and outer diameters of one end of the shaft are kept constant whereas the inner and outer diameters of the other end are reduced corresponding to different taper angles. The tapered composite driveshaft is modeled as a continuous rotorshaft based on Timoshenko beam theory and Classical Laminate Theory. Since the bearings are considered as rolling element bearings, the bearings stiffnesses are modeled using linear translational springs and the bearing damping is neglected. The potential and the kinetic energies of the composite driveshaft are obtained, and then, using the finite element method and Lagrange's equations, the equations of motion are derived. A Lagrangian finite element formulation is developed to investigate the dynamic characteristics of the driveshaft including the natural frequencies and critical speeds of the composite shaft which are influenced by fiber orientations, shaft length, shaft mean diameter, rotational speed and boundary conditions. In order to assess the accuracy and efficiency of the finite element model, several analyses are carried out and the results are compared with solutions that are available in the literature. The Campbell diagrams are obtained in order to quantify the effects of rotational speed on the natural frequencies of the rotordynamic system. The effects of shear-normal coupling, fiber orientations and stacking sequences on the dynamic characteristics of rotating composite shaft are investigated. It is shown that increasing the taper angle increases the bending natural frequencies and critical speeds of the tapered composite shaft and that decreasing the length of the tapered composite shaft and increasing the mean diameter increase the natural frequencies and the critical speeds of the driveshaft.

Keywords: Rotordynamics, Driveshaft, Composite material, Finite Element, Campbell diagram.

THREE-DIMENSIONAL FREE VIBRATION RESPONSE OF THICK LAMINATED COMPOSITE DISCS

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In the present paper, the three-dimensional vibrations of structurally-reinforced annular composite disc are studied. Such discs are used in turbine engines due to their lightweight and higher strength characteristics. The majority of the past research works conducted to investigate the dynamic behavior of circular annular composite disc are based on the Classical Laminate Theory (CLT), which provides reasonably-accurate results for thin discs but often overestimates the eigenfrequencies. A comprehensive research effort is yet to be made to study the dynamic behavior of thick laminated circular annular discs. The dynamic characteristics of such a sub-component of turbomachinery are studied in the present work using the Rayleigh-Ritz energy method. In the present work, a generalized three-dimensional variational formulation to investigate the in-plane mode and out-of-plane mode natural frequencies of clamped-free circular discs is developed. The uniform-thickness circular annular disc made with aligning the fibers in radial and circumferential directions, as shown in Figure 1, is considered, and effective engineering properties of the laminated disc are calculated using the averaged stress approach. These derived effective engineering properties are used to investigate the dynamic behavior of equivalent orthotropic circular disc with clamped-free boundary condition.

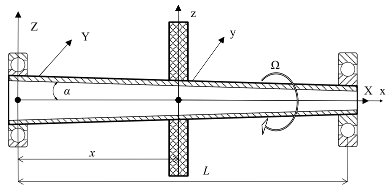

Figure 1: Driveshaft

A three-dimensional approximate solution based on the Rayleigh-Ritz energy method is developed, which in turn is based on the three-dimensional elasticity theory and linear strains. The trigonometric functions in the circumferential coordinate are employed in all the displacement components in the Rayleigh-Ritz method to calculate the natural frequencies and natural modes of the disc. The comparison of the frequency results calculated using the present approach with the results calculated based on the finite element simulation using ANSYS® is performed to evaluate the accuracy and efficiency of the developed approximate solution. A detailed parametric study is conducted to study the influences of various system parameters on the natural frequencies of the annular disc. In particular, the influences of various reinforcement configurations and layer thicknesses are investigated. Numerical and symbolic computations are performed using MAPLE® and MATLAB®.

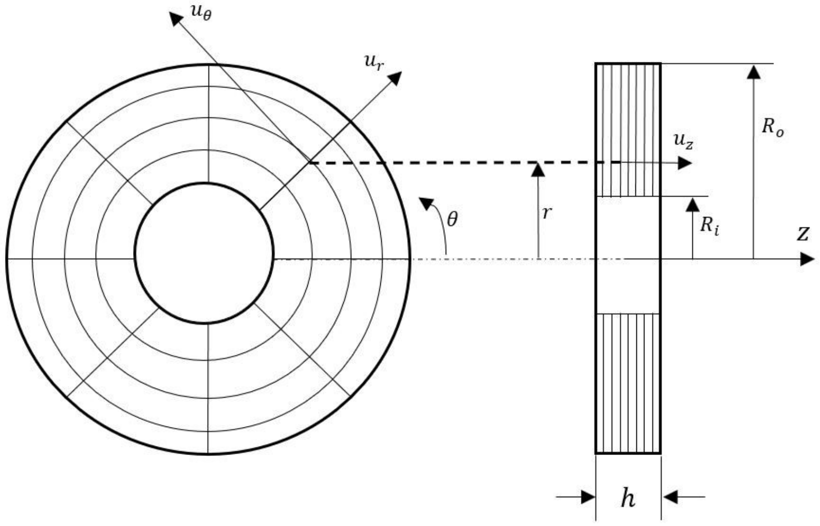

Figure 2: **Circumferentially and radially reinforced annular composite disc.**

Influence of projectile shape, stacking sequence, thickness on perforation characteristics of CFRP laminates subjected to impact

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It is of utmost importance to estimate perforation characteristics of carbon fibre reinforced polymer (CFRP) laminates in the design of protective civil and military structures. CFRP is preferred as a protective material against impact due to its excellent properties such as high specific strength, high toughness, high specific modulus, etc. The focus of this work is on two main areas of impact perforation study, determining perforation characteristics and understanding the perforation process. The influence of projectile shape, stacking sequence and thickness on perforation characteristics was also studied. To achieve this objective, impact experiments and numerical simulations were carried out. Cross-ply, angle ply and quasi-isotropic CFRP laminates, each of two different thicknesses (1 mm and 2 mm) were considered in this work. These square shaped laminates of span size 200 mm were impacted by rigid hemispherical and ogive nose projectile (CRH 2) for a wide range of velocities. Impact experiments were conducted on cross-ply CFRP laminates by taking both the rigid steel projectiles using pneumatic gun setup. Also, a numerical model was developed in ABAQUS/Explicit using Hashin damage criteria to understand the perforation process of CFRP sheets under impact. The precision of the numerical model was assessed by comparing the experimental results with numerical simulations and they were in good agreement with each other. Then, the perforation characteristics of angle ply and quasi-isotropic CFRP sheets were predicted with the help of validated numerical model by taking both the projectile. The influence of projectile shape, stacking sequence and thickness on the performance and energy absorbing capacity of these laminates at different impact velocities were analysed. Also, effective laminates from the considered layup sequence which will provide better energy absorption and damage resistance under impact has been sought.

Effect of impact location on the variation of residual dent depth in metallic honeycomb sandwich panels

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Honeycomb sandwich structures are common in aerospace applications due to their high in-plane strength and bending stiffness to weight ratio. An aircraft vehicle is likely to experience some form of impact loading throughout its lifetime, during maintenance (e.g., tool drops) or in-service activity (e.g., runway debris). Impact damage can cause significant reductions in structural stiffness and strength, leading to in-flight structural failures. Current literature shows that varying the panel and impactor configuration can result in different residual dent depths in the face sheet of honeycomb sandwich panels. However, no comprehensive studies have identified the effect of impact location with respect to the cells on the variation of residual dent depth in the face sheet. The current work presents a method that quantifies the expected variation in dent depth based on the impact location. This gives an idea about the damage variation that can be expected in simulations, experimental testing or in the field based on impacts occurring at random locations on the surface of a panel. Using the finite element analysis software ANSYS, dynamic simulations were conducted for various impacts using a spherical indenter on different locations relative to the cells. The analysis was performed on four different impact locations: the centre of a double-wall (P1), the centre of a single-wall (P2), the middle of a cell (P3), and at the intersection between cells (P4). The face sheet thickness, cell wall thickness, impactor size, impactor velocity, and cell sizes were also varied for a total of 76 simulations. It was found that for low-velocity impact events that produce barely visible impact damage (BVID

resulting in residual dent depths between 0.1 and 0.8 mm) in metallic honeycomb sandwich structures, the impact location is expected to cause variations between 0.028 and 0.314 mm in the dent depth. It was also verified that impacts occurring at the centre of a cell result in a higher residual dent depth than impacts centred over a cell wall. It was determined that thicker face sheets, larger impactor radii, thinner cell walls, smaller cell sizes and lower impact energies cause a decrease in dent depth variation across a panel, and the damage could vary by as little as 2% over a panel under these conditions. It was also concluded that the effect of impact location might disappear when the radius of the impactor is increased to over 30 mm as shown in the Figure below. The damage variation of the face sheet deformation decreases with increasing impactor size as the impactor size covers a larger panel area and distributes the damage over more cells.

In conclusion, it is recommended to use larger impactors to reduce the residual dent depths' variation due to potential differences in impact location during physical testing

Research on delamination behavior of multidirectional composite laminates under static loading

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Carbon fiber reinforced plastics have been widely applied in aviation, aerospace and other fields due to its excellent mechanical performance. For the commonly used composite laminates, delamination is one of the most dangerous failure modes because there is no reinforcement in the thickness direction. In order to accurately describe the delamination behavior of the multidirectional laminate, the following researches were made. An interface-dependent model of plateau fracture toughness in multidirectional laminates under mode I loading was developed. The most commonly used delamination propagation criteria were improved to accurately evaluate the delamination behavior of in multidirectional laminates by considering the effect of large-scale fiber bridging on the delamination behavior, which induce the significant resistance phenomenon. Besides, a novel physically-based mutilinear cohesive law were developed in cohesive zone modelling, and the analytically and experimentally methods to determine the bridging law were presented. Morever, a XFEM based crack-leading model was proposed to reveal mechanisms of the different delamination morphologies. These methods were applied to the design of the composite joints subjected to heavy out-of-plane load, a novel design of joint was proposed and a serious advanced structure adaptive joints were developed, which have been applied in the structure design of aircraft.
Keywords: Carbon fiber, multidirectional laminates, delamination, resistance phenomenon, cohesive zone model

Impact simulation of textile composites: from meso-scale model to multi-scale model

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The intertwined fabrics architecture of textile composites, as well as feasibility with integrated manufacture technologies, provide great potential for their increasing application in various fields, including aerospace, automotive and renewable energy et. al. This, on the other aspect, also raises additional challenges on knowledge and methodologies for the failure analysis of composite structures under various complicated service conditions. The complexity of failure behavior for textile composites is associated with the multiscale geometry and failure characteristics, and their interactions across different scales, which are further complicated under impact loads due to the introducation of rate effect. Because of the large dimension of specimens used in impact tests, accuracy and computational efficiency need to be properly balanced for impact models, to enable good predictivity and feasibility in engineering application. To address these problems, different modeling approaches, including high-fidelity meso-FE model, macro-scale subcell model, macro-scale homogeneous model and multi-scale model, are developed to study the impact failure behavior of textile composites. Validated meso-scale finite element (FE) models are adopted to simulate the quasi-static and impact failure behavior of the textile composites under different load conditions, taking into consideration the realistic test boundary conditions. A computational-efficient meso-macro method is developed to study the impact behavior of the braided and woven composites, capturing the failure initiation and progression. The impact simulation results compare well with the experimental results and provide insights on understading impact failure mechanism of the studied composites. Following by which, a novel generalized multi-scale modeling concept is proposed in purpose of further enhancing the computational efficiency and accuracy for impact simualtion. This presentation will introduce comprehensively our research progress in impact simualtion methods of textile composites, as well as the major considerations and insights learned from this study.

Keywords: ImpactTextile compositesMulti-scale modelMeso-scale model; Progressive failure analysis

Numerical development of a discrete semi-continuous element to model laminated and woven composite behavior during impact loadings

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The aim of this research is to simulate impact damage during the contact between the head of a passenger and a seat. The impact must not exceed a criterion called the Head Injury Criterion (HIC), established by the US Federal Aviation Administration (FAA), which measures the probability of head injuries. As a consequence, the knowledge of composite semi-structure behavior under low velocity impact tests might allow more specific understanding and modelling of the sources of dissipation. Low velocity impact tests on laminated and woven composites may activate numerous damage modes due to bending, tension, compression and shear effects. Matrix cracking, delamination or fiber fractures are part of these damages and are essential to dissipate energy. Numerical models with damages are usually built inside continuum mechanics framework that estimates the anisotropic stiffness, with complex damage models that can describe the mesostructure scale through characteristic lengths determined a posteriori. This representation can however fade some local effects. It has been established that after the ruin of the matrix, thin laminated composites behave like an assembly of truss in tension and lose their stiffness during bending1. These observations led to the implementation of a semi- continuous element made of a combination of truss and shell finite elements1 2 3 4. Currently these elements do not take into account possible fiber inertial effects during bending. In a very similar framework, estimating the compressive strength of composites5 also requires such an approach by integrating the flexural stiffness of the fibers. The present work focuses on the behavior of 2D or 3D laminated and woven composites during low velocity impacts implemented with the semi-continuous elements to show what this approach can bring compared to continuous models

based on Representative Elementary Volume (REV). The aim is to take into account local and global response by coupling the geometry (mesh) and the structure (composite fiber patterns). The element developed and implemented in Abaqus FEA (Dassault System) consists in a combination of 4 nodes 4 integration points shell (Mindlin theory) element coupled with 2 nodes 1 integration point beam or truss elements (Timoshenko theory). They are 30 different fiber configurations in order to represent all types of laminated and woven composite with their respective patterns. The semi-continuous element is able to model laminated and woven with homogenous or hybrid fibers, to use both truss and beam elements as fibers and could differentiate the damage between the matrix or the fibers, or specifically affect the bending contribution or the tensile / compressive properties of the fibers.
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References
1 Navarro, P. (2010), Étude de l'impact oblique à haute vitesse sur des structures en sandwich composite : application aux pales d'hélicoptère, Doctoral dissertation, Université Paul Sabatier, Toulouse III
2 Pascal F. (2016), Modélisation d'impact sur structures sandwich composites : application aux pales d'hélicotpères, Doctoral dissertation, Université Paul Sabatier, Toulouse III
3 F. Pascal et al. (2018), Impact damage prediction in thin woven composite laminates – Part I: Modeling strategy and validation, Composite Structures, Volume 190, Pages 32-42
4 Mahmoud B. et al. (2019), Experimental and numerical study of the damage mechanisms in hybrid unidirectional / woven composites under impact loading, Composite Structures, Volume 209, Pages 606-615
5 Bettadahalli-Channakeshava, A. (2020), Non local modeling of the compressive strength of composite structures, Doctoral dissertation, ISAE-ENSMA, Poitiers

Dynamic Analysis of Metallic Integrated Thermal Protection Systems using Variational Asymptotic Method with General Boundary Conditions in Thermal Environments

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An integrated thermal protection system (ITPS) for spacecraft reentry based on a corrugated core sandwich panel concept fulfills both thermal and structural functions, which are generally exposed to combined high-intensity loading environments. One concept of the ITPS uses a metallic corrugated-core sandwich structure. In this paper, a study is undertaken to investigate the dynamic characteristic and response of a representative metallic ITPS structure with general boundary conditions in thermal environments. A combination of the variational asymptotic method (VAM) and global structural analysis is proposed firstly to characterize the dynamic response of the metallic ITPS structure quickly. Generalized 2D Reissner-Mindlin type stiffness matrices including an equivalent transverse shear matrix are obtained based on homogenization analysis using the VAM without invoking any ad hoc kinematic assumptions quickly. The eigenfrequency equation is obtained by the use of the Rayleigh-Ritz method. The displacement field is expressed in simple algebraic polynomial forms, which can handle general boundary conditions in thermal environments. A substantial number of numerical examples concerning the critical buckling temperature and vibration characteristic of the plate are carried out to validate the convergence and accuracy of the proposed method. Finally, the effects of key parameters including the boundary conditions, geometry parameters, and thermal environments

on the structural dynamic characteristic of the metallic ITPS plate are discussed in detail.

Mixing layer-wise and refined equivalent-single layer FEs based on Lagrange expansions

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In the aeronautic engineering, in case of the design of an aircraft system, the finite ele- ment model of the structure is usually developed by combining 1D and 2D elements, which opportunely approximate the mathematical domains of ribs, stringers, panels, and other com- ponents. Clearly, this discretization results in a simplification of reality. Indeed, in many applications, a complete description of the 3D stress field of a certain portion of the model may be mandatory. To accurately capture these localized 3D stress fields, solid models or high-order theories are demanded. However, in order to make the model more efficient, i.e. to balance computational cost and accuracy of the results, a global/local approach can be adopted. A popular approach for the global/local analysis of structures consists of formu- lating multiple kinematic models. In particular, different subregions of the structure are analyzed with different mathematical models, so that particular areas of interest can be described through an accurate description, as the Layer-Wise (LW) approach when dealing with laminated materials, whereas lower-order kinematcs can be employed in the remaining zones. Although accurate, LW models may require the use of high computational efforts. Thus, in the last years, several efforts have been addressed by researchers to make the composite plate and shell models as accurate as efficient. One of the simple types of multiple-model method, for composite laminates analysis, is the concept of selective ply grouping or sublaminates (see [1]). This approach consists in creating some local regions in the plate/shell thickness direction, identified by specific ply or plies, within which accurate stresses are desired. The purpose of this work is the development of a mathematical model able to arbitrarily select multiple plies, within which the interlaminar stresses have to be accurately defined. The approach is developed in framework of the Carrera Unified Formulation [2], which allows the user to define the order of model as an input of the analysis, so that low- to higher-order models can be built in a global/local meaning without the need of any ad-hoc model. The proposed approach is applied to 1D beam and 2D plate/shell models, as well as on a stiff- ened panel from a real aeronautic application. The results show the capability of the present model to accurately describe the localized interlaminar phenomena in terms of stresses using the global/local approach.

References

Wang A.S.D., Crossman F.W., “Calculation of edge stresses in multi-layer laminates by sub-structuring”, Journal of Composite Materials, (1978)

Carrera, E. and Cinefra, M. and Petrolo, M. and Zappino, E., “Finite element analysis of structures through unified formulation” John Wiley Sons, (2014).

Free vibration of CNT and FGM reinforced doubly curved shells by discrete singular convolution and quadrature methods

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Laminated composite plates and shells are commonly used structural component with a wide application in automobile, aerospace, civil, mechanical, piping and petro chemical industries, nuclear, and marine engineering. It is important to understand its dynamic and modal behavior for acceptable, safely and accurate design of any mechanical system. Functionally graded materials (FGM) as known multi-functional materials and have broad usage in different engineering applications. Due to the potentially remarkable mechanical, thermal and electrically properties of carbon nanotube (CNT) reinforced functionally graded composites; they have been also widely used in aero-space, biomedical applications, marine, rocket and pipeline components, civil engineering, optical, electronic, chemical, biomechanics, nuclear engineering, and automotive industries etc. The accurate analysis of mechanical behaviors such as vibration and modal responses are currently of particular interest and studied extensively in this area. In this study, modeling and numerical solution of free vibration problem of doubly curved shells and plates with carbon nanotube (CNT) reinforced composites and functionally graded composites have been investigated. First-order shear deformation theory has been used for modeling of doubly curved shallow shells and plates with CNT reinforced and functionally graded materials (FGM). The method of discrete singular convolution (DSC) and harmonic differential quadrature (HDQ) methods were used for solution of equations of motion for shells and plates via discretization. Verification of the accuracy of the present DSC and HDQ results is verified by appropriate convergence study and checked with the results available in the open literature for isotropic, and FGM composite cases. The influence of volume fraction index, boundary conditions, types of CNTR, FGM index parameters and geometrical parameters on results have been investigated in details.

VIBRATIONS AND BUCKLING OF ORTHOTROPIC FUNCTIONALLY GRADED STRAIN GRADIENT NANO PLATES IN HYGRO-THERMAL ENVIRONMENT

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Nano structural components have been widely spreading recently due to their novel applications in several engineering fields. Such components have a nonlocal mechanical behavior that might force to employ generalized or higher-order elasticity theories to take into consideration effects on the nano scale. In this context, nonlocal strain gradient theory has been utilized for investigating the linear vibrations and buckling phenomena of nano plates where orthotropic mechanical properties are functionalized through the plate thickness. Reinforcing fibers of such orthotropic layers can be modelled by assuming a non-uniform distribution along each ply thickness. The homogenization of the orthotropic layers is performed by following the Halpin–Tsai approach starting from the two main constituents (fiber and matrix). Through-the-thickness functions are introduced to describe the variation of their volume fraction. As an evidence from industrial applications nano plate behavior depends on external stimuli such as hygro-thermal effects. For this reason, these effects have been included into the formulation in order to study their influence in the dynamic and linear buckling phenomena. The governing partial differential equations are solved via a finite element model where Hermitian shape functions are introduced due to the higher-order nature of the nonlocal theory selected which involved both in-plane and out-of-plane displacement parameters. Numerical applications are provided in order to show hygro-thermal effects on the vibration and buckling problems of nano plates, in particular, the effect of the fiber distribution along the ply thickness is underlined.

Buckling performance of variable stiffness composites considering material uncertainties via multiscale stochastic fibre volumes

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Keywords: Variable stiffness composites, defect modelling, micromechanics, Unified Formulation The novel manufacturing techniques of composite laminates are leading to a reduction in the amount of defects present at the mesoscale level of variable stiffness plates (VSP), see for instance the Continuous Tow Shearing [1] method that permits to avoid the misalingments and skip the presence of gaps and/or overlaps among tows. Nevertheless, the inner constituents of the composite material might not be flaw-exempt, e.g: void content, variation in the fibre volume, presence of different phases, etc. This fact leads to the need of a multiscale analysis of the whole VSP, which have been demonstrated to be computationally expensive for classic composite structures. In the recent years, the Carrera Unified Formulation (CUF) [2] has been extended to the micromechanical [3] and multiscale [4] analysis of material composites, providing solutions that required fewer number of degrees of freedom and, thus, a reduction in terms of CPU time. By using the CUF framework, extended to both VSP [5] and micromechanics, this work aims to show how variations in the fibre volume content of the material affect the buckling performance of VSPs. For doing so, stochastic fibre volume fields are generated by means of the Covariance Matrix Decomposition (CMD) [6]. Each component of the random field is assigned to a micromechanical model in order to homogenise the material elastic properties, thus leading to a spatially varying distribution of such properties.

References

B.C. Kim, P.M. Weaver, K. Potter. Manufacturing characteristics of the continuous tow shearing method for manufacturing variable angle tow composites. Composites: Part A 61, 2014. Pages 141-151.

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.

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.

I. Kaleel, M. Petrolo, E. Carrera, A.M. Waas. Computationally Efficient Concurrent Multiscale Framework for the Linear Analysis of Composite Structures. AIAA Journal 2019, Pages 1–10.

A. Pagani, A.R. Sanchez-Majano. Influence of fibre misalingments on buckling performance of variable stiffness composites using layerwise models and random fields. Mechanics of Advanced Materials and Structures 2020. DOI: https://doi.org/10.1080/15376494.2020.1771485

P. Spanos, B. Zelding. Monte Carlo treatment of random fields: a broad perspective. Applied Mechanics Review 51(3), 1998. Pages: 219-237

On effective properties of beam-lattice structures considering flexoelectricity

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Flexoelectricity phenomenon expresses a general property of all solid and fluid dielectrics. It relates the electric polarization with gradient of strains and vice versa the dependence of strains on the gradient of polarization. A magnitude of the flexoelectric effect is rather small, in general, but it could be significant and even dominant at nano- and micro scales where strains may exhibit large gradients. Nowadays this phenomenon is applied in various NEMS and MEMS in order to improve an apparent piezoelectric response. In this lecture we consider deformations of a particular class of beam-lattice structures called pantographic sheets. Such structures consist of two families of long fibers connected by pivots and demonstrate relatively high flexibility and strength. As flexoelectric response is well pronounced in case of bending dominant structures, flexoelectricity can affect the apparent electromechanical coupling in these structures. Our aim is to analyse the effective piezoelectric properties obtained after homogenization of these structures. Following and extending results of [1, 2] we derive effective piezomoduli and elastic moduli. Let us also note that flexoelectricity phenomenon is similar to flexomagnetic one [3]. So the proposed technique could be also applied to flexomagnetic materials. We discuss in brief some similarities in models.

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1. Eremeyev, V.A., Ganghoffer, J.F., Konopińska-Zmysłowska, V. and Uglov, N.S., 2020. Flexoelectricity and apparent piezoelectricity of a pantographic micro-bar. International Journal of Engineering Science, 149, 103213.
2. Malikan, M. and Eremeyev, V.A., 2020. On the dynamics of a visco–piezo–flexoelectric nanobeam. Symmetry, 12(4), 643.
3. Malikan, M., Uglov, N.S. and Eremeyev, V.A., 2020. On instabilities and post-buckling of piezomagnetic and flexomagnetic nanostructures. International Journal of Engineering Science, 157, p.103395.

Dynamic behaviors of two-dimensional micro-sized periodic structures based on second strain gradient elasticity theory

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Abstract: Micro-sized periodic structures have been widely used in different engineering fields. In this paper, the dynamic behaviors of complex 2D micro-sized periodic structure are studied utilizing a numerical method called the wave finite element method (WFEM). In addition, the structural characteristics are analyzed using the second strain gradient elasticity theory (SSG) which considers the higher order material coefficients. The dynamic stiffness matrix of the SSG model is established by transforming the lattice model with the nearest-neighbor, next-nearest-neighbor and next-next-nearest-neighbor interactions into the SSG continuous model. Dynamic behaviors in micro-sized beam grid are then calculated by WFEM. Band structures and forced response are discussed with the SSG and CT methods.

Keywords: Second Strain Gradient theory; Wave Finite Element Method; Continuum model; Lattice model; Band structure; Forced response.

Vibrations and Buckling of nonlocal laminated nanoplates solved by Finite Element Method

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This work presents a novel finite element (FE) based formulation for analysing the linear buckling and free vibration problems of plates governed by strain gradient theory. The present model is able to deal with general lamination schemes and arbitrary boundary conditions and its validity is tested against semi-analytical results as well as other solutions available in the existing literature. The constitutive relationship deals with stress components at each layer as a function of the nonlocal strains, according to the principles of the aforementioned strain gradient theory. The present FE formulation is based on the weak form of the governing motion equations derived via Hamilton's Principle. Such principle allows the identification of primary variables which are constitute by classical thin plate displacements as well as their first and higher-order derivatives. Therefore, membrane and bending degrees of freedom must be all approximated by means of Hermite interpolating functions. In particular, Conforming (C) and nonconforming (NC) approaches are consequently developed and compared in the present study in order to test their performances in terms of numerical computations. Validation and novel applications are provided for further studies within the present research topic.

Keywords: Vibrations and buckling, Laminated composite thin plates, Strain gradient nonlocal effect, Conforming and nonconforming finite elements.

The multi-physical isogeometric analysis method for static and dynamic characteristics of the magneto-electro-elastic structures

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In order to improve the calculation accuracy, convergence, simplify the process of applying boundary conditions of magneto-electro-elastic (MEE) structures, we proposed the multi-physical isogeomatric analysis method (MIAM). The generalized displacement fields (displacement, electric potential and magnetic potential) are approximated based on Non-Uniform Rational B-Spline basis functions, which construct an exact geometric model. Isogeometric analysis method has been introduced into multi-field coupling problems, and the basic equations of MIAM are deduced to apply in the static and dynamic responses of MEE structures. The displacement of different boundary conditions on the results of MEE structures are studied. The natural frequency is reported for the MEE materials for various Vf of BaTiO3 in the composite structures. Several numerical examples are carried out to verify the accuracy, convergence and efficiency of MIAM. The present method integrated design into analysis and optimization by using a basic function that can accurately model structures geometry and solution space which has great potential for the design and analysis of MEE structures.

Keywords: the multi-physical isogeomatric analysis method, magneto-electro-elastic structures, isogeometric analysis method, Non-Uniform Rational B-Spline basis functions

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Application of differential quadrature method to delaminated first-order shear deformable composite plates

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The first-order shear deformation plate theory is applied in this work to delaminated ortotropic composite plates. The methods of two (2ESLs) and four equivalent single layers (4ESLs) are utilized to capture the effect of delamination on the mechanical fields with sufficient accuracy. The governing equations are derived in the usual way, using the virtual work principle. However, the system of equations is solved by using the differential quadrature method. This method solves directly the governing equations together with the boundary and continuity conditions. Although it is well-known how to impose boundary conditions for plates and shells by using a specified grid, the continuity conditions between the delaminated and undelaminated parts of the structure are absolutely non-trivial. To assess the differential quadrature solution simply supported delaminated composite plates subjected to a concentrated force are analysed in accordance with four different scenarios. The concentrated force was placed at a specified grid point located at the middle point of the plate involving an integral equation at that grid point. A thorough analysis reveals that along the delamination front, and especially at the edges and corners of the delamination front the boundary and continuity conditions can be satisfied only by violating certain dynamic conditions, namely ignoring the normal forces on the one (delaminated) side and the bending moments on the other (undelaminated) side. The second finding of this study is that the delamination results in a significant perturbation in the mechanical fields and thus, the grid should be controlled such that the resonance of the solution near the delamination tip and the boundaries is reduced to a reasonable level or vanish entirely. To overcome this feature of the model the whole plate was divided into five regions. Two regions were assigned over the undelmainated part, the one next to the delaminated part involves a more dense grid. The delaminated part was created using thrre parts: one next to the undelaminated part, one having the concentrated force in the middle and another one, respectively. The continuity conditions between these parts are formulated in accordance with the previously mentioned concept. The mechanical

fields such as the displacement and stress are plotted along material lines crossing the delamination tip. The deflection function of the plates is also determined and used as a primary indicator for comparsion to results by analytical and finite element calculations. The analytical as well as the finite element results are provided from some previous studies. In the final stage the distribution of the mode-II and mode-III J-integrals are plotted along the delamination front and compared to the analytical and finite element solutions. Based on the current study the following conclusions can be drawn. The differential quadrature method is very sensitive to the continuity conditions formulated between the delaminated and undelaminated plate portions. The results show that the differential quadrature method is very accurate, however a relatively dense and well-controlled grid should be applied because of the delamination (perturbation effect) and the concentrated force. The method is more versatile than the analytical formulation, for instance even clamped or free edges can be modeled, what is more, embedded delaminations can also be captured.

Performance Evaluation of Carbon-Epoxy Composite Ablators under Aerodynamic Loading using Simulation Approach.

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Pyrolyzing ablative composite materials are widely used as thermal protective system (TPS) in space applications due to their resistivity towards high temperatures. Virtual designing and performance evaluation of these ablators as TPS requires modelling of coupled processes that involves heat transfer, mass transfer, pyrolysis reaction and thermo-mechanical erosion mechanisms. Till date, leading space and defence agencies are using their custom written computer codes to design ablative TPS. In this research work, COMSOL Multiphysics is used as virtual tool to design and simulate performance evaluation of carbon-epoxy composite ablators. At first, the complete Multiphysics modelling and the algorithm involved in the estimation of thermal erosion rate of carbon-epoxy laminates during aerodynamical ablation are presented. Three different modules namely Heat transfer in solids, Coefficient form PDE and deformed geometry are used to simulate thermal diffusion, density variation due to pyrolysis and surface mass loss rates respectively, during ablation process. Simulated thermal erosion results of 1-D, 2-D and 3-D geometries are reported by incorporating pyrolysis reactions, surface thermochemistry and mechanical erosion effects sequentially. Finally, the computed thermal erosion rates of carbon-epoxy laminates from COMSOL are compared with predictions generated from other computational tools including the Fully Implicit Ablation and Thermal (FIAT) Response code.

Key words: Thermal Protection Systems, Ablation, Carbon-Epoxy Composite Laminates, Pyrolyzing Ablator.

References 1. Risch, T., "Verification of a Finite-Element Model for Pyrolyzing Ablative Materials", presented at the AIAA 47th AIAA Thermophysics Conference, Denver CO, June 5-9, 2017. 2. Mohammadiun, H. M. (18 December 2012). Numerical Modeling of Charring Material Ablation with Considering Chemical-Reaction Effects,Mass Transfer and Surface Heat Transfer. Springer, 11.

5 Materials

Dynamic Measurements for Determining Mechanical Properties of MCC type Refractory Castable with Graphene Oxide

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The results of structure and physical mechanical properties of medium cement content (MCC) refractory castable with graphene oxide obtained by using a laboratory methods SEM, XRD, etc. are discussed in this paper. The addition of graphene oxide causes hydration and structural changes in aluminate cement, by reducing the duration of hydration induction and the formation of new crystallization centers. Also, the increased compressive strength and thermal resistance have a direct effect on the mechanical properties of MCC refractory castable specimens and the higher resistance to chemical corrosion. The usage of resonant methods keeps difficulty to maintain constant MCC refractory castable density and dimension values. Therefore, in order to improve the assessment of MCC refractory castable, it is necessary to refine its mechanical properties (Poisson's ratio, Young modulus), especially when the addition of graphene oxide is being used. This study allows to refine the formulas used for calculations, allows to better evaluate the internal MCC refractory castable mechanisms, but is also important for solving various tasks of materials modeling by digital methods. A testing stand is presented in Figure next page. The mechanical properties of MCC refractory castable with the addition of graphene oxide were determined on this bench and numerical calculations were performed on the basis of them.

a) b) c)

Figure 1. The stand for determination of mechanical properties of MCC (a – general view; b - fixation of specimens) and c - results of impact excitation (acceleration–frequency spectrum)

Figure 3: **The stand for determination of mechanical properties of MCC (a – general view; b - fixation of specimens) and c - results of impact excitation (acceleration–frequency spectrum)**

A multi-scale prediction model for longitudinal tensile strength of fuzzy fiber reinforced polymers

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Fuzzy fiber reinforced polymers (FFRP) are a group of hierarchical composites with nanofillers grafted or coated on the circumferential surfaces of core fibers. Benefitting from the introduced nanofillers in the fiber/matrix interphase, FFRP possess superior interfacial and mechanical properties than conventional fiber reinforced polymers. To quality the enhancement on the longitudinal tensile strength, a multiscale analytical model for FFRP is developed in the present paper. Two fundamental aspects are considered: the fuzzy interfacial shear strength (FISS) and the stress redistribution surrounding the fracture fiber. Firstly, the FISS, related to the nano-filler grafting strength and density, is estimated theoretically based on a twin-fiber single-lap joint test method. Subsequently, a statistic approach with consideration of FISS is applied to calculate the probability of fiber breakage propagation once the neighboring fibers break. Finally, FFRP's tensile strength is predicted according to the multiple fiber fracture. An excellent agreement is observed between the prediction results of the new model and available experimental data. Parametric studies indicate that the incorporation of nanofillers into the core-fiber/matrix interphase leads to significant enhancement to the FISS, and then to the longitudinal tensile strength of the composite. Moreover, the effect of contents of the two-scale reinforcements, the number of fracture fibers, as well as the radius and length of CNTs are discussed. The findings may have important implications in the future optimal design of FFRP.

Keywords: FFRP; tensile strength; fuzzy interfacial shear strength; multiple fiber fracture model

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Analysis of the influence of the structure of composites reinforced with aramid fibres on the detection of defects by IR thermography methods.

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Laminates are composites consisting of a matrix polymer and a few or several layers of reinforcement. A single laminate layer stacked on the other, connected stably to each other is called the lamina. Depending on the orientation of fibres in individual layers, we distinguish the following types of laminates: - unidirectional - i.e. those in which all layers of fibres are arranged in one direction, - transverse - also known as orthogonal or cross-ply laminate, consisting only of layers 0 ° and 90 °, - any - in which the arrangement of layers is free. The arrangement of fibres in individual layers has an impact on the thermophysical properties of the composite. This is directly related to the detection of defects in these composites using thermographic methods. The paper analyses the influence of the structure of a composite reinforced with aramid fibres on the possibility of detecting defects using thermography methods by means of numerical calculations.

Development of a submodel technique for FFT-based solvers in micromechanical analysis

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Keywords: micromechanics, Fast Fourier Transform (FFT), reduced order modelling, homogenization

In the context of microscopic heterogeneous materials, homogenization methods are applied to predict the effective constitutive relations. The overall behavior is commonly obtained by the analysis of a representative volume element (RVE). Hence damage mechanism are initiated at the microscopic scale, there is an inherent interest in the prediction and analysis of stress and deformation fields within a RVE. Most commonly classical finite element method approaches are used for this. Moulinec and Suquet introduced an efficient alternative technique for solving local fields of periodic cells based on Fourier series. The method works on a regular grid, which avoids meshing and makes direct use of microstructure images [1]. A significantly improvement was presented by Vondřejc et al. by reformulating the original problem in a variational form [2]. To accelerate the FFT-based simulation, further improvements, which are mostly based on the numerical solvers itself, have been conducted by several authors [3], [4]. With the development of a submodel technique, the analysis of microscopic structures can be accelerated massively. The key idea of the submodel technique is similar to its use in Finite Element Methods. However, instead of prescribing displacement on the cut surfaces of the local model, which is actually not possible in the framework of FFT-based solvers, a macroscopic strain is applied. The macroscopic strain is derived as the averaged strain in the partial region of the global model. To reduce the computational cost, the global model is coarsened by decreasing the number of pixels. Here, the comparison between the histogram of the original and resized image can be used as an error-estimator. Using the proposed submodel technique the computational cost can be reduced drastically. Moreover, the investigations regarding the bounds of image resizing are also quite interesting in terms of homogenization procedures, where only information about the averaged local fields are necessary. Further investigations have to conclude the validity with regard to non-linear problems.

H. Moulinec and P. Suquet. A fast numerical method for computing the linear and nonlinear mechanical properties of composites. Comptes rendus l'Académie des Sci. Série II, Mécanique, Phys. Chim. Astron., 318(11):1417–1423, 1994. URLhttp://cat.inist.fr/?aModele=afficheNcpsidt=4270815.

Vondřejc, Jaroslav ; Zeman, Jan ; Marek, Ivo: An FFT-based Galerkin method for homogenization of periodic media.
In: Computers Mathematics with Applications 68 (2014), Nr. 3, 156 - 173.
http://dx.doi.org/https://doi.org/10.1016/j.camwa.2014.05.014. –DOI https://doi.org/10.1016/j.camwa.2014.05.014. – ISSN 0898–1221

Vondřejc, Jaroslav; Liu, Dishi; Ladecký, Martin; Matthies, Hermann G.: FFT-based homogenisation accelerated by low-rank tensor approximations.
In: Computer Methods in Applied Mechanics and Engineering 364 (2020), 112890.
http://dx.doi.org/https://doi.org/10.1016/j.cma.2020.112890. – DOI https://doi.org/10.1016/j.cma.2020.112890. – ISSN 0045–7825

Kabel, Matthias; Böhlke, Thomas; Schneider, Matti: Efficient fixed point and Newton–Krylov solvers for FFT-based homogenization of elasticity at large deformations.
In: Computational Mechanics 54 (2014), Nr. 6, S. 1497–1514.
http://dx.doi.org/10.1007/s00466-014-1071-8. – DOI 10.1007/s00466–014–1071–8

The sensitivity of computational electrical response in CNT-polymer self-diagnostic nanocomposites to input model parameters

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Novel approaches in advanced structures and smart materials include structural health monitoring and self-diagnostic by monitoring change in material's electrical conductivity in response to applied deformations or damage development. Nowadays, the list of these functionalities is even wider, including the whole life cycle support for a structure. The perfect candidate to the role of the smart material is the CNT-polymer nanocomposite due to high intrinsic electrical conductivity and high aspect ratio of nano-filler particles. Computational methods, implemented in smart material design, have to model the change in electrical conductivity due to the change of conductive network on nanolevel. In our study, we observe that the input model parameters which have been discarded or missed so far in simulations, may play the key role in the determination of nanocomposite electrical response and the neglect of their role may lead to significant errors in modelling. To model a macro-response of a nanostructure, the approach of a representative volume element is utilised, where the CNT geometry generator creates the conductive CNT network within a given volume of the size of microns, providing the periodicity of the geometry at the boundaries. Tunnelling conductivity in-between the CNTs is calculated by the Landauer-Büttiker formula. The sensitivity of the electrical response is studied for a set of input model parameters, including CNT geometry and physical properties. Several key results have been discovered: • The intrinsic resistance of the CNTs is low due to the ballistic transport of electrons along them and is sometimes neglected in comparison to the resistance of joints. We quantify this effect and demonstrate that its neglect can lead to significant overestimation of the nanocomposite conductivity. • Most studies in the literature apply uniform boundary potentials to the periodic RVE geometry. We demonstrate that this leads to the overestimation of the nanocomposite conductivity, and a correct approach must employ periodic boundary potentials for the periodic geometry. • Often in the literature, the CNT geometry is ignored when they are modelled as straight rods, and, if not, only their curvature is taken into account. However, the path of a curve in a 3D space is characterised not only by its curvature but also by its torsion. To the best of our knowledge, our study is the first that takes the torsion of CNTs into account, and we demonstrate that this parameter is capable to remove the dependence of the resulting conductivity on the CNT segmentation length.

Study of the mechanical properties of a LDPE composite based on a modified ceramic charge

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The aim of this work was to develop a composite material of LDPE with different rates of lamellar inorganic charge (HDL) based on gibbsite. The second aim was to evaluate the loading rate effect on the thermal, mechanical, and rheological behavior of the material developed. Based on the literature review, gibbsite can be synthesized by fixation of the different lithium salts to obtain a lamellar structure, which can act as a charge in the LDPE. In this work, several characterization were used: - Infrared chemical characterization tests showed the presence of HDL charge in the matrix, which was confirmed by the appearance of the characteristic bands, as well as the increase in absorption depending on the rate of the added charge. - The rheological analysis by measuring the fluidity index of the various composites produced showed that the incorporation of the charge leads to an increase in the fluidity index of the LDPE / HDL composites, and consequently a decrease in viscosity and of the average molecular weight of the material. - As for the effect of the charge incorporation on thermal stability, the study showed a slight improvement in these properties for higher percentages. - On the other hand, the evolution of the mechanical properties of composites according to the rate of added charge can be summarized as follows:

- The results of the impact test showed that resilience decreased with the increase in the HDL charge rate. This is probably due to the formation of particle aggregates of the charge in the matrix.
- On the other hand, the results of the tensile test, showed a decrease in tensile stress and fracture strain of composites according to the rate charge added. However, the modulus of elasticity has little improved.

Key words: Composites materials, LDPE, Gibbsite, Mechanicals properties

Shape Memory Polymer Composites: Stimuli methods, Application areas, Challenges and Opportunities

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SMPs are smart materials widely accepted for potential applications in biomedical devices, aerospace, textile, civil engineering, biomedical, energy, electronic engineering and household products, with their large deformations, low density, good biocompatibility and other advantages. Due to the many limitations of SMPs in engineering applications, studies on shape memory polymer composites (SMPC) have increased gradually in terms of strengthening, innovation and improvement of driving methods, creation of special deformations and multifunctional materials. In this paper, materials used in the production, actuation mechanisms, fabrication methods, required test methods to determine shape memory behaviours of SMPCs are presented with particular focus on the recent trends in the field of fiber reinforced SMPCs. A special attention is paid to fiber reinforced shape memory thermoset composite materials due to their superior mechanical properties. Current and potential applications in wide range area from aerospace to biomedicine of SMPCs are introduced. Finally, considering with the advantages and current problems, the challenges and opportunities are shown in order to offer future prospects of SMPCs. Keywords: Shape memory polmer, shape memory polymer composite (SMPC), smart material, fiber reinforcement, thermoset polymer.

Analysis of the electroconsolidation of fine-dispersed structures out of Al2O3-WC nanopowders

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In the paper, the process of Al2O3-WC nanopowders electroconsolidation underwent theoretical and experimental analysis. Electroconsolidation is a sintering process, which can be classified as a spark plasma sintering or hot-pressing with some important patented modifications. Namely, during electroconsolidation, the electric current is applied directly to the graphite mold apart from mechanical pressure. High current generates high temperatures inside the mold, and the nanopowders are subject of pressure, temperature and electric current. Working parameters of electroconsolidation were 1600 °C and 45 MPa, which after 2-3 minutes provided full-dense fine-dispersed composite. Due to high

heating rate up to 500 °C/min, the grain growth was limited that resulted with enhanced mechanical properties of the obtained bulk material. The grains in the obtained bulk material were 500-700 nm, 5-6 times larger than the particles in the initial nanopowder. However, electroconsolidation at rates 250 °C/min and 50 °C/min resulted with respective grains 30-40 and 60-90 times larger than the powder particles. It is difficult to identify proper mechanisms of the consolidation even in a typical sintering processes despite they are examined for decades. Quick sintering at high heating rates poses additional theoretical problems, since vacancies flow is reduced, large pores are decreased, and grain growth is slowed down. When the porosity at the grain boundaries is quickly decreased, mobility in this area rapidly intensifies. Thus, high rate heating generates two opposite mechanisms. On the one hand, large number of small pores appears, and in the other hand, they provide conditions for the grain growth. The pores become the interference at the grain boundaries and thus grains tend to grow more intensely. During the heating under pressure, physical contact between grains leads to the formation of branched network of boundaries. The free surface energy is consumed by the boundaries formation, while the excessive energy is the main motor of sintering. High heating rate activates the sliding effect along grain boundaries leading to quick densification. Moreover, sintering mechanism is additionally powered by the energy of lattice imperfections, which in case of plasmochemically synthesized nanopowders is substantial. Due to the stresses in the necks of the sintered particles and gradient of vacancies concentration, diffusional displacement of the mass towards necks takes place. Methods for calculation of densification considering volumetric diffusion, as well as diffusion in boundaries and surfaces, allowed determination of the diffusion coefficients based on the experimental data. The results confirmed suggestion that the nanoparticles contained substantial amounts of linear imperfections and dislocations appeared in the contact area between the particles during sintering process under the electrical current and mechanical pressure.

Human femur: evaluation of mechanical strength by limit analysis

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Population aging, especially in the more developed Countries, is an indicator of well-being, nevertheless it poses a number of problems such as, among other, the increasing of bone-related diseases, skeletal fractures and osteoporosis, which affect the health system and have significant economic implications. In the last few decades, several scientific efforts have been made to predict and describe the human bones mechanical behaviour under different loading conditions, see e.g. [1] and references therein. However, the complexity of the bone material depending, in contrast to engineering materials, by several external factors such as age, conditions of growth, type of feeding, environmental and working circumstances, has not allowed scientists to find approaches of general applicability, so that the research in this area is very active. Finding motivation on the above remarks, the present contribution proposes the application, in the above outlined context, of the Limit Analysis Theory, so focusing on the ultimate bone mechanical conditions. A sufficiently accurate and reliable prediction of the peak/collapse load for a human long bone is attained. In particular, a Finite Element (FE) numerical technique, namely the Elastic Compensation Method (ECM), is promoted to address the human femur limit analysis. The ECM is an iterative procedure made of sequences of linear elastic analyses, through which the elastic moduli of the constituent material are systematically varied to simulate the process of stress redistribution arising within the structure suffering an increasing load till the attainment of its strength threshold. The ECM has been applied by the authors in the past to structures made of engineering materials like steel, composites or reinforced concrete [2]. To deal with human bone material, a constitutive model of Tsai-Wu-type in principal stress space is assumed for the human bone [3], the latter is modelled in 3D and viewed, at a macroscopic level, as a structural element made of a composite anisotropic material. The obtained numerical results, even if at an early stage, when compared with the ones present in literature and obtained via experimental findings, [4], encourage the authors to continue the undertaken research.

References
1. Murphy W., Black J., Hasting G., 2016. Handbook of Biomaterial Properties. 2nd Ed. Springer, New York, NY.
2. De Domenico D., Pisano A.A., Fuschi P., 2014. A FE-based limit analysis approach for concrete elements reinforced with FRP bars. Composite Structures, 107, 594-603.
3. Doblaré M., García J.M., Gómez M.J., 2004. Modelling bone tissue fracture and healing: a review. Engineering Fracture Mechanics, 71, 1809-1840.
4. Dall'Ara E., Luisier B., Schmidt R., Pretterklieber M., Kainberger F., Zysset P., Pahr D., 2013. DXA predictions of human femoral mechanical properties depend on the load configuration. Medical Engineering Physics, 35, 1564-1572.5.

Additively Manufactured Foam under Compression

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In current work syntactic foam-based functionally graded material (FGM) is developed using fused filament fabrication (FFF). FGM is printed using lightweight filaments of glass micro balloon (GMB) reinforced high-density polyethylene (HDPE). Flat wise compressive behavior of 3D printed HDPE and syntactic foam-based FGM (0-20-40) are studied as per ASTM standard. Results reveal that the compressive modulus of the FGM is higher compared to neat HDPE with a slight decrease in strength. This is due to induced void content formed during the 3D printing. These voids enhance the weight reduction potential of the foams and help in improving damping and buoyancy properties. The specific modulus and strength of 3D printed FGM are higher compared to neat HDPE. Results of SEM analysis showed that sustainability of filler was good in pre-compression tested samples without any GMB failure which signifies that all the chosen process parameters for printing FGM are appropriate, whereas breakage of GMB filler is observed in post-tested samples.

Keywords: 3D printing; Syntactic foam; Glass micro balloons; Functionally graded material.

Rotational 3D Printing of Carbon Fiber Reinforced Epoxy Composites with Controllable Fiber Orientation

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Carbon fiber reinforced epoxy resin composites play a vital role in application of aerospace, traffic vehicle and lightweight engineering. The composites exhibit exceptional mechanical performance that often arises from complex fiber orientation in the material. Controlling fiber orientation in materials is very challenging. A set of rotary extrusion 3D printing equipment was built to change fiber orientation. Using this equipment, orientation of short fibers in the printing trajectory can be

controlled by changing the rotation speed of the nozzle relative to the printing speed. Carbon fiber reinforced epoxy resin composites suitable for rotary extrusion were prepared by adding fumed silica to change the rheological property of the material. The orientation of short fibers along the radius in the printing trajectory at different rotational speeds was studied. The orientation angle (the angle between the fiber direction and the extrusion direction) increases first and then decreases along the extrusion trajectory radius direction, and reaches the maximum value at 0.5 – 0.7R (R is the approximate radius of the extrusion trajectory). The orientation angle depends on rotational speed. The effects of different fiber orientation states on the tensile and bending properties of printed products were analyzed. The performance of the product can be controlled by changing the rotation speed. The local performance customization printing process is explored by changing the rotation speed and scanning direction.

Optimization of Thermal Profile for Automotive Composite Part using Non-Isothermal RTM Cure Simulation

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Abstract: During the curing cycle of Liquid Composite Moulding process, there observes the excessive temperature gradient and substantial temperature overshoot in the composite part. This happens due to exothermic nature of cure reaction and low conductivity of the composite part. This results to matrix micro-cracks, geometrical distortions and residual stresses. This article develops the finite element model to optimize the temperature gradient during non-isothermal cure cycle. Initially, the parametric sweep analysis carried out for a range of temperature from 320 K to 420 K. This will help to specify the final cure time and also help to identify the lower and upper bound of mould temperature during formulation of optimization problem. This range of cure temperature also verified by conducting experiments using Dynamic Scanning Calorimetry (DSC) for epoxy-vinyl ester resin. The simulation results has shown consistent stability and reasonably accurate predictions with Experimental data. Followed by the numerical simulation study, the single objective optimization problem is developed to minimize the squared error between weighted average temperature along the domain at final cure time and mould temperature. Along with transient heat transfer model and cure rate model, the optimization toolbox used from COMSOL multi-physics simulator to address this optimization problem. The degree of cure and temperature variation along the thickness direction were studied with respect to cure time. At the initial period of cure reaction there observed large variation in cure conversion between boundary points and centre points. But, as the curing reaction proceeds that is after around 2000 seconds the difference in cure conversion along the domain has reduced and at final cure time it becomes negligible. This observation determines the uniformity in temperature and degree of cure along the domain of automotive composite part at final cure time.

References

1. Y. K. Hamidi and M. C. Altan, "Process Induced Defects in Liquid Molding Processes of Composites," Int. Polym. Process., vol. 32, no. 5, pp. 527–544, 2017.
2. D. Rouison, M. Sain, and M. Couturier, "Resin transfer molding of natural fiber reinforced composites: cure simulation," Compos. Sci. Technol., vol. 64, pp. 629–644, 2004.
3. K. I. Tifkitsis, T. S. Mesogitis, G. Struzziero, and A. A. Skordos, "Stochastic multi-objective optimisation of the cure process of thick laminates," Compos. Part A, vol. 112, pp. 383–394, 2018.

Keywords: Kinetics modelling, epoxy-vinyl ester resin, curing of polymers, mould temperature, degree of cure, numerical optimization.

Numerical analysis of mechanical behaviour of lattice and porous structures

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Lattice and porous structures have attracted attention in scientific literature due to the development of 3D printers that facilitate their manufacturing. A thorough understanding of the mechanical behaviour of these structures is necessary. In this work, several lattice and porous structures are analysed using the finite element method. Eleven configurations have been studied using periodic boundary conditions, in order to numerically estimate their elastic mechanical properties (Young's modulus, shear modulus and Poisson's ratio) as a function of the structure porosity. In addition, a tensile fracture test has been modelled to analyse the predicted fracture pattern as well as the stress-strain curve for each structure. It is shown that structures based on spherical holes distributions lead to stiffer structures in tensile and shear conditions. The distribution of cavities has a strong influence on the mechanical behaviour. The square distribution improves stiffness, while the hexagonal distribution improves the shear modulus. Random distributions clearly decrease the stiffness and strength of the structure, although the damage in these structures is more progressive. Therefore, this work provides a comparative study to assess the influence of the lattice topological structure on some mechanical properties of interest in structural engineering, as a function of porosity.

Keywords: lattice structures; topological optimization; homogenization; mechanical properties; finite element modelling

On the effect of geometrical fibre arrangement on damage initiation in CFRPs under transverse tension and compression

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The mechanical performance of composite materials is largely dependent on its microstructure. To efficiently design composites, it is essential to have a good estimation of the effect of the microstructure on residual stresses that arise from cooling from manufacturing temperature. Damage initiation in CFRP has been investigated for a range of microstructures with different randomness in the positioning of the fibres. In this work, we have developed 2D numerical models of composite material reinforced by longitudinal fibres. By means of periodic boundary conditions, we analyse the mechanical behaviour considering the cooling effect and tension/compression transverse loading. The influence of the randomness on the mechanical behaviour and the damage initiation has been

also studied. As expected, we find a strong effect of the randomness of the fibre arrangement on the damage initiation. We are able to relate the damage initiation to the quantification of the randomness in the model. Normal and shear stresses in the fibre interfaces have been analysed and related to the geometric distribution randomness. It is found that increasing the distance of separation between any neighbouring fibres the damage in the interface is reduced.

Keywords: fibre arrangement; randomness distribution; interface damage; finite element modelling.

A novel design concept for radar absorbing structures and lightning strike protection using Nickel-coated glass/epoxy composites

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A thin layer of Nickel (Ni) has been successfully coated on glass fiber by electroless plating technology to achieve the excellent radar signal absorber. Particularly, nickel-coated glass fibers have been efficiently applied to absorb broadband microwave and increase mechanical properties in 5-slab and honeycomb core composite structures. In addition, it is well-known that one of the best solutions for lightning strike protection is covering Aluminum (Al) or Copper (Cu) mesh/foil on the outermost layer of composite structures to reduce thermal damage from high electric current of lightning based on their low electrical resistance. Thus, with the moderate electrical properties of Nickel compared to Al or Cu that could be expected to receive a good possibility of lightning strike protection by using Nickel-coated glass fibers. In order to further develop new multifunctional materials, in this study, three different models were designed to experimentally and numerically evaluate the radar absorbing and lightning strike protection performance. Three models were used different stacking sequence with three main materials including pristine glass fiber reinforced epoxy (GFRP), nickel coated fiber reinforced epoxy (NCF), and form core. In the experiment, the return loss in X-band frequency of models was investigated firstly, and then artificial electric current of 160 kA was applied at each model. Two software of CST Microwave Studio and Abaqus were utilized to simulate return loss and damage of structures, respectively. The experimental and numerical results will be compared, and damage mechanism of models will be discussed.

The prediction of abrasion resistance of mortars modified with granite powder and fly ash using artificial neural networks

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The prediction of abrasion resistance of mortars modified with granite powder and fly ash using artificial neural networks Abrasion resistance is one of the most important features for objects where forces act on the surface causing rubbing top layers away. For the purpose of this work, the Bőhme disc method that complies with European Standard EN 13892-3 was used to determine the depth of wear. The samples used were mortars containing fly ash, granite powder and their combinations as partial substitutes for cement. Fly ash can contribute to improvement of several mortar properties like water requirement, workability, setting time, compressive strength and durability. Granite powder can be used as a filler to improve the packing density of the aggregate. This results in reduction of the cement content, together with carbon footprint. Current methods of determining abrasion resistance in use share similar disadvantages, including damaging samples surfaces and time-consuming testing. Application of artificial intelligence could contribute to optimization of non-destructive testing of abrasion resistance. Only few researches have been focused on this field. The study seeks for

answer to the following question: is it possible to build the system predicting the abrasion resistance of mortars with granite powder and fly ash with satisfactory accuracy?

Table 1: Selected input and output parameters used in abrasion prediction ANN method

Cement	Fly ash [-]	Granite Powder [-]	Cycle of testing [-]	Mass of specimen [g]	The depth of wear [mm]
1	0	0	4	356,56	0,79
1	0	0	4	373,21	1,00
0,9	0,1	0,1	4	362,15	0,98
0,9	0,1	0,2	4	354,24	1,05
0,8	0,0	0,2	4	370,63	0,74

According to gathered sources, only a few attempts have been made to predict abrasion resistance for cementitious composites. As proven by the most similar study, it is possible to predict the abrasion resistance for self-consolidating concrete, based on the components content. However, no research on prediction the abrasion resistance for mortars with fly ash and/or granite powder as partial cement replacement was found. Fly ash can contribute to improvement of several mortar properties while granite powder to reduction of the cement content, together with carbon footprint. Current knowledge of examining abrasion resistance for such mortars involve several disadvantages, including application of devices that destroy surface with the need to repair it afterwards, examining samples created especially for testing to avoid damaging the pavement, which makes them differ in properties from the main structure or long lasting laboratory tests. Application of artificial neural network in abrasion resistance prediction can contribute to optimization of the process. The assumption of input values into the network as mainly mortar components avoids much of the experimental part and allows the end result to be predicted even before the mix is made. It was proven that the accuracy of the analysis is at satisfactory level.

Modeling of Bleeding of Cement Pastes Modified with the Addition of Granite Powder

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The properties of fresh cement paste have usually significant impact on the properties of hardened composites. One of the important fresh properties of cement pastes is bleeding. Bleeding is the crucial phenomena related to fresh properties of the cementitious mixes used in civil engineering. Bleeding is the process of dispensing the water from the inside of the mixture towards the top. Cement pastes are the mix of cement (or different types of binders or else powder additives) with water. Bleeding is a property that could determine the characteristics of hardened composites. Too large a volume of dispensed water may reduce the mechanical properties of cement pastes, on the other hand, too small a volume of dispensed water may result in cracking of the surface of cement pastes due to shrinkage. Bleeding in cement pastes is a complex process that depends on many factors. The structure of the cement pastes is usually heterogeneously and it is difficult to estimate the influence of its components on bleeding of cement pastes. Currently, it seems accurate to say that bleeding is a process of heterogeneous and variable in time. There is additionally a visible relationship between the volume of dispensed water and the type and properties of cement and additives in cement pastes. Bleeding is a process also related to the rheological properties of pastes. The preparation of the ingredients and the mixing procedure also influences the bleeding process.

In order to determine the bleeding properties of cement pastes modified with the addition of granite powder, bleeding tests were performed. It can be concluded from the obtained results that the addition of granite powder changes the course of the bleeding process. The volume of bleed water was greater for the reference series than for the series with the addition of granite powder. Thanks to the conducted research, it is also possible to describe the course of the bleeding process and divide it into various phases: 1 - initial bleeding (0-30 minutes after mixing), 2 - accelerated bleeding (30-60 minutes after mixing) and 3 - stable bleeding (+60 minutes after mixing), the phases are significantly different from each other. Thanks to the conducted research, it was possible to create a numerical model of the bleeding process. The creation of the bleeding model will allow you to freely define bleeding of cement pastes and modify it in such a way that it does not cause damage and damage of cementitious composites.

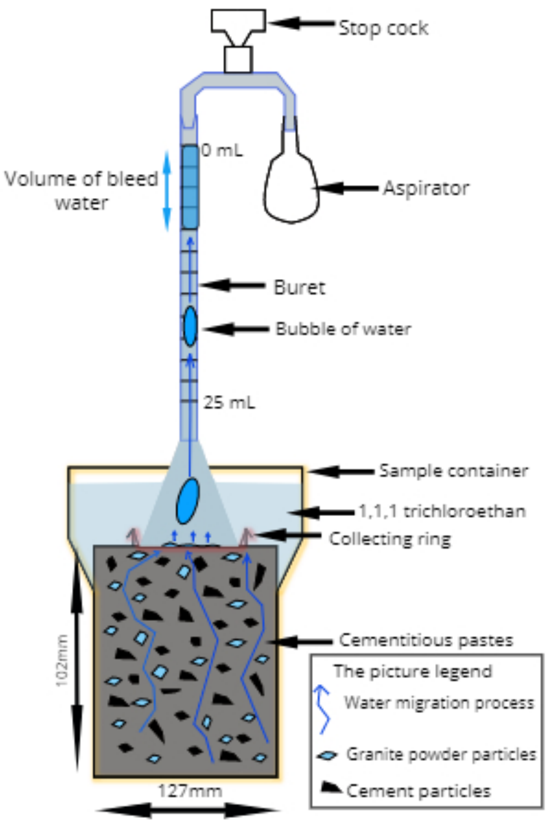

Figure 4: **Cement pastes bleeding process research (a) test diagram (b) photo from research conducting**

DETERMINATION OF MECHANICAL PROPERTIES OF CFRP COMPOSITE REINFORCED WITH ABACA AND KENAF FIBERS

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Industries are in need of eco-friendly materials that may replace the conventional materials by virtue of their high strength to weight ratio. Composite materials of natural behaviorfulfill the above needs withacombination of two or more materials. In this work, the natural fibers namely Abaca and Kenaf are taken as reinforcement and CFRP as matrix material. For fabrication of composite laminate, compression molding technique is used. Mechanical tests like tensile, flexural and impact test were performed. It is found that CategoryII shows better mechanical properties than other two Categories which recordedtensile strength of 196MPa, the Flexural strength of 263.85MPa and energy absorbed as 6 J.Also SEM has been incorporated to observe the internal structure of the hybrid composite and it founds that there is a significant improvement in the structure of hybrid composite which has fewer blow holes and cracks. The application of the hybrid composite can be implemented in the automobile industries where the natural fibers can be the alternative for the conventional materials.

Modelling spring-in distortions of L-shaped structural profiles pultruded at different pulling speeds.

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The pultrusion of L-shaped profiles is accompanied by the occurrence of spring-in distortion. This paper aims to develop and experimentally verify a numerical model predicting spring-in distortion value arising after manufacturing of glass fiber/vinyl ester resin 75 × 75 × 6 mm L-shaped profiles pultruded at pulling speeds. The following thermophysical properties of fully cured resin were measured: specific heat by Differential Scanning Calorimetry (DSC), thermal conductivity by Laser Flash Analysis (LFA), coefficient of linear thermal expansion by Thermomechanical Analysis (). The curing behavior was described using DSC. Young's modulus and strength of the fully cured resin were determined at 20°C, 40°C, 60°C, 80°C, and 100°C in tension. The evolution of the storage and loss moduli due to the temperature change was measured by Dynamic Mechanical Analysis (DMA) in a three-point-bending mode for the fully cured resin specimens. Subsequently, all the obtained properties of resin were coupled with those of reinforcement materials and used for the solution of pultrusion thermo-chemical and mechanical problems. To characterize the elastic modulus of resin Cure Hardening Instantaneous Linear Elastic (CHILE) model was utilized. Effective mechanical properties of unidirectional (UD) and fabric reinforcement were obtained using Self-Consistent Field Micromechanics (SCFM). Results of numerical simulations, performed for three different pulling speeds of 200 mm/min, 400 mm/min, and 600 mm/min, were compared with the spring-in distortions obtained in previous experiments.

Good agreement between the results was found.

Keywords: Pultrusion, shape distortions, spring-in, Cure Hardening Instantaneous Linear Elastic (CHILE) model, Finite element analysis (FEA)

The durability of polymer-cementitious floor composite made of epoxy resin modified with recycled fine aggregate and concrete substrate

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Long durability of the floor is very desirable property. The floor protection can be performed by epoxy resin coating. However, is the thin layer of the epoxy resin can always protect the lower parts of the floor? In the research the floor made of concrete substrate and epoxy resin coating was analyzed. To the epoxy resin aggerate extender was added. The quartz sand (commonly used extender) was replaced by 0, 20, 40, 60, 80 and 100% of recycled fine aggregate, made of building demolition wastes, to analyze its impact on the strength results. The grain size distribution of recycled fine aggregate was adapted to quartz sand. After 35 days of concrete (28 days) and epoxy resin (7 days) curing time samples were tested using destructive methods. Sixteen composite specimens were prepared to perform flexural tensile strength test and thirty-two specimens for compressive strength test. The tests results show that thin coating layer and type of extender do not have significant influence on flexural tensile and compressive strength of floor made of polymer-cementitious composite. The numerical models were prepared to verify stress distributions in analyzed cases and also to compare them with strength results obtained by destructive test methods. The numerical models confirmed that the critical stress was occurred mostly in concrete substrate not in the epoxy resin coating.

Keywords: epoxy resin coating; concrete substrate; floor; polymer-cementitious composite; durability; recycled fine aggregate; building demolition wastes.

6 Optimization

Optimization for FPF Strength of tapered composite tubes subjected to combined axial and torsional loadings based on genetic algorithm

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Composite tubes are widely used in automobile, mechanical and aerospace engineering applications. In engineering practice, such composite components are often subjected to multiple simultaneous loadings in service. The First-Ply Failure (FPF) of the composite tube is an important design consideration. Seeking the optimal design of the composite tube is a major design requirement in weight-saving and high-performance engineering applications. Tapered composite tube with variable mean diameter offers outstanding design tailoring and high-performance dynamic response capabilities. In the present work, the failure behavior of tapered composite tubes subjected to combined axial and torsional loadings, as shown in Figure 1, is determined considering the First-Ply Failure (FPF) characteristics. The optimal stacking sequences of the composite tubes with different values of taper angles are determined. The first-ply failure envelopes of the composite tube are developed based on the Classical Laminate Theory and Finite Element Modeling and Analysis. The FPF characteristics of the composite tube are determined 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 tapered composite tube developed using the commercial software ANSYS®. The FPF of the tube is determined based on the Inverse Reserve Factor (IRF). Genetic Algorithm (GA) is a robust and efficient method that is being used for the optimization in a wide range of practical engineering problems. The stacking sequence of the tapered composite tube made of a Carbon Fiber Reinforced Polymer (CFRP) composite material, subjected to combined axial and torsional loadings is optimized for the maximum FPF strength, based on the Genetic Algorithm. The effect of the taper angle of the composite tube on the optimal stacking sequence is studied.

Continuous fiber angle optimization method

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In the present study, in the field of optimal design of fiber reinforced composites, a design optimization method using bilateral filtering is proposed to solve the problem of gap / overlap in the manufacturing of fiber reinforced composites. A circular filtering area is defined for each finite element. In this area, the sensitivity of this element is filtered by the bilateral filter, namely domain filtering and range filtering. The filtered sensitivities are used to update the corresponding design variables. Through numerical several examples, the effectiveness of the method was verified.

Key words: Fiber reinforced composite; Fiber angle; Bilateral filtering

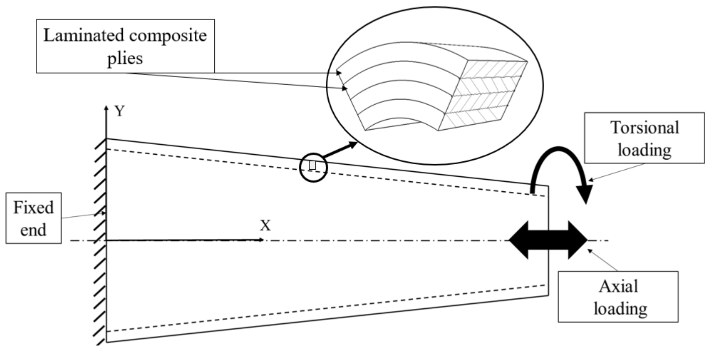

Figure 1 Tapered composite tube subjected to axial and torsional loadings

Figure 5: **Tapered composite tube subjected to axial and torsional loadings**

7 Functionally graded materials and structures

Mathematical model of wear of two-layered coating on elastic substrate

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Multilayered coatings have many applications in industry, including wear protection of friction pairs. Optimization of coating composition is a laborious task that requires a lot of tribological tests. Mathematical modelling explaining dependence of wear resistance on coating composition and thickness helps to reduce the costs associated with development of wear-resistant multilayered coatings. To analyze effect of coating thickness and ratio of elastic and thermal characteristics of coating layers and substrate on wear, we consider a transient contact problem of coupled thermoelasticity on sliding of a rigid body over a surface of a two-layered coating bonded to elastic substrate. Frictional heating of the interface between the rigid body and coating is taken into account. Solution of the problem is constructed using the Laplace integral transform technique and obtained in the form of contour integrals. These integrals are calculated by means of complex analysis, giving convenient formulas for determination of temperature, displacement and stresses in the coating and substrate and also coating wear. The obtained formulas allowed us to study wear resistance of the coating depending on the problem parameters and determine the conditions leading to thermoelastic instability, including effect of the elastic moduli and thermal expansion ratio mismatch between coating layers and substrate.
This research was funded by the grant of the Government of the Russian Federation, grant number 14.Z50.31.0046.

Keywords: wear, coating, mathematical modelling, thermoelasticity, thermoelastic instability

Approximated analytical expressions for displacements of the surface of an FGM-coated half-space under thermal and electric loading

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Piezoelectric half-space with a functionally graded coating is considered under elastic deformation of a half-space caused by thermal heating (uniformly distributed temperature in a circular area) and electric potential difference applied through the same circular area on the surface. All groups of thermoelectroelastic properties vary in depth of the coating according to arbitrary independent functions. Outside this circular area the surface is stress-free and thermally insulated. Using the Hankel integral transformation technique, the problem is reduced to the solution of the system of dual integral equations. This system is solved in an approximated analytical form using the bilateral asymptotic method. Analytical expressions for the distribution of the displacements, temperature and electric potential of the surface are obtained. The expressions are asymptotically exact for both small and large values of the relative coating thickness. Features of the deformation of the coated materials are discussed and illustrated by the numerical examples.
This work was supported by the Government of the Russian Federation (grant No. 14.Z50.31.0046).

Theoretically-experimental study on nanoindentation of coated solids

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Nanoindentation of a coating-substrate system by an axisymmetric punch is studied. An effective mathematical model is proposed based on an approximated analytical solutions of contact problems for coated elastic solids. The coating is assumed to be homogeneous or functionally graded with arbitrary varying elastic moduli in depth of the coating. The solution of the contact problem is asymptotically exact for small and large values of a relative coating thickness and of high accuracy for coatings of intermediate thickness. The differences in indentation of coated and non-coated solids are studied. Simplified analytical expressions for the indentation stiffness and indentation depth are obtained in a form convenient for engineering calculations. Accuracy of the simplified expressions is analyzed in details. Experimental data for coatings of different thicknesses are provided to approve the model. Parametric analysis is conducted to establish the applicability of the model.
This work was supported by the Government of the Russian Federation (grant No. 14.Z50.31.0046).

Efficacy of in vitro restoration of mechanical properties and mineral density of carious enamel: infiltration, sealing with composite and glass ionomer cement

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On the first clinically visible stage of caries enamel demineralization without cavitation occurs. In such cases enamel usually presents a near intact surface layer with a subsurface porous area. Due to partial dissolution of carbonated hydroxyapatite crystallites the pores are formed as a result of etching caused by carbohydrate metabolizing cariogenic biofilm bacteria producing organic acids. This phenomenon is called a white spot lesion (WSL). The dental clinician chooses a strategy for treating caries depending on a number of factors (size of the area, its localization, degree of activity, etc.) applying the classical classification by G.V. Black [1] and the recommendations of the International Federation of Dentists (FDI) [2]. With early manifestations of WSL, treatment may be limited to methods of non-invasive dentistry (including the use of antibacterial therapy [3]) and restoration of the optimal mineral composition of the area of caries by using remineralizing agents containing compounds of calcium, phosphorus, fluorine, and hydroxyapatite [4]. However, clinicians are often faced with situations when such methods are not enough, and a stronger intervention is needed. Thus, they have a choice - to use traditional methods of preparation and sealing (using composite materials, cements etc) or to resort to minimally invasive treatment (infiltration). The present study is devoted to in vitro estimation of influence of three WSL treatments - infiltration, sealing with glass ionomer cement and composite - on the set of strength characteristics including mineral density, modulus of elasticity and indentation hardness. All extracted permanent teeth were collected for orthodontic purposes from individuals in the dental department of Rostov State Medical University clinic, the patients provided informed consent. Nanoindentation was carried out using Nanotest 600 (Micro Materials, UK) system equipped with diamond Berkovich indenter in the Nanocenter of Don State Technical University (https://nano.donstu.ru/). The estimation of mineral density was carried out using X-ray computed microtomography on the Xradia Versa 520 (Zeiss, USA) device. The main aim of the research is to help to evaluate the efficacy of modern approaches to caries treatment, thereby helping a dental clinician in choosing the most optimal treatment strategy for patients. This research was funded by the Government of the Russian Federation, grant number 14.Z50.31.0046. The authors would like to thank Professor Michael Swain for constructive criticism of the research design.

Keywords: enamel, caries, nanoindentation, X-ray microtomography, mechanical properties, scanning electron microscopy

References

1. Black, G. V. (1914). A Work on Operative Dentistry: The technical procedures in filling teeth (Vol. 2). Medico-dental publishing Company.
2. Fisher, J., Glick, M., FDI World Dental Federation Science Committee. (2012). A new model for caries classification and management: the FDI World Dental Federation caries matrix.
3. Memarpour, M., Fakhraei, E., Dadaein, S., Vossoughi, M. (2015). Efficacy of fluoride varnish and casein phosphopeptide-amorphous calcium phosphate for remineralization of primary teeth: a randomized clinical trial. Medical Principles and Practice, 24(3), 231-237.
4. Feng, C. H., Chu, X. Y. (2013). Efficacy of one year treatment of icon infiltration resin on post-orthodontic white spots. Beijing da xue xue bao. Yi xue ban= Journal of Peking University. Health sciences, 45(1), 40-43.

8 Concrete-FRP

Behavior of concrete filled GFRP tubular columns with inner various section shapes of GFRP

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Axial compression test was presented to investigate 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 nominal concrete compressive strength, different winding GFRP tube thickness and different column height were tested. The failure mode, ultimate bearing capacity, ductility and initial stiffness of columns were mainly analyzed. The failure modes of columns were grouped according failure characteristics of these columns under axial compressive loading. Based on load-displacement curves, effects of test parameters on ultimate bearing capacity, ductility and initial stiffness of columns were analyzed. Besides, strain development of the three groups' columns during the test was investigated according to eight columns. Based on test results and mechanical mode of core concrete being confined with GFRP tube, this paper proposed a calculated formula which was used to predict ultimate bearing capacity of circular concrete filled winding GFRP tubular columns with inner various section shapes of pultruded GFRP, and a good agreement with the test results was achieved. Keywords: CFGT columns, various section shapes of GFRP, ultimate bearing capacity, failure mode, ductility, initial stiffness

THE INFLUENCE OF THE TYPE OF THE FORMWORK ON THE AS-CAST CONCRETE SURFACE MORPHOLOGY.

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In civil engineering elements are rarely made of concrete as the only material. Very often concrete elements are covered using overlays or coatings such as plaster (walls), epoxy resin (industrial floors) or another layer of concrete (repaired elements). To ensure proper durability of such composite there is a need of good adhesion between the layers. This adhesion is obtained very often using additional bonding agent without paying attention to the way the concrete surface is prepared. It is known that proper surface treatment will increase the adhesion between the layers for all of the above-mentioned examples. If someone take walls as an example, before shotcreting the sandblasting is commonly used. On the other hand shotblasting or grinding are usually used to prepare the concrete substrate for another layers of epoxy resin floors. In accordance to the literature, the most complicated to choose is the type of treatment for repairing the concrete element. It has to be compatible with the material used as a repair overlay or a repair coating. In order to describe the influence of these treatments on concrete surface many morphological parameters are calculated. There are many examples of the correlation between the height, volume of functional parameters and the adhesion between the layers in concrete composites. Unfortunately there is a lack of similar complex research for the concrete surfaces left as-cast after hardened in the formwork. Thus, there is a necessity of such research to be performed describing the morphology of the concrete surfaces after hardening process in the different types of the formworks. The tests will be performed using different types of the formworks commonly

used in construction practice such as wood, plywood, steel, plastic and oriented strand boards. After hardening the morphology of the concrete samples surfaces will be described. The description of the morphology will not be limited to the parameters from height, volume and functional groups but also the influence of the type of the formwork on the microcracks creating process will be analyzed. The complex research provided in the article will fulfill the gap in literature about the influence of the type of the formworks on the as-cast concrete surface morphology. Results of these research will be beneficial for the construction practice as they might reduce the usage of the concrete surface treatment in some examples where choosing the proper type of the formwork would be a better solution.

Analysis of influence of selected nanoadditives on mechanical performance of high-strength layered cementitious composite in concrete floors.

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Recently, there is an increasing interest in modifying the composition of cement composites from the point of view of the desired properties of the top layer in the concrete floors. This is mainly due to the need to ensure the appropriate durability of the composite as well as the need to meet the conditions related to the function of the top layer. Therefore, solutions that could improve the desired properties of these layers are being sought. One of such new effective solutions is the modification of the top layers with nanoparticles [1]. The article presents the analysis of influence of the three types of nanoparticles (amorphous SiO2 nanospheres, Al2O3 nanopowder, and tetragonal crystalline TiO2 nanoparticles) on the mechanical performance of high-strength layered cementitious composite in concrete floors. To compare the top layers with the modification of the above-mentioned nanoparticles and various methods of applying the top layer, the mechanical performance ratio (MPR) has been used. This parameter allows to compare the mechanical performance of top layers based on many properties, taking into account their importance from the point of view of the function that the top layer will perform [2]. The impact of key properties in terms of the most common configurations of top layers in concrete floors, i.e. pull-off adhesion between the top layer and the substrate, abrasion resistance, pull-off tensile strength of the top layer, compressive strength, and bending tensile strength was considered in the analysis.

Jacek M. Szymanowski, Łukasz Sadowski, The influence of the addition of tetragonal crystalline titanium oxide nanoparticles on the adhesive and functional properties of layered cementitious composites. Composite Structures. 2020, vol. 233, art. 111636, s. 1-11

Kurda, Rawaz, Jorge De Brito, and José D. Silvestre, Combined economic and mechanical performance optimization of recycled aggregate concrete with high volume of fly ash. Applied Sciences. 2018 Jul;8(7):1189.

Applicability of Prestressed Near Surface Mounted CFRP Bar System according to Condition of Reinforced Concrete Beam

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The existing external prestressing system has the disadvantage that is exposed to the external environment. Near surface mounted (NSM) fiber reinforced polymer (FRP) system was developed to overcome aforementioned disadvantage. This study investigated the reinforcement effect and applicability of NSM CFRP system according to material properties and reinforcing amount. In the

four-point loading tests, ten RC beams with a length of 6.4 m were fabricated. The experimental parameters were concrete compressive strength (20 MPa, 40 MPa), amount of rebar (1,161 mm3, 860 mm3), number of prestressed CFRP bar (0, 1, and 2), and number of non-prestressed CFRP bar (0, 1, and 2). Four un-strengthened RC control beams were fabricated as references by dividing into normal case, low concrete compressive strength case, low amount of rebar case, and low concrete compressive strength and amount of rebar case. One RC beam was reinforced with the non-prestressed NSM CFRP bar system. Five RC beams was reinforced with the prestressed NSM CFRP bar systems. In the experiment, the ultimate strength of strengthened RC beam with prestressed NSM CFRP bar system increased by up to two times compared to the un-strengthened control beam. The flexural performance of the prestressed NSM CFRP system increased as material properties of RC beam increased. The strengthened RC beam with NSM CFRP system was verified by comparison with the finite element model, and the parametric study was performed according to the concrete compressive strength and amount of rebar using finite element analysis (FEA).
Keyword: Near surface mounted, CFRP, Applicability, Flexural performance, Finite element analysis

Shear Analysis of basalt fiber-reinforced concrete deep beams reinforced longitudinally with BFRP bars using Strut-and-Tie Modeling

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Fiber Reinforced Polymer (FRP) Composites are known for their high strength to weight ratio, non-corrosive feature, and lightweight material. Basalt composites (i.e. bars, sheets, discrete fibers) are emerging construction materials and growing in the civil industry. Incorporating basalt discrete fibers into the concrete mix can enhance the energy absorption, ductility, and post cracking behavior of structural members. On the other hand, Basalt FRP (BFRP) bars can be a viable alternative to the traditionally used mild steel rebars as the flexural reinforcement. The main focus of this research paper is to adopt the strut and tie modeling (STM) according to the ACI 318 to evaluate the shear responses of the tested beams. The capability of the STM method is assessed in validating the experimental results for the ultimate shear strength of Basalt Fiber Reinforced Concrete (BFRC) short beams reinforced with BFRP bars. A total of eight 2 meters long beams with a rectangular cross-section of 150 x 260 mm tested in four points loading were included in this study. The considered beams had longitudinal reinforcement only without web reinforcement for shear. The web reinforcement is removed to investigate the net effect of basalt microfibers on the shear response of shear deficient short beams. The study outcomes demonstrated that adding basalt microfibers increased the load-carrying capacity of beams by 42 % compared to the reference beams. This enhancement is attributed to the crack bridging mechanism of basalt fibers and hence by arresting the cracks prevented them from further propagation. However, the prediction by the constructed STM was conservative because the method does not account for discrete fiber contribution in shear capacity.

Research on square concrete filled GFRP tube columns strengthened with CFRP sheet

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This paper presented a test with 108 squares pultruded concrete filled GFRP tube (CFGT) columns which were used to investigate the behavior of the columns strengthened with CFRP sheet. Categories of failure modes were grouped according to the failure characteristics of these columns under

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

9 Joints

Damage monitoring of adhesive-bonded composite T-joint by the embedded smart composite fasteners

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This paper develops a multi-functional smart composite fastener (SCF) that can monitoring the shear forces by using piezoelectric sensors and increase the strength of adhesive-bonded structures. A method to design and manufacture the SCF is presented in this paper. To enable the experimental study, 6 SCFs were embedded in an adhesive-bonded composite T-joint. Shear tests were carried out on the T-joints under healthy condition and two different damaged conditions. Finite element models of the T-joint were built to understand the relationship between the structure damage and the piezoelectric sensor signals. Experimental and finite element results demonstrate that the damage of T-joint under shear loading could be monitored by the SCFs well.

Keywords: Shear force monitoring, Damage detection, T-joint, PZT sensor, Composite structure

THE CHEMICAL AND MICROSTRUCTURAL ANALYSIS OF THE ADHESIVE PROPERTIES OF EPOXY RESIN COATING MODIFIED WITH WASTE QUARTZ POWDER

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Recently, industrial floor coatings are made of epoxy resin. Despite the high importance of the epoxy resin coatings for civil engineering, the research to date mainly concerns the epoxy resins, not the epoxy resin coatings. The main disadvantage of the epoxy resins is its harmfulness to the environment, especially to aquatic organisms. Long-term work on the production and application of these resins can cause severe allergies to workers. Compounds contained in epoxy resins can persist in the environment for a very long time. It should also be mentioned that these epoxy resins are very expensive. Therefore, there is a need to carry out research on the properties of these coatings, especially research on the epoxy resin coatings modified with waste powders. It is possible to find a solution to reduce the total mass of epoxy resins used to make the coatings. An ideal solution could be to replace part of the epoxy resin mass with a waste material, e.g. waste quartz powder. Waste quartz powders come from the extraction and processing of mineral resources. Fine quartz powders, are extremely hazardous in this form because they are often float in the air, get into the soil and water. Waste quartz powders have the potential to cause pneumoconiosis, respiratory failure, idiopathic pulmonary fibrosis and even cancer in humans and affect the nervous system in animals. These powders will not be harmful when incorporated in a solid material. With the above in mind, the goals of these studies were: to reduce the amount of epoxy resin in the coatings, to reduce the amount of waste quartz powders stored on landfills, to reduce the hazardous effects of quartz powders by using them in hardened epoxy resin coatings. The main goal of the research was to find an amount of waste quartz powder that would improve or at least not deteriorate the adhesive properties of the epoxy resin coating. The pull-off strength of the epoxy resin coating is particularly important for the durability of the coating. Its minimum value is 1.5 MPa. In order to obtain adequate pull-off strength of the epoxy resin coatings, the substrate should receive a mechanical treatment with thorough vacuuming of the surface. Therefore, the specific goal of these research is to analysis the

impact of the morphology of the concrete surface on this pull-off strength. Another specific research goal is analysis of the microstructure and chemical composition within the interphase zone between epoxy resin modifies with waste material and the substrate. The tests were carried out on a 5 cm thick substrate made of C30/37 concrete. The substrate was divided into two areas with different methods of substrates surface treatment. Ground surface - the surface was mechanically grinded, then vacuumed and bonding agent was applied. Patched surface - the surface was patched after concreting, the surface was only vacuumed and bonding agent was applied. On both types of the surfaces, five squares with dimensions of 0.20 m x 0.18 m were separated and one square for reference sample. Before applying a bonding agent, the morphology of the concrete surface was be examined using a 3D laser scanner, on the surface with dimension of 50 mm x 50 mm (under each measuring point where pull-off tests will be carried out) located 3 on each measuring square. These tests are aimed to evaluate the surface morphology of the concrete substrate and determination of volume parameters of roughness using the MountainsMap program. An epoxy resin coating was then applied with a gradually increasing content of the selected waste quartz powder. The reference squares were covered with the epoxy resin coating without waste quartz powder. The measurements of the pull-off strength of the epoxy resin coatings were performed after the coating hardened using the pull-off method according to ASTM D4541. The chemical composition of the material was analyzed in the interface between epoxy resin modified with waste quartz powder and the substrate using a scanning electron microscope and X-ray micro CT. Then, the microstructure of the samples were evaluated using a micro-computed tomography. Analyzing the obtained data in ImageJ and Mathematica, graphs of fractional share of pores along the sample's height of the subsurface zone were obtained.

Analysis of the stress singularity in composite adhesive joints

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Adhesives offer significant advantages when joining composites, since they do not create discontinuities in the material, unlike bolting or riveting. In composites, these discontinuities can lead to tears, burrs and delamination, in addition to stress concentrations. The analysis of the stress singularity in composite adhesive joints can provide a better understanding of joint behaviour and it is mesh independent. Unlike common fracture mechanics approaches, the Intensity of the Singularity Stress Field (ISSF) of the adhesive/adherend interface corner does not require an initial crack, but it is a concept similar to the Stress Intensity Factor (SIF). The aim of this work is to study the stress singularity of composite adhesive joints with eight different overlap lengths, by determining the exponents of the singularity and its intensity or magnitude. A method for joint strength prediction using the ISSF is also proposed.

10 Thermal problems on Composite Structures

Influence of manufacturing technique on buckling and post-buckling behaviour of thin-walled, composite channel-section columns – experimental and numerical studies

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In this study, static compression of thin-walled, composite columns with channel cross-section is presented. Under inspection are taken experimental and numerical analyses of specimens with dimensions 240 mm × 80 mm × 38 mm (height × web's width × flange's width) and thickness equal to 1.2 mm made of GFRP prepreg tape and symmetric layup [45/-45/45/-45]s cured in the autoclave. Two curing cycles were applied to manufacture the specimens – the fast one and the slow one. Moreover, in this study, the influence of the manufacturing technique on buckling behaviour was checked. In each of processes, two types of columns were formed – channel section and square cross-section. Square cross-section profiles were later cut along the flanges to form channel-section profiles. The object of those two operations was to verify how the speed of the autoclaving process and initial shape of the columns affects the distribution of residual stresses inside the material, and as a consequence, buckling loads and post-buckling stiffness. Manufactured in this manner four series of the specimens were subjected to static compression tests. The study had shown that curing speed is not significantly affecting buckling and post-buckling behaviour of the columns when manufacturing technique does – channels manufactured as cut into half square-section profiles tend to buckle at higher critical loads and have higher post-buckling stiffness. Also, after cutting the square profiles, higher distortion in form columns' twist occurs. To explain this behaviour, a numerical model of static compression preceded by the cooling of the composite in the autoclaving process simulation has been prepared. Experimental results have been compared with the numerical ones – in terms of critical loads, post-buckling behaviour and post-manufacturing distortions.

Keywords: buckling, stability, composites, GFRP, residual stresses, thin-walled structures

A Novel Semi-analytical Approach for Thermal Properties of Fuzzy Fiber Reinforced Composites

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In order to comprehensively understand the thermal conductive behaviors by adding carbon nanotubes (CNTs) into traditional carbon fiber reinforced composites (CFRCs), a novel multiscale semi-analytical model is presented in this work to study the effective thermal conductivities and localized responses of fuzzy fiber reinforced composites (FFRCs). Firstly, an interlayer model is established at the first level including aligned CNTs and embedded polymer matrix. At the second level of the hierarchical structure, the three-phase model is established to simulate representative unit cells of two distinct geometries for fuzzy-fiber reinforced composites (FFRCs). The Locally exact homogenization theory (LEHT) is further developed to predict the effective thermal conductivities and localized fields at each level. After guaranteeing the convergence of the proposed approach, the predicted results of fuzzy-fiber reinforced nanocomposites are verified against the available simulations in the literature and finite element method (FEM). The results demonstrate that the longitudinal thermal conductivity is least affected by the CNT coating, while the transverse thermal conductivity is signif-

icantly enhanced for the carbon fiber reinforced composites. The thermal conductive performance of FFRCs is then demonstrated by varying the CNTs' geometric and thermal parameters. More importantly, from a top-down procedure, the localized heat-flux/temperature distributions are recovered using the semi-analytical multiscale model, to predict the possible crack initiations starting within the microstructures.

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