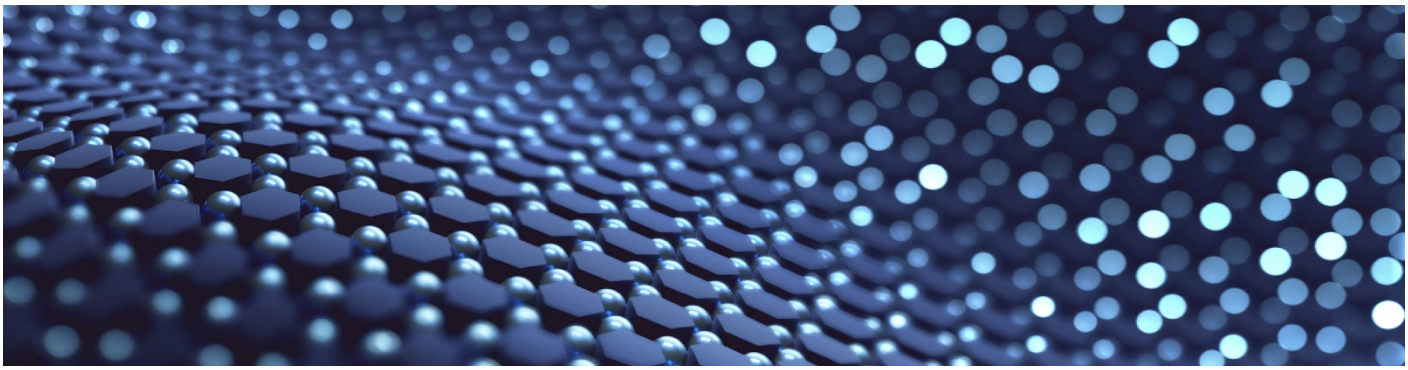
4th International Conference on Mechanics of Composites

9-12 July 2018

Universidad Carlos III de Madrid, Spain



Chairs: A. J. M. Ferreira (Univ. Porto, Portugal), Carlos Santiuste (Univ. Carlos III, Spain)

BOOK OF ABSTRACTS

Book of Abstracts

14470 | NUMERICAL MODELLING OF SOFT ARMOUR PANELS UNDER HIGH-VELOCITY IMPACTS (Composite Structures)

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Nowadays, the role of personal protection is crucial in order to minimize the morbidity and mortality from ballistic injuries. The aim of these research is to investigate the behavior of UHMWPE fibre under high-velocity impact. There are two different UHMWPE packages: ‘soft’ ballistics packages (SB) and rigid ‘hard’ ballistics packages (SB). UHMWPE UD has not been sufficiently analyzed since new SB layers have been manufactured. This work, compares the impact behavior of different UHMWPE composites using spherical projectiles. Firstly, the parameter affecting the ballistic capacity are determined in order to define an optimal configuration to fulfill the requirements of manufactured. Then, the experimental test are conducted on different single SB sheets under spherical projectiles. Finally, the FEM model is validated with experimental test on multilayer specimens of the different UD materials considered. A FEM model is developed to predict the response of UHMWPE sheets under ballistic impact and calibrated with the previous experimental test. The FEM model includes Hashin failure criteria to predict the different failure mechanisms of the composites. An excellent agreement between numerical predictions and experimental results was found. The authors acknowledge the Regional Government of Madrid under the project IND2017/IND-7762.

14514 | Fracture Toughness Evaluation of DCB specimen with New 1-thread Stitching in thickness direction. (Reinforcing method for composite materials)

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Laminated composite material has been widely used not only the aircraft structure but also the primary structure of other machinery such as automobile, ship, robot and etc. Laminated composite materials have high specific strength and stiffness, but the material properties of laminated composites in the thickness direction are much weaker than those of in-plane directions. Many researchers have developed the 3-D reinforcing method for laminated composite materials. Recently, we proposed new 1-thread stitching method combined with advantage of conventional stitching and Z-pinning. The proposed new 1-thread stitching process is a method to insert discontinuous fiber into laminated composite materials in through-thickness direction by perforated needle with air pressure. The New 1-thread stitching method can minimize in-plane damage of composite materials and improve z-directional properties through vertically aligned fibers and randomly arranged fibers on the composite surface.
In this paper, new 1-thread stitching equipment was made and the mode-I fracture toughness of composite specimens reinforced with new stitching method were evaluated by DCB(Double Cantilever Beam) test.

14517 | Static strength of RTM composite joint by new stitching method (Reinforcing method for composite materials)

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Resin transfer molding (RTM) is a mass production process that can replace the autoclave process, and composite lap joints are widely used in composite structures. When a tensile load is applied to a single lap joint, not only shear stress but also tensile peel stress are produced due to the eccentric load effect. Reinforcing the composite joint in the thickness direction can reduce the shear stress generated in the joint as well as the peel stress, which can contribute greatly to the strength increase of the composite joint. Several reinforcing methods have been developed to improve through-thickness directional material properties, and stitching method is generally used. However, the conventional stitching method has a disadvantage in that it is not only complex in equipment but also can not use highly elastic brittle fibers such as carbon fiber. Recently, we proposed new 1-thread stitching method to minimize bending of carbon fibers and prevent their fracture.
In this paper, a composite single-lap joint specimens using a new 1-thread stitching method were fabricated by a RTM process and their strengths were evaluated. The strengths of composite joint specimens fabricated with different stitching intervals and patterns were compared with those of specimens without stitching process.

14519 | A study on the in-plane tensile strength of composite stitched by the carbon fiber (Reinforcing method for composite materials)

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Carbon fiber reinforced composites are increasingly used in aircraft main structures due to their high specific strength and specific stiffness. But, composite laminates have low strength in the through thickness direction.
As a solution to this problem, new techniques for reinforcing the thickness strength are continuously being developed. Stitching and z-pinning method are two typical methods to strengthen the through thickness direction strength. However, When the techniques are applied to prepreg, the reinforcement fiber in the prepreg is damaged, and the properties in the in-plane direction greatly degrades. In this study, we investigated the difference between in-plane physical properties of carbon fiber-embedded composite and laminated Z-pinned composite laminates using a stitching method.

14520 | Structural Analysis of Composite Laminate Using Novel Stitching Process (Reinforcing method for composite materials)

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Based on previous studies, using the novel stitching process with only one thread, to compare the performance between the no-stitched and stitched laminate through the energy release rate with a modified Mode I analysis, it was concluded the needed to perform more analysis under standard test methods. In order to improve the results between the experiments and FEM analysis, standard test method for Mode I and Mode II were performed using different stitching patterns, and compare the through thickness strength with other reinforced methods. The stitched laminate properties obtained from the experiments are the main goal of this study, to design a numerical model which is necessary to predict the adequate behavior of the laminate using the proposed stitching process.

14386 | 3-3 PIEZOELECTRIC METAMATERALS WITH NEGATIVE AND ZERO POISSON'S RATIOS (Auxetic materials and structures)

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Multifunctional structures are attractive for the development of energy conversion devices, structural health-monitoring systems, actuators, and sensors. Electroactive cellular materials such as piezoelectric cellular materials (PCMs) play a key role in advanced multifunctional composites industry by virtue of their unique elastic, dielectric and electromechanical coupling characteristics. The architecture-property relationship of cellular materials (PCMs) can be exploited to optimize piezoelectric cellular materials for specific applications. However there is a need to fully understand the role of the geometric cellular features on the dependence of the effective electromechanical properties.

Here, we propose three classes of novel 3-3 piezoelectric metamaterials based on honeycomb like cellular networks. These included conventional hexagonal honeycomb structure, a re-entrant feature which is known to generate auxetic behavior and a semi-re-entrant which is constructed using alternate conventional and auxetic layers. The conventional honeycomb, re-entrant and semi re-entrant show variety of deformation behavior and can produce positive, negative and even zero Poisson's ratio in certain configurations. Passive response of such cellular materials have been extensively studied. Here, three dimensional finite element (FE) models of 3-3 PCMs were developed to study their electromechanical properties. We investigate the effect of orientation of ligament for these three class of cellular materials on the effective electromechanical properties and their suitability in specific engineering applications such as hydrophones. Moreover, we investigated the role of anisotropic properties of cellular material constituents, the sensitivity to the poling direction and its orientation with respect to the porosity of the cellular materials on the electromechanical properties of PCMs. FE results were compared with the analytical solutions available in the literature. Numerical results showed that the excellent piezoelectric properties can be obtained and PCMs exhibit unique combination of properties (low impedance and more sensitivity) couple with auxetic type deformation.

13597 | Fundamental Frequency of Laminated Composite Thick Spherical Shells (Beam, Plate and Shell Theories and Computational Models for Laminated Structures)

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Spherical shells are used mainly for storage of gas, petrol, liquid, chemicals, and grains. Shell applications are bodies of transportation structures such as motor vehicles, ships, and aircraft. In other words spherical shells are largely used in several engineering fields.
In this paper we are going to use the third-order shear deformation thick shell theory to investigate an analytical solution of frequency characteristics for the free vibration of laminated composite thick spherical shells. The equations of motion are obtained using Hamilton's principle. The finite element technique using the well-known packages MATLAB and ANSYS to confirm the derived equations, in this way we obtain our analytical results. Also we considered the fundamental natural frequencies and the mode shapes for simply supported cross ply laminated composites (0,90), (0,90,0), (0,90,90,0) spherical shells, then we compared the results with the classical theory and the first order shear deformation theory, in this way we combine the higher accuracy and the lower calculation efforts.

Keywords: Spherical Shell, Natural Frequency, Free Vibration, Hamilton's principle, Laminate Composite, Equations of motion.

13863 | Structural Mechanics of Anti-Sandwiches: Theory, Numerics, Applications (Beam, Plate and Shell Theories and Computational Models for Laminated Structures)

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In structural mechanics, a classical Sandwich is a composite with thin, shear-rigid skin layers and a relatively thick, shear-soft core layer. Contrary, Anti-Sandwiches exhibit thick, shear-rigid skin layers and a thin, shear-soft core layer. Photovoltaic modules and laminated glasses are prominent applications. Classical approaches to structural analysis fail at such extraordinary low stiffnesses and extreme thinness of the core layer [1]. Therefore in [2], a so called eXtended LayerWise Theory (XLWT) was developed. Therein, every layer is considered separately while layer-coupling is realized by constraints at the interfaces. Here, we limit our considerations to geometrical and physical linearity. Materials considered obey none pronounced orientation dependence [3]. Our composite is in virgin state, i.e. damage or delamination remain unconsidered.
Since closed-form solutions of the governing equations are laborious and strongly restrictive in context of available boundary conditions, a computational solution approach is introduced using the Finite Element Method [3]. In order to determine the required spatially approximated equation of motion, the principle of virtual work is exploited. The discretization is realized via quadrilateral elements with quadratic shape functions and nine degrees of freedom per node.
In present study, this approach is used to determine deformations at static loading as well as natural vibrations. Thereby we employ characteristic geometric dimensions and material properties [5, 6]. We restrict ourselves to a transversally symmetric composites. The strategy developed proves itself to be particularly efficient.

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14331 | Nonlinear Analysis of a Laminated Composite Plate Under Thermal Environment (Beam, Plate and Shell Theories and Computational Models for Laminated Structures)

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In this study, nonlinear static analysis of a cantilever square laminated composite plate is investigated under thermal environment. In the nonlinear model of the laminated plate, total Lagrangian finite element model is used in conjunction with the three-dimensional continuum approximations in order to obtain more realistic results in contrast with plate theories. The considered non-linear problem is solved considering full geometric non-linearity by using incremental displacement-based finite element method in conjunction with Newton-Raphson iteration method. The material properties of laminated composite plate are considered as orthotropic and temperature-depended. In the finite element model, eight-node three-dimensional finite elements are used. In the solution of the finite element formulations and obtaining of the numerical results and graphs, MATLAB program is used. Convergence study is performed. The effects of the fibber orientation angles and the stacking sequence of laminates on the nonlinear thermal displacements are investigated for different values of non-uniform temperature rising in the numerical results. Also, the difference between the temperature dependent physical properties and the temperature independent physical properties is discussed on the nonlinear displacements of the composite laminated plate.

14342 | Failure of pre-damaged channel section column under uniform compression – numerical and experimental investigations (Beam, Plate and Shell Theories and Computational Models for Laminated Structures)

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Nowadays more and more composite materials are used in different branches of industry. The newest materials appear first in aerospace and aircraft industry and then in sport, automotive industry and finally in or civil engineering and many others. For more than one decade the fibre reinforced or fibre metal laminate as well as functionally graded plate and shells have been very well known and applied in different structures. Authors of this paper have been focused on GFRP laminate and thin-walled profile manufactured in autoclaving technique. In spite of quite long time of usage of mentioned above material and lots of paper dealing with buckling, postbuckling and failure of various type (shapes and materials) of thin-walled structures, there are still lack of paper showing the influence of impact pre-damage (e.g. barely visible impact damage – BVID) on buckling, postbuckling and failure of profiles made of FRP laminates. The similar to propose in this paper investigation have been performed by Chen et. al. and published in J. Constr. Steel Res. 137: 325-341 (2017), who take into consideration steel thin-walled tubes with rectangular cross-section. They checked the influence of lateral impact on the axial bearing capacity, considering different impact energy, loading position and width-thickness ratios.
Taking above into account it has been decided to investigate the influence of impact damage includuding barely visible impact damage on postbuckling behaviour and failure load of channel section beam made of unidirectional GFRP laminates with different layer arrangement. The channel section column with the following overall dimension have been consider: length L = 250 mm; width of flange a = 40 mm, width of web b = 81 mm, wall thickness appx. t = 0.88 mm. Column under investigation have been made of eight-layer laminate, where each ply is made of unidirectional high modulus glass fibre reinforcement epoxy resin and manufactured in thinpreg technology. The profiles have been manufactured in autoclaving technique with four following layups: [0/90/0/90]s, [0/-45/45/90]s, [90/-45/45/0]s, [45/-45/45/-45]s.
The experimental investigation and numerical simulation of impacted channel section columns under uniform compression have been performed. The experimental tests have been performed in two steps. First, the channel section column has been pre-damaged in different places with different energy of impact. The mid-width of flange or mid-width of web in different position in longitudinal direction have been chosen. In the second step the impacted and non-impacted column have been subjected to uniform compression till failure. Based on obtained results the influence of impact position, impact energy (area and type of damage) and layer arrangement on buckling load, postbuckling behaviour and failure load of impacted and non-impacted column have been analysed. The numerical simulations have been performed employing commercial software based on finite element method. The results of experimental tests allowed to validate the developed numerical model. The proposed numerical model including progressive damage analysis with employed on of the following failure criterion: Hashin, Puck or LaRC allows to analyse the behaviour of considered structures in full range of load till failure. In numerical simulation, the different simplified damaged models have been introduced.

14356 | CRITICAL VELOCITY EVALUATION OF ROTATING LAMINATED COMPOSITE DOUBLY-CURVED SHELLS (Beam, Plate and Shell Theories and Computational Models for Laminated Structures)

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This research aims to investigate the dynamic behavior of rotating shells. This topic is extremely innovative and deserves to be studied in depth, especially as far as doubly-curved geometries are concerned. In fact, the few papers that deal with this structural problem are limited to singly-curved shells of revolution, such as cylinders and cones. In contrary, the proposed formulation can easily describe the dynamic behavior of shell structures characterized by variable radii of curvature. In addition, a completely general rotating mechanism can be studied, since the angular velocities can be indifferently applied along each principal direction of the three-dimensional space. A combination of more velocity components can be applied as well. A massive set of parametric investigations is performed to evaluate the critical velocities of different rotating structures. This parameter, in fact, is important in shell design, in order to avoid instability phenomena. From the mechanical point of view, several advanced constituents are analyzed, such as laminated and granular composites. The theoretical framework is based on Higher-order Shear Deformation Theories (HSDTs). The solution of the dynamic problem in hand is solved numerically by means of the Generalized Differential Quadrature (GDQ) method, due to its accuracy, stability, and reliability features. The proposed approach is validated through the comparison with the results available in the literature for simpler geometries.

14360 | Buckling and post-buckling analysis of cracked composite plates via a single-domain Ritz approach (Beam, Plate and Shell Theories and Computational Models for Laminated Structures)

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Thin and moderately thick composite multi-layered plates are widely employed in many engineering applications, especially in naval and aerospace structures. These structural components can experience in service the presence of cracks, generated for example by corrosion, fatigue or accidental external causes. Cracks can affect the load carrying capability, buckling and post-buckling behaviour of plates; therefore, their effects need to be investigated and taken into account for fail safe or damage tolerant design. Additionally, attention should be devoted to the interaction of cracks with buckling and post-buckling behaviour, as the energy release rate in post-buckling regimes can be adversely affected and unexpected critical safety issues could manifest.

Different approaches have been proposed to model cracked plates and, among others, the Ritz method has been successfully used showing adequate accuracy and computational efficiency. A possible strategy to obtain Ritz solution for the cracked plate problem is based on the decomposition of the domain under consideration into several sub-domains over which standard admissible functions are introduced; continuities of displacements and slopes along interconnecting edges between contiguous sub-domains are then restored by enforcing suitable interface conditions. This strategy provides accurate results also for complex structures, like stiffened panels, but it does not possess the convergence features of the original Ritz method and does not account for the crack tip singular behaviour. To overcome such drawbacks, the original single-domain Ritz formulation has to be applied with special trial functions, which account for the presence of the crack by describing the discontinuity of the solution across the crack and the tip singularity.

In the present work, a single-domain Ritz formulation for nonlinear analysis of general quadrilateral multi-layered composite plates with straight cracks is presented, based on the first order shear deformation theory and von Karman assumptions for plate geometrical nonlinearity. The employed trial functions consist of the product of Legendre orthogonal polynomials supplemented with special functions able to describe the discontinuity across the crack and the singularity at the crack tip; boundary functions are used to fulfil the homogeneous essential boundary conditions. The problem governing equations are inferred via the stationarity of an energy function penalized to account for non-homogeneous essential boundary conditions and for the no-interpenetration condition along the crack faces. For post-buckling analysis, the resulting nonlinear system is solved via Newton-Raphson algorithms. Convergence studies and results are presented for buckling and post-buckling of plates with a through-the-thickness crack, highlighting differences in the crack behaviour between pre- and post-buckling regimes, which can noticeably affect the plate residual strength. The performed analyses show the efficiency and potential of the method, which provides accurate results in conjunction with reduced number of degrees of freedom and simplified data preparation, with respect to other techniques

14361 | Free vibration of symmetric angle-ply layered circular cylindrical shells filled with quiescent fluid under first order shear deformation theory (Beam, Plate and Shell Theories and Computational Models for Laminated Structures)

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Vibrational behaviour of symmetric angle-ply layered circular cylindrical shell filled with quiescent fluid is presented. Wave equation is expressed for irrational inviscid fluid. The equations of motion of cylindrical shell in terms of stress and moment resultants and derived using first order shear deformation theory. By substituting strain-displacement relations and stress-strain relations into the equations of motion one can obtain the equations which are coupled in the displacements and rotational functions. These displacement and rotational functions are assumed in separable form to get a system of ordinary differential equations in one variable. Bickley-type spline of order three is applied to approximate the displacement and rotational functions, together with the equations of boundary conditions, such that a generalized eigenvalue problem is obtained. Then, the eigenvalue problem is solved for eigenfrequency parameter and associate eigenvectors of spline coefficients. The eigenvectors are spline coefficients in which the mode shapes are constructed. Bickley-type spline is used since it gives more accuracy and also uses of lower order approximation in solving boundary value problem. Parametric studies on thickness-to-radius ratio, length-to-radius ratio, ply angles, material properties and number of layers under different boundary conditions are investigated. Three and five layered shells under clamped-clamped and simply-supported boundary conditions are studied. Two types of materials, which are Kevler-49 Epoxy (KGE) and AS4/3501-6 Graphite/Epoxy (AGE) are used. The convergence study is made in order to fix the number of iterations. A comparison between empty and fluid-filled shell is carried out and result shows that the frequency of fluid-filled shell is lower than the frequency of the empty shell. This is due to the fluid that provides added mass to the shell. From the investigations, by increasing the length of the shell, the frequency decreases. In contrast, the frequency increases as the shell thickness increases. Meanwhile, the frequency of C-C boundary conditions is higher than the frequency of S-S boundary conditions. Geometric parameters, material properties, angle orientation, number of layers and boundary conditions have significant effects on the frequency of the shell.

Keywords

Free vibration, cylindrical shell, first order shear deformation, inviscid fluid, splines

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Acknowledgement

This work was funded partially by Kuwait Foundation for the Advancement of Sciences (KFAS) under Project code: PR17-16SM-05 and thanks to the President of Kuwait College of Science and Technology for his continues support to complete this work.

14366 | Green's functions for unsymmetric composite laminates with holes, cracks, or inclusions (Beam, Plate and Shell Theories and Computational Models for Laminated Structures)

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Due to the highly designable characteristics of composite laminates, in practical applications it always has the possibility to design a plate with unsymmetric composite laminates. For such kind of laminates, the material properties is not symmetric with respect to the mid-plane, and the stretching and bending deformation may be coupled together. Unlike the analysis of pure stretching or pure bending in metallic plates or symmetric laminates, the coupled effect would turn the problem from two- to three-dimensional, which complicates the analysis. In order to deal with the coupled stretching-bending deformation, the Stroh-like formalism was developed around fifteen years ago (Hwu, 2003). Since the Stroh-like formalism has been purposely arranged into the form of Stroh formalism for two-dimensional linear anisotropic elasticity (Ting, 1996; Hwu, 2010), almost all the mathematical techniques developed for two-dimensional problems can be transferred to the coupled stretching-bending problems. By taking this advantage, several Green's functions for unsymmetric composite laminates have been obtained. Although the Green's function for the infinite composite laminates has been successfully applied to the boundary element method, its associated solutions for holes, cracks or inclusions cannot be applied correctly due to the discontinuity of some physical quantities, which has not been noticed in the literature.
In the mathematical expression of Green's function, most of discontinuity comes from the complex logarithmic function. Although the discontinuity of complex logarithm, which is a multi-valued function, can be eliminated in all the physical quantities by the identities derived in Stroh-like formalism, the requirement is that the branch cuts for all transformed arguments need to be jumped simultaneously. This may not be difficult for the Green's function of infinite laminates since it is expressed in terms of the standard complex variable. However, the Green's function for holes, cracks and inclusions are expressed in terms of the transformed complex variables, which are variables mapping the ellipse into a unit circle. With these transformed complex variables, a single straight branch cut in the z-domain may turn into four curved branch cuts in the mapped domain and the requirement of simultaneous jump across the branch should be treated carefully (Hwu, et al., 2017). On the other hand, the discontinuity may also occur due to the neglect of constant terms in the Green's function for inclusion problems. Although the constant term represents rigid body motion and can be neglected for stress analysis, its associated values in matrix and inclusion may be different, and hence the difference between the constant terms of matrix and inclusion should be added in the Green's function to satisfy the continuity requirement of perfect bonding.
By suitable adjustment of branch cuts and adding of the constant terms, the Green's functions for unsymmetric composite laminates with inclusions, published in the literature, have been corrected and verified in this study. By considering an extremely soft inclusion this function can also be used for the cases with holes. Moreover, a straight crack can be approximated by limiting the minor axis of the ellipse to zero.

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14372 | Transient Wave Propagation and Early Short Time Transient Response Analysis of Piezoelectric Shells (Beam, Plate and Shell Theories and Computational Models for Laminated Structures)

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The method of reverberation ray matrix (MRRM) have been successfully utilized to study the transient wave problem in beams, planar trusses and infinite layered solids. In this work, the MRRM is exploited to investigate the early short time transient responses of piezoelectric cylindrical shells with finite size under impact load. Based on the Donnell shell theory, the reverberation matrix in the dual local coordinates for a single layer in the cylindrical shell is derived. With the help of the Laplace transformation, the transient responses under imposed impact load can be predicted. Through the numerical simulations, the early short time transient responses can be further elucidated thoroughly.

14378 | Numerical modelling of the pseudo-ductility effect in +-45° angle-ply laminates under biaxial loading (Beam, Plate and Shell Theories and Computational Models for Laminated Structures)

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The pseudo-ductility phenomenon has been extensively studied analytically and experimentally in different configurations of angle-ply laminates due to its ability to suppress damage, when fibre rotation appears permitted by the matrix plasticity [1-4]. The studies carried out to date have focused on characterizing the pseudo-ductile response of the laminates by means of tensile tests [1-3] and recently in bending testing [4]. However, no reference has been found describing pseudo-ductility in angle-ply laminates under biaxial loading conditions.
This work aims to reproduce numerically the complex pseudo-ductile response of +-45° angle-ply laminates in uniaxial and cruciform specimens utilised for obtaining biaxial states. The numerical model is based on Hashin's damage theory and its results are contrasted with the experimental data obtained from tensile uniaxial tests and, once the uniaxial data are accurately modelled, with the results of tensile-tensile biaxial testing. In the biaxial case the complexity of the non-linear material problem is increased by the geometry of the cruciform specimen, in which the pseudo-ductile effects are strong in the uniaxially loaded arms while the damage accumulation and the fibre rotation should be minimised in the central region biaxially loaded. The strong influence of the arms non-linear response on the central region observations are pointed out.

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14391 | A single layer shear deformation plate theory with superposed shape functions for laminated composite structures (Beam, Plate and Shell Theories and Computational Models for Laminated Structures)

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A single layer shear deformation plate theory is proposed in order to analyze statics and dynamics of laminated composite structures. The previously suggested shape functions of five-degrees of freedom plate theories are superposed in order to increase the accuracy of the theory. Governing equations and boundary conditions of laminated composite plates and beams have been obtained using minimum total energy principle. Simply supported plate and beam bending, vibration and buckling problems have been solved and obtained results have been compared with the previous results.

14472 | Coupling effects in transient analysis of FGM plates bending in non-classical thermoelasticity (Beam, Plate and Shell Theories and Computational Models for Laminated Structures)

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Given that the thermal stresses mainly at the interface between two different materials are the significant factors of failure of the laminated composite structures, there is an enhanced request to replace laminated composite structures by structures made of micro-composite materials exhibiting the properties of continuously nonhomogeneous continua. In addition to elimination of interface discontinuities, the functional gradation (FG) of material coefficients brings new phenomena in bending of FGM plates as compared with homogeneous ones. There are known coupling effects between the in-plane deformations and bending modes even in plates subjected to stationary mechanical loadings. Another coupling can arise between thermal and mechanical fields in thermoelasticity. In the classical thermoelasticty, the heat conduction is described by the parabolic PDE when the temperature change propagates with infinite velocity. Much more realistic is the non-classical treatment with wave propagation of heat. In this paper, the unified formulation for bending of FGM plates under transient thermal loads is developed within the generalized thermoelasticity with taking into account the assumptions of the Lord-Shulman theory as well as the Green-Lindsay theory of thermoelasticty and the assumptions of the Kirchhoff-Love theory as well as the 1st 1nd 3rd order shear deformation plate bending theories. By proper selection of two key factors and material coefficients, we can switch between various theories. Moreover, we can study various coupling effects by changing the parameters of functional gradations of particular material coefficients in numerical simulations. For numerical solution, the strong formulation is developed with meshless approximation of spatial variations of field variables. The time integration is carried out by the Wilson time stepping technique.

Acknowledgement
The financial support of the Slovak Research and Development Agency under the contract No. APVV-14-0440 is greatly acknowledged.

14500 | Dynamic response of laminated windshield under head impact: Experiments and analytical modelling (Beam, Plate and Shell Theories and Computational Models for Laminated Structures)

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Head impact on windshield is often the dominating cause of death for vulnerable road users (VRU). Due to its physical resilience and energy dissipation capacity, laminated glass has increasingly been used as automotive windshield to protect VRU from fatal head injuries. In order to improve structural crashworthiness, or to assess the consequence of hazard for VRU, it is pertinent to achieve a thorough understanding of the deformation and damage of laminated glass under impact loadings. Although numerical approaches can provide full scale analysis for the aforementioned problem, they are too expensive and not available for quick assessment. The objective of this study is to develop an approximate analytical model capable of providing, in a computationally efficient way, accurate and robust predictions of the transient dynamic response of a rectangular laminated glass subject to low-velocity headform impact. The mathematical framework of the analytical model is based on first-order shear deformation plate theory and accounts for the effects of non-linear large deformations as well as propagation of flexural waves. A stress-based damage criterion is introduced to predict glass fracture process. A set of experiments will be carried out for polyvinyl butyral (PVB) laminated glass subjected to the headform impact with a range of impact velocities. Analytical predictions of transverse central displacement, velocity and acceleration are found in excellent agreement with those from the experiments. The analytical model developed is a valuable tool for preliminary safety assessment, where simpler-to-apply analytical approach is preferable over FE analysis which is often too time-consuming.

14538 | Decomposition method applied to the solution of laminated thick plates in bending (Beam, Plate and Shell Theories and Computational Models for Laminated Structures)

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The aim of this paper is to obtain the mechanical response of laminated thick plates by using the Adomian’s decomposition method. The Mindlin's plate theory along with Rayleigh-Ritz method and equivalent single layer concept are used. The operator’s decomposition is based on a constitutive decomposition that superposes isotropic and anisotropic terms of the constitutive tensor at the lamina’s level. This implies the superposition of an isotropic and anisotropic stiffness at the plate’s level. By the recursive scheme of the decomposition method, a thick plate’s isotropic solution, which is homogeneous, is enhanced by anisotropic inhomogeneous contributions. Numeric results are shown and compared with those found in the literature.

14539 | Finite element analysis of filament winding cylindric tubes considering zig-zag regions (Beam, Plate and Shell Theories and Computational Models for Laminated Structures)

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The paper's objective is the comparison of the mechanical behaviour of cylindrical tubes constructed by filament winding considering and neglecting the zig-zag region inside the diamonds generated by the manufacture process by Finite Element Analysis. Generally, the behaviour of such components is evaluated by considering the regions as triangles, which results in the zig-zag being represented by a straight line. Moreover, some asymmetries regarding the process are neglected by such approach. A numeric procedure that simulates the manufacture process is developed, resulting in an exact ply configuration of the cylinder. The comparison study is carried out to analyse the influence of the zig-zag and the pattern on the stress profile of these components under internal pressure.

14641 | An exact two nodes beam element based on unified and integrated method (Beam, Plate and Shell Theories and Computational Models for Laminated Structures)

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This paper presents two nodes and three degrees of freedom per node based on unified and integrated (UI) method to construct locking-free finite elements for bending of shear deformable beam element. In this UI method, the total displacement is split into bending displacement and shear displacement which causes the rotations, curvatures and shear deformations can be defined as first, second and third derivatives of bending displacement, respectively. The new UI beam element, is formulated based on a pure displacement formulation and utilizes bending displacement, shear displacement and rotational as three degrees of freedom at the nodes. A continuity of C2 Hermite shape functions is developed from polynomial expansion at continuity of 5th degree for bending displacement. The formulation of element takes account of the effect of shear transversal forces in order to behave appropriately in the analysis of thin and thick beams. The resulting UI beam element is absolutely free from shear locking and preserves the high accuracy of the standard locking-free finite elements and classical Bernoulli Euler element. Finally, several numerical tests are presented to confirm the performance of the proposed formulations.

14697 | Large displacement analysis of laminated composite frames considering shear deformation effects (Beam, Plate and Shell Theories and Computational Models for Laminated Structures)

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Geometrically non-linear beam formulation, based on a seven-degree-of-freedom shear deformable beam model is presented aimed for the large displacement analysis of the composite beam type structures. Arbitrary laminate stacking sequence configurations are considered. Shear deformable beam theory accounts for the flexural-torsional response of a composite beam, also considering the coupling between bending and non-uniform torsion appearing when considering non-symmetric cross-sections. The incremental equilibrium equations for a straight thin-walled beam element are formed by the virtual work principle on the basis of updated Lagrangian formulation and the nonlinear displacement field. Displacement field accounts for restrained warping and the second-order displacement terms due to large rotations. Numerical results are obtained for the several benchmark examples in order to verify the presented model.

14750 | ON SOME REFINED BEAM AND PLATE THEORIES (Beam, Plate and Shell Theories and Computational Models for Laminated Structures)

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Equivalent Single Layer (ESL) theories are often used to study the response of composite and sandwich structures. One large family of ESL plate theories is based on a five-variable theory. In the assumed displacement field, three variables describe the motion of points on the reference surface like in the classical plate theory. One additional variable is added to each of the in-plane displacements to account for transverse shear deformations. These variables are multiplied by a function of the transverse coordinate z that describes the transverse shear stress distribution. Many such functions have been proposed in the literature and the goal of this study is to assess the merits of twenty five such functions f(z).

Deriving the equations of motion in a general way leads to the definition of additional stiffness and inertia parameters. Some of the parameters depend on the choice of the shear shape function f(z) while others are not. It is often said that the introduction of a new function f(z), often without any rationale, gives rise to a new theory. These theories will be assessed in several ways: (1) Plots of the shear stress distribution show only minute differences between the twenty five functions considered here; (2) Similarly, the rigidity and inertia parameters show only small variations when switching from one shear shape function to another; (3) The ability of these theories to model the dynamic behavior of homogeneous, functionally graded, or multilayer structures will be assessed considering harmonic wave propagation. Dispersion curves will show small differences as different functions f(z) are selected.
The kinematic assumption above assumes transverse inextensibility. Another set of beam or plate theories accounting for both transverse normal and shear deformations is obtained by adding another variable to the transverse displacement approximation multiplied by a function g(z) describing the transverse normal stress distribution through the thickness.

A family of four-variable theories has emerged in which the transverse displacement is split into a bending component and a shear component. The displacement field appears to be a restriction from the five-variable theory. Its performance will be examined here, possibly for the first time.

This presentation will cover three families of single layer plate theories with many variants that have been developed recently ant it will show that most of them are very similar and produce nearly identical results.

14783 | Nonlinear Stability and Failure Analysis of Composite Shell Panels with Embedded Delamination (Beam, Plate and Shell Theories and Computational Models for Laminated Structures)

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The nonlinear static stability and first-ply failure analyses of laminated composite cylindrical shell panel subjected to no-uniform mechanical loadings is studied using layerwise finite element formulation based on B-spline basis function. In the present formulation, linear Lagrange interpolation function is used to represent the out-of-plane displacement variation and in-plane displacement variation is interpolated by B-spline functions over the plate element. At the location of delamination the displacement fields are discontinuous and are modeled by Heaviside step functions. The stability of delaminated composite panel is solved in two steps as the prebuckling stress distribution within the panel is not known a priori. In the first step, the panel prebuckling stress distributions are evaluated and subsequently, stability of the panel is studied. The cylindrical shell panel is modeled using Donnel shell theory. Employing von Kármán type of nonlinearity, postbuckling equilibrium path of the delaminated composite panels are traced. In the delaminated region, virtual, springs are added to prevent interpenetration of lower and upper sublaminates. The non-uniform in-plane load at which the first-ply failure of the lamina occurs has been detected by Tsai-Wu quadratic interaction criterion. The influence of radius-to-thickness ratio, boundary condition, size of embedded delamination and non-uniform mechanical in-plane load on the static instability of composite cylindrical panel is reported.

14915 | Asymptotic equivalence of DKMT and MITC3 composite plate elements **(Beam, Plate and Shell Theories and Computational Models for Laminated Structures)**

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This paper presents in a unified and comparative manner, the formulation of two triangular plate bending composite elements, i.e. MITC3 and DKMT which are published in 1993 and 2004. Both elements have 3 nodes and 3 dof per node (one displacement and two rotations), take into account of transverse shear effects, are valid for thin to thick plates, and give good results in classical benchmark and patch tests. The numerical results using DKMT and MITC3 elements show the optimal and uniform convergence for thin and thick plates with an advantage for DKMT due to semi quadratic interpolation for the rotation variables. As a main contribution of this article, the paper presents asymptotic equivalence of DKMT and the MITC3 elements with respect to element slenderness ratio.

14916 | Asymptotic equivalence of DKMQ and MITC4 composite plate elements **(Beam, Plate and Shell Theories and Computational Models for Laminated Structures)**

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This paper presents the formulation of MITC4 and DKMQ composite quadrilateral elements in a unified and comparative manner. Both elements take into account of transverse shear effects, valid for thin to thick plates, have 4 nodes and 3 dof per node (one displacement and two rotations) and give good results in classical benchmark. The paper includes convergence behavior analysis for composite plate with an advantage for DKMQ due to semi quadratic interpolation for the rotation variables. As a main contribution of this article, the paper presents asymptotic equivalence of DKMQ and MITC4 elements with respect to element slenderness ratio.

13830 | Mechanical behaviour of rammed earth column: A comparison between unreinforced, steel and bamboo reinforced columns **(Composite structures in civil engineering)**

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This paper presents an experimental study on the behaviour of cement stabilized rammed earth (CSRE) column reinforced with steel under axial loading and its comparison with unreinforced and bamboo reinforced columns.Effects of structural parameters such astie / stirrup spacing on the failure pattern,lateral and axial deformation of columns are studied. Test results show that the load-capacity of columns increases with increase in lateral / tie reinforcement ratio.Maximum axial and lateral deformations at peak / ultimate load occur in columns with least tie spacing.The behaviour of CSRE columns reinforced with close tie spacing is characterized by gradual spalling of cover at the failure zone leading to a loss of load-capacity before the lateral confinement becomes effective. Steel reinforced columns perform better than other column types in terms of load-capacity; hence it may be used as structural member adjacent to walls for low-rise rammed earth houses. Lastly, the reinforcement technique proposed in the current study can be adopted in the field for enhancement of greater strength and performance of columns.

13832 | Trilinear softening functions for the simulation of the fracture behaviour of fibre reinforced cementitious materials based on a cohesive crack approach **(Composite structures in civil engineering)**

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When randomly distributed fibres are added to the concrete mix, the material is commonly known as fibre reinforced concrete (FRC). Given the outstanding performance of the combination of steel and concrete, the most employed fibres in concrete structural elements have been steel fibres. However, the advances in new materials have allowed the production of structural macro-polyolefin fibres showing comparable residual tensile strengths [1]. Such a type of fibres has have become an attractive alternative due to their chemical stability, good performance in concrete fresh state and lower dosages in weight. The composite material has been termed polyolefin fibre reinforced concrete (PFRC).
Another cementitious matrix that has been reinforced with fibres is cement mortar, which has shown advantages in reduced-thickness elements. In order to limit shrinkage cracking, glass fibres randomly distributed have been employed forming glass fibre reinforced cement (GRC). The presence of glass fibres can not only increase the flexural and tensile strengths but also its ductility and toughness.
In order to boost the structural use of this materials, research has focussed on modelling their behaviour when subjected to tensile and flexural stresses. In such a sense, one remarkable model is known as the smeared crack approach. The latter has been commonly assumed when there is no localisation of the cracks and when the opening of the cracks is reduced. In contrast, the when crack is localised the so-called discrete approach has provided

accurate results, being one of the most used models for plain concrete the cohesive crack approach. Such approach reproduces the fracture tests of plain concrete if the type of softening function is appropriately defined [2]. Several authors have studied the suitability of using diverse softening functions, which may vary from an exponential function to a linear or bilinear one. Such function has been profusely used due both to its simplicity and the accurate results that it provides.
In this study, the softening functions have been modified to reproduce the fracture behaviour of various types of FRC commonly produced nowadays. The study sought to assess the suitability of trilinear softening functions in order to obtain accurate numerical simulations of fracture tests with a wide variety of PFRC and GRC mixes, as shown in more detail in references [3, 4]. Moreover, the changes introduced by the variation of the fibre dosage in PFRC will be discussed in detail. In the case of GRC, the softening functions of three types of GRC are also analysed. Finally, comparing all the functions obtained, some additional conclusions were obtained.

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13840 | Flexural toughness of high performance concrete reinforced with chopped basalt fibre (Composite structures in civil engineering)

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Chopped basalt fibre is a nonmetallic fibre made from basalt rock melted at high temperature. It provides high resistance to alkaline environment, good fire resistance and extremely good strength properties. It can be very beneficial to reinforce high performance concrete and reduce its high brittleness. Basalt fibre reinforced high performance concrete (BFRHPC) is considered as an excellent new material for use in construction industry especially in highway, long span bridges, high-rise residential and industrial buildings. In this article the main aim of the investigation is made of applicability of the ASTM C 1609 procedure for testing toughness of basalt fibre reinforced high performance concrete. All mixtures exhibited hardening behaviour of deflection and the volume content of chopped basalt fibre varied in the high performance concrete matrix. Nine mixtures were made with a fibre content of 0, 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, and 2%, respectively. The water/binder ratio and the amount of superplasticizer were constant. Beam specimens of size 100 × 100 × 500 mm were tested at three point static flexural loading at 28 days to obtain the flexural strength of FRHPC. The flexural toughness parameters were obtained using procedure according to ASTM C 1609. The addition of chopped basalt fibres reduced the workability and compressive strength of BFRHPC. However, fibres have improved the splitting tensile and flexural tensile strength of BFRHPC. Moreover, the results show the positive enhancement effect of chopped basalt fibres on flexural toughness increase.

13843 | Composite Tunnel Structures Monitoring with Highly Accurate Model Generation (Composite structures in civil engineering)

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Inspection of construction work for composite tunnel structures is becoming feasible with the development of measurement technologies. Terrestrial laser scanning (TLS) is one of the popular technologies applied in engineering measuring fields, which can obtain large population of dense point cloud within a relatively short time. This presentation applies TLS to scan a tunnel structure after construction work, where the over- and under- construction of tunnel is analyzed based on highly accurate B-spline model of the tunnel profiles. The accurate model is compared with the design model for various profiles and deviations of the two models are computed. The over- and under- construction of tunnel is then inspected for arbitrary profile at different positions of the central curve.

14471 | Verification of bond behavior and model with modification reinforcing condition of transverse strand in Textile Reinforced Concrete (Composite structures in civil engineering)

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Textile reinforced concrete, which replaces reinforcing steel with textiles in concrete matrix, can prevent the durability degradation due to corrosion of steel of traditional reinforced concrete structures. Therefore, the interest of TRC is increasing as an alternative to the existing steel reinforced structure. In addition, the strand intersection in textile and weft strands acts as an anchor to resist the longitudinal load. And these anchors make it easy to attach the textile to the fine concrete matrix, thereby achieving complete adhesion between matrix and textile, which is the basic condition of the composite member. However, because of the characteristics of the textile reinforcing both the longitudinal and transverse directions at the same time, the behavior of the textile under load in the matrix is very complicated and there are many difficulties in analyzing the TRC behavior. In order to solve this problem, various models of bond and behavior of textile in the matrix are suggested by many research, however further studies to verify the model are required for actual verification. Therefore, in this study, pull out test with AR (Alkali Resistance)-glass textile was performed. One longitudinal strand which is warp direction was set and the number and length of transverse strand which is weft direction were changed to examine the effect of the textile intersection and weft reinforcement as anchors. Also, the result of pull out test was compared with the proposed behavior model in other research. As a result, the load capacity was improved by the presence of the transverse strand, and the change of the behavior was analyzed according to the transverse reinforced condition.

14483 | Finite element modelling of axially loaded large-dimension circular concrete-filled steel tube stub columns (Composite structures in civil engineering)

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Researches on the behaviors of the large-diameter CFT columns are quite limited for the lack of large capacity of testing machines. Although finite element technique is an alternative and efficient method for simulating the behavior of columns, the existing models generally perform well only for simulating small-diameter columns, not for the large-diameter columns. In this paper, the commercial software ABAQUS is used to simulate the behavior of the CFT columns, finite element models that are suitable for large-diameter CFT columns are developed. The performance of the proposed model was verified by comparison with the experimental tests of CFT columns with diameters ranging from 100 mm to 820.8 mm and those predicted by an existing model which has been widely used in the analysis of CFT columns. It has been found that the results predicted by the proposed model agree well with the experimental data and are more accurate while comparing with the existing model.

14493 | Development of Sustainable FRP-UHPFRC Composite Girder Systems for Accelerated Bridge Construction (Composite structures in civil engineering)

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This study aimed at studying the composite behavior of precast Ultra-High Performance Fiber-Reinforced Concrete (UHPFRC) slabs and Fiber-Reinforced Polymer (FRP) I-shaped girders. Monotonic testing of nine large-scale girders under four-point flexural loading was performed. The testing program included testing of two series of the FRP-UHPFRC composite girders, named H-series and G-series. Specimens of the H-series girders were made out of optimally fabricated hybrid carbon/glass FRP (HFRP) I-girders and were topped with segmental precast UHPFRC slabs. Twelve precast fiber reinforced and ultra-high performance concrete segments were employed to form the topping slabs of the H-series specimens. The G-series girders were composed of segmental UHPFRC slabs and glass-fiber-reinforced polymer (GFRP) I-girders. The G-series girders featured externally bonded GFRP plates connected to the soffit of the GFRP I-girders. The validity of both high-strength mortar as well as epoxy was evaluated for connecting the precast UHPFRC segments. The test results showed that girders with high-strength mortar connections exhibited a slightly better ductile behavior than the ones with the epoxy-connections. The test results of the G-series girders demonstrated a pseudo-ductile behavior. The study revealed many advantages for the use of UHPFRC slabs and FRP I-shaped girders and encouraged their field applications in demonstration projects. Two short demonstration pedestrian bridges made of girders, utilizing the H-series and G-series promising concepts, were constructed on areas where there is an exposure to harsh environmental conditions. In addition to demonstrating a sustainable solution in severe environmental conditions, the construction of the two bridges exhibited a fast construction solution that is vital for wide-spread applications of the accelerated bridge construction concept.

14569 | Fiber-Reinforced Polymers based stirrup for reinforcing concrete structures (Composite structures in civil engineering)

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Compact steel reinforced concrete elements are used in the construction sector, for example in the field of traffic area construction and hydraulic engineering. For transmission of loads by traffic loads, earth and water pressures such concrete components have a corrosion-susceptible steel reinforcement. To ensure corrosion protection in the concrete permanently, however, a minimum concrete coverage of several centimeters of the reinforcing bar is required and to very thick wall thicknesses with a significant increase in weight. The transportation to the operation site as well as the montage and especially the installation are affected by the high weight of the construction components. Furthermore, steel reinforced elements influence electric and magnetic fields, requiring special and expensive precautions.
Especially in the field of concrete reinforcement fiber reinforced polymers (FRP) components rate as an important alternative to steel reinforce concrete elements. The current state-of-the-art shows that primarily FRP reinforcements in linear form are produced made by pultrusion in combination with thermosetting polymer systems and fibers. These thermosetting matrix systems cannot be deformed after their hardening without damage as a result of the strong connectivity of the polymer chains. Thus, a subsequent flexure of the reinforcement, e.g. with energy supply, is excluded. The FRP stirrup reinforcements differentiate clearly from their characteristics in comparison to straight bars due to their design. The curved FRP stirrup reinforcements show a different fiber architecture and surface profiling resulting in significantly reduced compartment characteristics. Furthermore, the individual radii of curvature (dbr) of the FRP reinforcements is process related restricted to a minimum of seven times the value of a bar diameter (dbr ≥7 ds) significantly narrowing the application range and complicating the acceptance on the market.
The aim of the project was the development of GRP stirrup reinforcements with reduced radii of curvature with high load capacity. An improvement in load carrying capacity could be proven in extensive investigations based on international testing methods and verified by practical tests.
In the course of this investigation it was clearly shown that the new developed stirrup reinforcements made of BFRP with lower radii of curvature have in comparison to the to date FRP stirrups according to the state-of-the-art much more potential. This primarily concerns the reduction of radius of curvature (from 7 ds to 4 ds) with simultaneous significant increase of stirrup tensile strength (from 675 MPa to 725 MPa), the increase of bonding characteristics (from 22 MPa to 30 MPa). Thus, the future application of BFRP stirrup reinforcements opens a variety of new application fields for lighter and more efficient construction.

14579 | Topology optimization design of plate structures in elastic medium by using classic plate theory (Composite structures in civil engineering)

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This study contributes to evaluate topology optimization design of plate structures in elastic medium by using classic plate theory. Topology optimal method is produced as an alternative to provide reasonable material assignments based on stress distributions. The mathematical formulation of topology optimization problem solving minimum structural compliance is an alternating active-phase algorithm with the Gauss-Seidel version as an optimization

model of optimality criteria. Stiffness and adjoint sensitivity formulations linked to potential strain energy are derived in terms of density variables and Winkler-Pasternak parameters considering elastic foundation to apply to the current topology optimization. Several numerical examples verify efficiency and diversity of the present topology optimization method of elastic thin plates depending on Winkler-Pasternak parameters with the same amount of volume fraction and total structural volume.

14610 | Nonlinear vibrations of periodic Timoshenko beams - tolerance averaging approach. (Composite structures in civil engineering)

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The subject of this contribution are nonlinear vibrations of periodic Timoshenko beams. The aim of the contribution is to formulate and apply a mathematical model describing behaviour of beams which properties varying along longitudinal direction. Hence, in a modelling of such beams various methods are used, which can be threated as macroscopically homogeneous. To take into account the effect of the microstructure on behaviour of these beams the tolerance modelling method is applied. The nonlinear equations with functional, highly oscillating, periodic and often non-continuous coefficients, are replaced by equations having constant coefficients.
The method enables derivation of model equations involving terms dependent of the microstructure size. In the modelling procedure the are applied some concepts as: a slowly-varying function, a tolerance-periodic function, an averaging operator. The tolerance method is based on two fundamental assumptions. The first is the micro-macro decomposition, where basic unknowns are decomposed on macro deflections and fluctuation parts, assumed in the form of a product of the known fluctuation shape functions and unknown fluctuation amplitudes. The new unknows – macro deflections and fluctuation amplitudes are slowly-varying functions. The second assumption is the tolerance averaging approximation, in which some terms are treated as negligible small. Using these concepts and assumptions, after some manipulations the averaged model equations can be derived. In this note a comparison between various material and geometric properties is shown.
The application of the proposed model in free and forced vibration analysis will be shown and the influence oh the varying material properties on vibrations frequencies will be disused. As an example there is considered a periodic beam. In order to solve the problem the Galerkin method was used in the analysis. The solutions of the tolerance model equations, as well as the loads, were assumed in the form of truncated trigonometric series. Free and forced vibrations are then converted into a system of the first order ordinary differential equations and solved by forward numerical integration. The calculations are performed using procedure based on Runge-Kutta-Fehlberg method.

This contribution is supported by the National Science Centre of Poland under grant No. 2014/15/B/ST8/03155.

14620 | Membrane, Pseudo-Membranem Semi-Membrane Shell Theory of Hybrid Anisotropic Materials (Composite structures in civil engineering)

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While shell theories are normally divided and accepted by membrane and bending, this paper concentrate to further details of the membrane theory, which are particular behavior only due to the anisotropic nature of material properties of multilayer shell wall thicknesses. The isotropic versions of the theory developed nearly a century by Vlasov and it has been efficiently utilized to design and analysis. Due to the isotropic property of the material, the pseudo membrane or semi-membrane phenomenon were not appeared in the classical shell theory. However, the modern aerospace vehicle structures and outer space rocket fuel storage tanks designed efficiently by the modern however not much for composite materials, while most of recent structural materials are of the combination of anisotropic materials. To develop and describe the theories, we first introduced asymptotic integration method, then the characteristic length scales during the course of non-dimensionalyzing the variables. The pseudo-membrane phenomena was happened solely by the imbalance of the wall thickness due to the anisotrophic combination. The semi-membrane theory was developed the longest possible length scale of the shell geometry. In the case of semi-membrane shell theory, the edge effects due to the prescribed boundary condition penetrate differently depending on material orientations and properties of each layer but all within the limit of length scale (ah)1/2 where Donnell-Vlasov bending theory is valid. Demonstrated that beyond the limit of edge effective zone, membrane or pseudo-membrane state dominates, it is traditionally named semi-membrane state. New simplified governing equations of semi-membrane theory of cylindrical shell are formulated and the physical interpretation of the theory is described.

Keywords

Hybrid Anisotropic Materials; Pseudo-membrane and Semi-membrane shell theory; Laminated cylindrical shells; ;Characteristic Length Scales

14643 | Structural behavior of precast/prestressed concrete composite members with separately cast bottom flange (Composite structures in civil engineering)

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Precast/prestressed concrete (PC/PSC) structures can lead to enhance the material efficiency and structural performance by introducing prestress to the concrete, and, in particular, they allows to control deflection by upward camber. As the span length gets longer and the amount of prestressing strands becomes larger, excessive camber may occur. If the camber is not properly controlled, it can degrade structural performance and constructability. In this

study, therefore, a segmental PSC composite member, whose prestressed bottom flange was fabricated separately from the web and top flange of the section, was developed to easily control the camber. The structural performances of the segmental PSC composite members with T and I shaped sections were evaluated by flexural and shear tests as well as direct shear tests with variable surface conditions. The experimental results showed that the segmental PSC composite members can provide flexural and shear performance equivalent to those of monolithically cast specimen.

14650 | Effect of delamination geometry on buckling strength of a composite stiffened panel (Composite structures in civil engineering)

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In many industries, such as aerospace, mechanical, marine and civil engineering, composite stiffened panels are used as one of the main structural component, the stiffeners are used to improve the strength/weight ratios and reduce costs of the structure. Moreover, the biggest advantage of considering composite materials in the panel other than conventional material such as steel usually provides major weight savings. This is partly due to the specific properties and low weight of the individual components, and partly because it is possible to manufacture composites for very particular purposes. It also offers several advantages over conventional materials, such as resistance to chemicals and thermal and electrical insulation properties. However, any structural system may reach its limit and buckle under extreme circumstances by a progressive failure of local components such us delamination which is one of the most common failure modes for composite structures.
In this work, the buckling behavior of a laminated carbon epoxy prepreg stiffened panel under compression loading was studied by finite element analysis where we've generated a localized geometric imperfection in between the plies, also we have considered varied sizes and positions for this defect to assess its influence on the buckling strength. For this reason, Riks analysis in Abaqus CAE was achieved. This type of analysis is used usually to study the instability and the post-buckling behaviour by predicting unstable, geometrically nonlinear collapse of a structure, it executes a step by step buckling analysis to provide complete information about a structure's collapse. It was found that the presence of a defect and also its size and position have a major influence on the critical buckling load of the stiffened panel.

14785 | Fatigue behaviour of braided BFRP rebars for civil engineering applications (Composite structures in civil engineering)

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ABSTRACT
Basalt Fibre Reinforced Polymer composites were recently introduced as a possible replacement to steel in civil engineering applications, due to both their excellent corrosion resistance and their high strength-to-weight ratio. These materials also have the potential to provide long-term durability, while minimising maintenance costs. However, limited data are available in the literature regarding their fatigue performance, and most of them are focused either on their static behaviour or on aerospace applications rather than structural ones. The aim of this research is to experimentally evaluate the mechanical properties, and more specifically, the tensile fatigue performance of braided Basalt Fiber Reinforced Polymer (BFRP) reinforcement. Three different rebar designs with a 5, 8 and 10 mm diameter are manufactured, using braiding and a vacuum assisted resin infusion technique. All types are developed using basalt fibres and epoxy resin as reinforcement and matrix respectively. Tensile fatigue tests on BFRP samples are performed using Instron 500 Universal Testing Machine in accordance to B7_ACI 440.3R-04 standard. All samples are tested under a fixed load ratio of 0.1 and a loading frequency of 4 Hz. The minimum and maximum load vary accordingly, with the latter ranging from 20 to 60% of the quasi-static tensile strength. Throughout the whole duration of the fatigue cycling test, the applied load, displacement and specimen elongation are electronically recorded every 10th cycle. The number of repeated loading cycles to failure and stress applied is then used to generate S-N curves for each sample. A reference specimen of each type is also used for the evaluation of the static tensile performance following the B2_ACI 440.3R-04 standard. Initial results confirmed a sufficient fatigue performance of braided BFRP rebars with a high stiffness retention and good damping properties. Moreover, composites with a lower fibre volume fraction and a higher void content seem to exhibit an increased fatigue stress sensitivity with a reduction of the fatigue limit at elevated fatigue cycles.

KEYWORDS
Braided BFRP rebars, fatigue behaviour, characterisation of FRP composites.

ACKNOWLEDGMENTS
This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 642453.

14893 | 3D FEM analysis of a buckling delamination of a piezoelectric sandwich rectangular plate with interface edge cracks (Composite structures in civil engineering)

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In this work a buckling delamination problem of a sandwich PZT/Metal/PZT rectangular thick plate within the scope of the 3D linearized theory of stability loss in the framework of the piecewise homogeneous body model is studied. It is supposed that between the face and core layers of the sandwich rectangular plate there is an interface edge crack and around these edge cracks an ideal contact conditions are satisfied. Also assume that this plate is subjected to bi-axial uniformly-distributed compressive forces acting on two edge surfaces and on the upper and lower surface and, also cracks surfaces of the plate neither mechanical nor electrical load are act. In addition, all the lateral surfaces of the plate is simply supported mechanically and also grounded for the PZT layers' surface only. In the analyzing procedure, before the plate is loaded (i.e. in the natural state), the free planes of the plate have insignificant initial imperfections. Due to action of the aforementioned compressive forces the evolution of the initial imperfections is investigated and as a result of this investigation the values of the critical buckling forces for the considered sandwich plate are found from the criteria, according to which, the initial imperfections grow indefinitely with the compressive forces [1-5]. Mathematical modeling of the considered problem is formulated within the scope of the three dimensional exact geometrically nonlinear equations of electro-elasticity in the framework of the piecewise homogeneous body model. The corresponding boundary-value problems are solved numerically by employing the 3D finite element method (3D-FEM). Acknowledgement: This work was supported by Research Fund of the Yildiz Technical University. Project Number: 2016-07-03-DOP03. Keywords: Buckling, piezoelectric plate, 3D FEM

14897 | The effect of rigid polyurethane foam filler on the mechanical properties of epoxy-based composites (Composite structures in civil engineering)

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According to statistical data [1], around 311 million tons of polymer materials were manufactured in 2014 (including 59 million tons in Europe). These are impressive values. The level of recycling plastic waste is much less attractive, unfortunately especially in Poland. According to Polish Central Statistical Office data [2], in 2014, 56% of plastic waste went to landfills in Poland. For comparison, in Germany, the Netherlands and Switzerland, only about 1% of waste was subject to storage [1]. These data indicate that the issue of recycling is still very important and it is necessary to research and develop technologies that allow us to manage the plastics waste around us. According to the data provided by PlasticsEurope from 2016 (Plastics - The Facts 2016) [3], the polyurethanes account for about 7.5% of total plastics consumption, which gives about 3.5 million tonnes per year. Polyurethanes are a material disadvantageous to recycling. While soft foams find many applications, the waste of rigid foams (used mostly as insulation materials in construction technology and refrigeration devices) is a much bigger problem. The interest of entrepreneurs in the management of their waste is growing significantly.
Waste from rigid polyurethane foams can be used in the production of façade decorative elements. These are the products of the insulation materials industry, which are used for finishing the façade of buildings. Mentioned elements are usually made of expanded polystyrene (EPS) of appropriate density and are coated with a composite layer based on epoxy resins and mineral additives. The composite layer increases their attractiveness and mechanical resistance, including, for example, damage by birds. One of serious problems related to this is the question of the relationship between the thickness of the composite layer, the strength of the layer and the mass of the element. Which is directly related to the need for adequate durability of adhesive masses, with the help of which these elements are attached to the facade of buildings.
As part of the cooperation conducted by the authors of this study, the idea of using rigid PUR foam waste as a filler of a resin composite serving as the outer layer of polystyrene façade decorative elements was created. Thanks to the addition of appropriate fractions of shredded PUR foams, a significant reduction in the mass of the elements was achieved, which allowed to increase the thickness of the composite layer and at the same time opened other possibilities to increase the attractiveness of this type of elements. Composites containing 10, 30, 50 and 100% by volume of ground PUR recyclate were prepared and tested. The mechanical properties were evaluated. The properties of the obtained samples were compared using a filler with grains smaller than 2 mm and grains with a diameter in the range of 2-3 mm. Both higher hardness and impact strength were noted for a polyurethane filler with a smaller grain diameter, with the same volume content. In the case of densities, samples containing a larger size of polyurethane filler grains are characterized by lower than those with smaller grains. This is due to the absorption of resin into the empty spaces of the filler's cell structure.

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14393 | Composite Blade Propeller : A Design Assessment Approach (Composites in Innovative Applications)

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Composite materials blade for propeller offers lot of technological benefits for ships propulsion: lightness, resistance, less cavitation, less acoustic emission, etc. However, no standards exist to assess and validate the design resistance of this type of propeller and few full scale applications have been already tested. The objectives of this paper are to present requirements and methodology developed to assess a composite materials propeller design and its validation by sea trials. The proposed design evaluation is based on tests and analytical and numerical computations. A test pyramid has been determined, from the raw material characterization to full scale test, in order to validate the design and also the blade fabrication. In addition, two calculation approaches have been investigated to estimate stresses in laminate layers. The first one is based on Cantilever Beam Method, an analytical solution, and the second one used numerical tools such as Procal and Finite Element Model (FEM). Finally, safety factors have been defined taking in consideration type of stresses, production process, computation and material type.

14426 | Mechanical Model of Superconducting multi-filamentary composite wire (Composites in Innovative Applications)

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The superconducting composite wire, serving as the basic unit cell of the cable-in-conduit-conductors (CICCs), is a typical multi-filament composite which is always subjected to a cyclic loading under the operating condition. Due to the sensitive of strain on superconducting performance. Investigation of the mechanical behaviors of superconducting composite strand is not only related its mechanical reliability, but also related to the superconducting performance of superconducting wires.
In this study, we established a three-dimensional finite element model of superconducting wire under the axial load and analyzed its mechanical behavior. The model accounts for the initial thermal residual stress and damage of superconducting filaments of strands. The Numerical results show that the proposed model can predict the tension stress-strain curve of strands accurately, including the "platform" in high strain interval. In addition, the characteristics of hysteresis loops the stress-strain curves of superconducting wire under axial cyclic load are also obtained from our model, which is also well in agreement with experimental data. After that, we built a three-dimensional multi-filamentary finite element model and a three-dimensional homogenizing finite element model of superconducting triplet respectively. Some comparisons between them are given. The obtained results show the predicted value of the multi-filamentary finite element model of superconducting triplet is more close to the experimental data than that of homogenizing finite element model. Meanwhile it also can give more accurately stress/strain distribution characteristics of strands. However, in the modeling of higher-level cables, homogenize method is more available due to its less computing and saving resource.

14441 | Mechanical Modeling of the nonlinear response of novel tensegrity metamaterials (Composites in Innovative Applications)

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The category of “extremal materials” has been introduced to define materials that simultaneously show very soft and very stiff deformation modes [1], and are called unimode, bimode, trimode, quadramode and pentamode materials, depending on the number of soft modes. Extremal materials that are receiving increasing interest are the so-called pentamode lattices, which consist of diamond-like lattices featuring five soft modes of deformation. The unit cell forming the this lattice is made of four rods meeting at a point. Previous studies show that pentamode lattices confined between stiffening plates have the ability to carry unidirectional compressive loads with sufficiently high stiffness, while behaving very soft in shear [2]. Because of their unusual mechanical features, these structures have been proposed for transformation acoustics, elasto-mechanical cloak, and seismic isolation (refer, e.g., to [2]-[3] and the references therein).
This study examines the mechanical behavior of a novel class of mechanical metamaterials alternating class θ tensegritry structures [4] and stiffening plates. Analytical formulae for the vertical and bending stiffness properties are developed, and the dependence of such quantities on the main design parameters, which include the lattice constant, the solid volume fraction, the cross-section area of the rods, and the layer thickness, is studied. The potential use of the analyzed metamaterials as novel seismic-isolation devices and impact-protection equipment is highlighted.

Keywords: Metamaterials, tensegrity, soft modes, pentamode.

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14489 | MECHANICAL MODELLING OF THE MICROMEGAS DETECTORS FOR THE ATLAS NEW SMALL WHEEL (Composites in Innovative Applications)

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In order to benefit from the expected high luminosity performance provided by the Phase-I upgraded LHC at CERN, the New Small Wheel (NSW) will be installed in the ATLAS detector during the Long Shutdown 2. The ATLAS NSW will be equipped with a new technology for the detection of muons: the MicroMegas (MM) detectors. The MM detectors consist of different panels made of composite materials and when charged particles traverse the drift space, they ionize the gas and liberate electrons; the avalanche of electron takes place in the amplification region after the mesh and they are detected by R/O strips to reconstruct the trajectory of muons produced after the collision. Very tight mechanical tolerances are given in the design phase and they must be preserved from the panel construction to the final operation in the ATLAS cavern.
In this paper the construction procedure of these very precise particle detectors is described and the mechanical modelling to predict their mechanical behavior is presented. Finally, the experimental tests done to validate the numerical models are discussed.

14505 | Using polymer composites for mechanical power management (Composites in Innovative Applications)

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With the exception of very large-scale energy storage systems, as pumped hydro or compressed air management, high power density systems, as supercapacitors or flywheels, usually show low energy density values. In addition, the capital expenditure and operational costs of these systems are high, especially if they are evaluated per operational cycle. Other problems associated with the aforementioned systems are quick self-discharge and inherent risk due to short circuits or mechanical instabilities.

In this work, we present a low cost, robust mechanical power management system based on the use of elastically deformable elements. We show that the energy and, specially, the power density achievable with such a concept are comparable or even superior than those of other competitor concepts.

While traction or compression are the stress states with bigger associated energy density, their practical application is problematic, so we have developed an energy storage and power management system based on bending. In this work, we present a full carbon fiber, 15kg spiral spring, designed, manufactured and tested at UPM. We will show the results of static, fatigue and dynamic testing of both test coupons and complete systems, as well as the obtained energy and power density results.

Spring design is based on the trade-off between energy density and operational, fatigue life, maximizing power density, by performing an adequate materials selection, which turns out to be high strength carbon fiber, as well as resin type and ply sequence. We have also developed the manufacturing and testing procedure. The concept shows very promising results in terms of cost and performance.

14544 | Development of the Spread Tow Carbon Fabric Composite Bipolar Plate (Composites in Innovative Applications)

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The carbon fiber composite bipolar plates has been developed as an ideal substitute for the brittle graphite bipolar plate of vanadium redox flow battery (VRFB) due to its high mechanical properties. However, the conventional woven carbon fabric composites have undulations by peak-valley structures which reduce the contact area with adjacent components in the VRFB stack causing the interfacial contact resistance increament.
To overcome this matter, the bipolar plate made of spread tow carbon fabric composite is developed. The interfacial contact resistance is measured and compared with that of the conventional carbon fabric and unidirectional composites. Also, mechanical properties are measured with respect to the stacking sequence. Finally, carbon nano-particles are imbedded in the carbon composite to minimize the electrical resistance and improve the mechanical properties.

14563 | Novel LHC Collimator Materials: High-Energy Hadron Beam Impact Tests and Non-Destructive Post-Irradiation Examination (Composites in Innovative Applications)

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CERN Large Hadron Collider (LHC) is the most energetic particle accelerator in the world. The LHC collimation system, which protects the machine components from stray particles, must adopt materials able to withstand extreme conditions (temperature, pressure, strain-rate, radiation). An intense R&D campaign was launched at CERN to develop and explore new materials for collimation purpose. Candidate materials must possess excellent thermal shock resistance, high electrical conductivity, geometrical stability and resistance to radiation damage. From a complete thermo-mechanical characterization two novel composites, Molybdenum-Graphite and Copper-Diamond, were identified as the most promising ones. In order to assess the material behaviour in the extreme operational regime, in 2015, both composites were tested under intense proton beam impact at the CERN HiRadMat facility, together with a standard collimator material, Carbon Fibre-Carbon. In 2017, the activation level decreased enough to start an extensive post-irradiation campaign. Metrology observations, 3D-tomography and ultrasonic technique, were adopted to evaluate the topography of the composite blocks after impact, highlighting the localized spallation induced by the beam. This paper intends to provide an overview of the most traditional thermo-mechanical characterization of the two composites, together with the particular scenario of beam impact tests and non-destructive post-irradiation results.

14625 | Synthesis, characterization and dynamic-mechanical properties of styrene-acrylate/nanoclay interpenetrating polymer network (IPN) for damping applications (Composites in Innovative Applications)

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Interpenetrating polymer networks (IPNs) as a branch of multicomponent polymeric materials have gained great attention in the last decades mostly due to their numerous applications. These include ion exchange resins, toughened plastics, adhesives, hydrogels and specially, vibration and noise damping materials. Although polymers possess good damping capability over their glass transition region, the main advantage of IPNs is their ability to widen the glass transition region. This feature makes them a good candidate for vibration and sound damping applications. For instance, IPNs in the form of waterborne latex have shown potential as damping coatings. This latex IPNs are synthesized through emulsion polymerization and usually have a multilayer core/shell structure. Good damping materials should exhibit a high loss factor (tan δ> 0.3) over a temperature range of at least 60–80 °C so as to be efficient in wide temperature and frequency ranges experienced in real damping applications. It has been shown that certain inorganic fillers could enhance the damping properties of IPNs. However, little has been done concerning the effect of nano sized fillers on damping properties of multilayer core–shell latexes.
In this study, Latex IPNs with multilayer core-shell structure were synthesized via a three-stage semi-continuous emulsion polymerization technique. A mixture of monomers (Styrene, Methyl methacrylate and Buthyl acrylate) with the crosslinker (Ethylene glycol dimethacrylate) were used to synthesize a three-layer styrene/acrylate core-shell waterborne latex. The composition ratio of monomers in the three layers were changed in a way that Tg was decreased from the core to the last shell. In addition, two types of montmorillonite nanoclays, a natural montmorillonite (Na-MMT) and an organically modified montmorillonite (OMMT) were used to see their effect on the damping properties of styrene-acrylate/nanoclay nano composite. The nanoclays (0.5 wt%) were included in the core during the latex synthesis. The size, size distribution, film topology and the dynamic-mechanical behavior of the dried latex film were studied by dynamic laser scattering (DLS), atomic force microscopy (AFM) and dynamic mechanical analysis (DMA) respectively.
Results showed that all the latex particles synthesized in this work were of monomodal distributions confirmed by DLS analysis. Moreover, the spherical morphology of the latex particles was observed via AFM images. The study of the film forming capability of the core, shell 1 and 2 latexes showed that the film formation was mainly controlled by the Tg of the outermost layer of the latex. The maximum loss factor (tan δ max) of the multilayer styrene-acrylate latex was about 1.7 with an effective temperature region of -10.6 - 23.4°C. The addition of OMMT nanoclays to the core, increased the average size of the latex particles from 58.5 to 73.6 nm, whereas the Na-MMT only slightly increased the average particle size (60.7 nm). This result was also confirmed by AFM where larger particles could be observed via incorporation of OMMT in the latex compared to Na-MMT nanoclays. The addition of hydrophilic nanoclay (Na-MMT) decreased both tan δmax and the effective temperature region. However, the OMMT nanoclays could effectively enhance the damping capability of the multilayer latex by a noticeable increase of the tan δmax to 2.5 and also the area under the tan δ curve. This difference in results was ascribed to favorable inclusion of OMMT in the monomer phase due to its hydrophobic nature while the hydrophilic Na-MMT is not possibly incorporated well into the polymer particles during polymerization. Therefore, it seems that the OMMT nanoclays could increase the damping capability via limiting the movement of polymer chains and inducing internal friction between the nanoclay surface and polymer chains.

14770 | Experimental and numerical study of a new structural composite for innovative cars (Composites in Innovative Applications)

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The use of composite materials in automotive industry is increasing due to the high strenght-to-weight ratio interesting to design new structural parts. Lightweight structures are important in terms of vehicle performance, that usually implies fully or hybrid monocoque chassis structures based on materials like carbon fiber reinforced polymer (CFRP) composite, titanium or aluminum alloys. Improving performance without compromising comfort is one of the

most important aims when building a car. In order to achieve this objective, several experimental testing and provisional calculations must be done in order to get desired fuel consumption, a lateral and longitudinal resistance during dynamic behavior related to a crash, torsional and bending stiffness of the chassis and aerodynamic performance, always with a competitive cost in mind. A direct way to get improvements in these fields is to reduce the weight of the car as much as possible without penalizing the stiffness and the strength. A key point for this goal is to develop and design new composite materials and techniques to manufacture it without price increase to product it. In this study, a hybrid monocoque structure is proposed based on new high strength composite skins separated by a PVC core material The optimization of this kind of sandwich structures allows an important reduction in terms of costs and weight, and, at the same time, to improve the structural performance in terms of stiffness. Torsional stiffness of the proposed chassis has been evaluated and compared to a metallic frame structure using a combined numerical and experimental methodology. Experimental tests have been chosen to fulfill the requirements of a prestigious international competition, Formula SAE, ensuring the final result according to safety aspects. These requirements imply three point bending test, perimeter shear test and Harness fixture testing. Finally, manufacturing process of a hybrid monocoque structure has been carry out for a real composite chassis car without a high tooling cost.

13812 | DURABILITY LIFING OF AIRCRAFT COMPOSITE STRUCTURES (Durability of composite materials)

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Currently, the fatigue life and residual strength of damaged aircraft composite structures under operational loads is not fully understood. This leads to structures generally being designed to a no damage growth criterion with many knock down factors included to cover unknown/untested effects. Thus, full optimisation of composite aircraft structures is unlikely to be achieved under the no damage growth criterion. In 2009 the US Federal Aviation Administration (FAA) introduced a slow growth approach to certifying composite, adhesively bonded structures and bonded repairs which could improve the situation and is worthy of further investigation. In this paper the growth of some (limited) damage types available in the literature is reviewed and a framework proposed to address the damage tolerance assessment of composite aircraft structures.

14328 | The work of compressed plate with a central cut-out, made of composite in an asymmetrical arrangement of layers (Durability of composite materials)

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Thin-walled carbon/epoxy composite plate elements with a regular-shaped central cut-out under compressive loading are investigated. The objective of the study is to examine whether these elements can be used as elastic elements and whether it is possible to shape their structural rigidity by changing the cut-out geometry or the laminate's lay-up. The natural, lowest buckling mode of thin-walled plates under compression is flexural mode. This mode exhibits a small postcritical rigidity and is reached at low loads. To achieve a higher structural rigidity, it is necessary to force buckling into a higher mode that is characterized by vertical warping of the plate in the region of the central cut-out (flexural-torsional mode). To force buckling into this higher mode, an unsymmetrical lay-up with flexural-torsional coupling is used. This approach leads to obtaining the natural, lowest mode of buckling (flexural-torsional), one that allows for stable performance of the structure in a postcritical range (there is no transition to flexural mode). The proposed solution is numerically analysed by the finite element method. The scope of the numerical analysis is twofold: (1) to perform a linear analysis in order to determine the critical load and obtain the lowest buckling mode (flexural-torsional); and (2) to perform a nonlinear analysis of compressed structures with geometric imperfections reflecting a specified buckling mode. As a result, postcritical characteristics of the structure are determined, depending on variable height and width of the cut-out. The results demonstrate that it is possible to shape the rigidity of the elastic plate element by changing the cut-out geometry. The analysis is conducted in a safe operating range, i.e., below the critical parameter of the composite material as determined via failure initiation criteria. The numerical results are then verified by experimental tests for selected variants of plate with a central cut-out. The numerical and experimental postcritical equilibrium paths are compared.

The research reported in the paper was conducted under the project UMO-2017/25/N/ST8/01066 financed by the National Science Centre Poland.

14329 | Numerical and experimental failure analysis of thin-walled composite profiles with top-hat cross-section subjected to axial compression (Durability of composite materials)

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The study investigates numerical and experimental research of the load capacity of thin-walled composite columns with top-hat cross-section subjected to axial compression. The discussed columns were made of carbon-epoxy laminate with different symmetrical layers arrangements, relative to the middle plane of laminate in cross configuration [0/90/0/90]s. The experimental research was conducted with the use of the universal testing machine Zwick Z100 in the full load range, until total failure. During the experimental studies post-critical equilibrium paths of construction were determined, defining the dependence of compression force-deflection, enabling the validation of the numerical models. Based on the determined post-critical equilibrium paths, the value of critical load of the structure was calculated using the approximation methods. Simultaneously, the numerical analysis was carried out using the finite element method in Abaqus® software. The analysis of critical state was determined on the basis of linear eigenvalue analysis, enabling determination of the critical load value and corresponding buckling mode. The next stage of the numerical simulation involved solving the problem of nonlinear stability of the structure with initialized geometrical imperfection corresponding the lowest buckling mode. The geometrically non-linear issue was solved by the incremental-iterative Newton-Raphson method. The determination of load capacity of the composite structure in the post-buckling state was performed using the progressive damage criterion, wherein the initiation of damage of the composite material was done based on the Hashin's criterion, while the progression of damage was described with the energy criterion, enabling stiffness degradation of finite elements. High convergence of numerical and experimental results carried out on actual structures was achieved, which confirms the adequacy of developed numerical models of composite structures. Results presented in the paper were conducted under the UMO-2015/19/B/ST8/02800 project, financed by the National Science Centre Poland.

14330 | The analysis of sensitivity to geometric imperfections of compressed thin-walled composite profiles (Durability of composite materials)

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The study investigates the effect of eccentric load on the stability and postcritical states of thin-walled carbon/epoxy composite channel-section columns under compression. Tests are performed on physical models of these structures produced by the autoclave technique. The columns have a symmetrical 8-ply lay-up. The test specimens are subjected to compression on a testing machine provided with a special fixture for introducing eccentric compressive loads. In the tests, loading force, column shortening, deflection and strains of the column walls and web are measured. The experiments involve examination of the operating performance of the structure undergoing buckling and determination of its postcritical equilibrium paths describing the relationship between force and deflection. The obtained characteristics led to determination of the critical load for real structures by suitable approximation methods. Based on the experimental results, numerical models of composite structures are designed and verified by the finite element method. The scope of the numerical analysis includes performing a nonlinear analysis of stability, which allows for determination of the buckling mode depending on the amplitude of compressive load eccentricity and the corresponding critical loads. The second stage of the analysis involves performing a nonlinear analysis of the structures with implemented geometric imperfections reflecting the lowest buckling modes. The nonlinear analysis is performed using the Hashin criterion to determine effort of the composite material. The computations are run until the critical parameter is reached in the Hashin criterion, allowing for description of the failure initiation mechanism in the composite material. Based on the results, postcritical equilibrium paths of the numerical models are determined. The equilibrium paths are then compared with the experimental characteristics of real structures. The numerical results and experimental findings show a satisfactory agreement. The results confirm that the numerical models are adequate for estimating the stability loss and performance of composite structures in the postcritical range, depending on the amplitude of compressive load eccentricity. The research reported in the paper was conducted under the project UMO-2015/19/B/ST8/02800 financed by the National Science Centre Poland.

14398 | Fully Coupled Heat Conduction and Deformation Analyses of Viscoelastic Polymeric Fiber Reinforced Composites (Durability of composite materials)

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This study presents an integrated micromechanical model-finite element framework for analyzing coupled heat conduction and deformations of FRP composites structures. An isotropic rate-dependent constitutive model is used for the matrix, while the fiber is assumed to follow transversely isotropic response. The constitutive model for the heat flux follows the classical Fourier law. A simplified micromechanical model consisting of four sub-cells, i.e., one fiber and three matrix sub-cells is formulated to obtain the effective thermomechanical properties and time-dependent micro-macro field variables due to coupled heat conduction and nonlinear thermo-viscoelastic deformation of a FRP composite. Previously developed time integration algorithm for simultaneously solving the equations that govern heat conduction and thermo-viscoelastic deformations of isotropic homogeneous materials is integrated with the micromechanical model together with the macroscopic energy equation to determine the effective coupled thermo-viscoelastic response of the FRP composites. Macroscopic analyses on FRP composites structure under cyclic loading is studied, incorporating the energy dissipation in the viscoelastic matrix that is converted into heat. This heat generation alters the viscoelastic properties of the matrix, and subsequently influences the micro- and macroscopic response of the composites. The effect of loading direction on the matrix softening and macroscopic hysteretic response of the FRP composites is studied. Pronounced strain increases due to matrix softening could lead to damage initiation and failure of composites.

14418 | Durability study of adhesive joints used in high-speed crafts manufactured in composite materials subjected to impact fatigue (Durability of composite materials)

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Marine high-speed crafts manufactured in composite materials exhibit macroscopic failures in hull sections and bonded joints after long periods of use. This damage could be produced by low frequency impacts between the vessel and the water surface know as Slamming. The low energy impacts between the water surface and the hull are examples of impact- fatigue conditions. In some fast boats including the type of boat studied, the cabin- hull assembly is made with adhesive joints and this adhesive joint can be studied as a simple lap joint due to the geometry of the assembly. This study presents experimental results and finite elements analysis aim to study the mechanical behavior and durability of adhesive joints present in some fiberglass high speed crafts in dynamics and quasi-statics conditions. The results of impact-fatigue test show an improvement of the joint's mechanical properties depending on the resin–adhesive thickness used. On the other hand, a finite elements analysis at quasi-statics conditions shows that the polyester resin used as an adhesive could damage the mechanical properties if the resin is thicker than a certain limit. Additionally, a finite elements analysis at dynamics conditions allows estimating life span of the adhesive joint under impact-fatigue conditions.

14503 | Effect of thermal and strength regeneration treatments on the mechanical performance of basalt fibres (Durability of composite materials)

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An environmentally friendly disposal of composite waste represents one of the most important challenges in the industrial and academic composites community. In an attempt to reduce the environmental impact of synthetic polymers and reinforcements, there has been an increasing interest in the use of natural fibres as reinforcement in polymer matrices. In this regard basalt fibre, a natural fibre of mineral origin, is characterized by excellent sound insulation properties, resistance to heat and a good chemical inertia [1]. In addition, its potential role in replacing glass as reinforcement in polymer matrices with a view to enhancing the environmental sustainability of such composites has been recently confirmed [1]. Recently, also for basalt fibres, a severe loss in strength after thermal treatment has been reported [2], thus preventing their re-use in structural composite materials at the end of a

recycling process. Studies on glass fibres [3,4] have confirmed the possibility to restore the strength of thermally damaged filaments by means of chemical treatments. In the wake of such researches, the present work aims at investigating how chemical treatments can be used to regenerate the strength of thermally degraded basalt fibres. In an attempt to shed light on the mechanisms controlling basalt fibre strength loss, FIB milling has been used to determine the fracture toughness of single basalt fibres. This evaluation, never reported on basalt fibres, is important in order to assess any changes occurring in the flaw-strength relationship caused by thermal exposure. To simulate a composite recycling process, basalt fibres were thermally conditioned in air at 400°C, 500°C and 600°C for 25 minutes. To regenerate the fibre strength, the thermally conditioned fibres were immersed in a NaOH solution (1.5 – 3 M) for 5 and 10 min at 90°C. Tensile properties of virgin, thermally treated and regenerated fibres were determined in accordance with ASTM C1557 and the scatter of the Young's modulus and tensile strength was statistically analyzed using a two-parameter Weibull distribution.
A Fei Helios Nanolab dual beam system was used to mill a micro-sized notch into the fibre surface via ion beam sputtering [5]. Following milling, the fracture stress of the notched fibres was determined using the single filament test to determine whether the mode I fracture toughness changed due to heat treatment. In conclusion, cross-sections of the fractured fibres after tensile tests were investigated by scanning electron microscopy. Results indicated that the chemical treatment is able to generate considerable fibre strength recovery and FIB milling can be successfully used to determine the fracture properties of basalt fibres.
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14513 | Multi-scale analysis of unidirectional flax-epoxy composites hygrothermal ageing (Durability of composite materials)

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In the actual environmental awareness, innovative solutions have been studied to reduce the environmental impact of composites. Vegetal fibers are more and more used as reinforcement instead of synthetic ones, challenging the manufacturing and the durability prediction of these materials.

It has been proved that flax fibers specific mechanical properties can compete with glass fibers' properties [1]. However, it is known that this kind of fibers are hydrophilic and that the water content plays a significant role on their mechanical properties and on the composites too [2]. In most cases, the matrices used to produce bio-based composites are less hydrophilic than fibers. Thus, the environment moisture changes induced differential swelling effect inside the material [3] and could impact the composite durability due to interfacial shear stress. Moreover, almost all studies focused on immersion ageing which could really be damaging for vegetal fibers, with hydrophilic components extraction phenomenon [4]. But this kind of ageing is not necessarily realistic for the material application. The impact of differential swelling effects between material components could furthermore be intensified by humidity cycles. Thus it is important to quantify the influence of repeated exposure of such materials to high/low relative humidity conditions on their properties.

The aim of this study was to evaluate the influence of hygrothermal cycles on a flax based composite's properties. The first step was to produce a high-grade flax-epoxy composite with a controlled and adapted manufacturing process using controlled constituents, and to characterize this material through a multi-scale analysis. A thermo-compression process has been developed and many parameters (such as fibers conditioning, curing temperature, cooling speed…) have been settled to improve mechanical and physicochemical properties. This allowed to adapt manufacturing to flax fibers and epoxy matrix in order to obtain a high-grade bio-based unidirectional composite. Then we chose to realize an ageing on this material and on its different constitutive phases. The evolutions occurring over this ageing have been monitored by multi-scale analysis to better understand the involved mechanisms.

Depending on the material and the sensitivity of the phases, different behaviors have been observed during ageing. Some materials have been widely impacted with properties decrease, but others proved to be more resistant to this type of ageing. These results are promising for the development of this kind of bio-based materials.

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14536 | Electrical Characterization Of Modified And Unmodified Multiwalled Carbon Nanotubes Filled Graphite/Natural Rubber Nanocomposites Under Constant Amplitude Fatigue Loading (Durability of composite materials)

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The extraordinary properties such as high aspect ratio, strength, modulus, excellent electrical and thermal conductivities of multiwall carbon nanotubes have generated scientific and technical interests in the development of nanotube-reinforced elastomer composites. Graphite is a layered material with a high aspect ratio in its exfoliated state; it is also one of the strongest materials per unit weight and has unique functional properties (e.g., excellent electrical and thermal conductivities, and excellent lubricating properties). Also, graphite is cheap compared to carbon nanotubes.
To improve the characteristic of the elastomer, reinforcing it with nanofillers that possess multifunctional attributes are of great importance.
In the present study, functionalized multiwalled carbon nanotubes (FMWCNT) (1, 2 and 3 phr's), unfunctionalized multiwalled carbon nanotubes

(UFMWCNT) (1, 2 and 3 phr's) and graphite (GT), (1 phr) reinforced six different rubber nanocomposites were prepared by using two-roll mixing machine. Rheological, mechanical, electrical sensitivity variation of the fatigue properties of the nanocomposites were extensively studied.
There is not a significant variation in the density of composite by addition of the nano graphite and MWCNT's. Maximum deviation between all nanocomposite is 0.5 %. The general tendency of hardness varies depending on the amount of nanofillers.The interaction between graphite, FMWCNT, and UFMWCNT has been observed to affect increasing hardness. Absorbed energies were affected by the addition of the graphite and both type Multiwalled Carbon Nano Tubes (MWCNT) by affecting molecular friction of rubber chains by nano-fillers. Test results of the tensile strength of the produced hybrid composites via MWCNT fillers amount for both types. The UFMWCNT filling shows better tensile strength than FMWCNT for all cases. It has been observed that the rheometer curves of the UFMWCNT filled mixtures are more widely spaced and scattered. The crosslinking is slowing due to the reduction of fluidity. As it is observed, by increasing the UFMWCNT loading, the ML and MH are increased, ts2 slightly decreased. On the other hand, the improved interfacial interactions due to the NR Rubber as matrix decreased the mobility around the MWCNTs, and therefore the increase in the ML, MH and the decrease ts2 was also observed. Conductive properties of the nanocomposites were also studied. UFMWCNT filled base rubber showed better conductivity than MWCNT filling. On the contrary of the expectation by the amount of FMWCNT or UFMWCNT were increased, the average electrical resistivity ascended from 3.3x106 Ω to 7.48x106 Ω and from 3.98x106 Ω to 4.29x106 Ω, respectively. The reason for this, nonuniform distribution of MWCNT's, originated from the agglomeration of MWCNT's in the GF/NR nanocomposites.

Figure 1. Tensile strenght graph according to the amount of the MWCNT and UFMWCNT

Figure 2. Electrical resistance change at static condition according to the amount of the MWCNT and UFMWCNT

Figure 3. (a) Test equipment for nanocomposites, (b) Electrical conductivity measurement system, (c) Test results displays.

14568 | Piezoresistive response under flexural loading of glass fiber/carbon nanotube/epoxy composites exposed to seawater ageing **(Durability of composite materials)**

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When composite laminates are exposed to the marine (seawater) environments, a severe degradation of material properties are prone to occur owing to moisture absorption. This seawater degradation makes composite materials more susceptible to fail due to the presence of damage mechanisms such as matrix cracking, fiber/matrix interfacial debonding and delamination. Thus, novel strategies that assure the reliability and integrity of composites laminates during their service life are essential, especially under conditions where they are exposed to seawater environments. Recent research progress in the field of nanotechnology has shown that the use of nanomaterials like carbon nanotubes (CNTs) can be effectively incorporated to materials at larger scales for obtaining composite laminates with multifunctional properties. One of the most interesting properties that composite laminates with CNTs can possess is piezoresistivity, which represents an important material parameter for the development of self-sensing structural materials. However, to the best of our knowledge, research on the piezoresistive properties of composite laminates with CNTs exposed to seawater ageing has not been investigated. In this work, glass fiber/epoxy composite laminates with multiwalled carbon nanotubes spray-coated on their fibers are manufactured and exposed to seawater ageing with the purpose of investigating their sensing strain capabilities under monotonic and cyclic flexural loading. For that, Three-point bending tests and electrical resistance measurements are simultaneously carried out on beam-type specimens. The results of the monotonic and cyclic bending tests indicate that the glass fiber/carbon nanotubes/epoxy composites show good piezoresistive sensing characteristics suitable to detect in situ damage and strain monitoring through the change in their electrical resistance.

13811 | Dynamic analysis of functionally graded carbon nanotube-reinforced laminates **(Dynamics of Composite Materials)**

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In present paper vibration analysis of functionally graded carbon nanotube-reinforced composite laminates is presented. Different types of functionally graded aligned reinforcement distributions of carbon nanotubes along the thickness of laminates are considered. Material properties are estimated by a micro mechanical model using some effective parameters. The governing equations are developed based on third order shear deformation theory. A nine node isoparametric finite element with seven nodal unknowns at each node is used. The obtained results in terms of frequencies, mode shapes are compared with available results in literature. The effects of carbon nanotube volume fraction, length-to-thickness ratio, boundary conditions and others geometrical parameters are also examined.

13846 | Dynamic visco-elastic properties of fiber based energy absorbing materials **(Dynamics of Composite Materials)**

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Flocked energy absorbing material, or FEAM, is a novel form of pseudo-composite material that has potential relevance in a wide range of engineering

applications. FEAM consists of monofilament fibers of different deniers flocked onto substrates in varying densities to form single or double-sided layers that are separated by fabric dividers. When used for impact protection, FEAM absorbs energy through the buckling and bending of the fibers. Because this class of materials is relatively new, much of its mechanical behavior is not understood. This study aims to address that by investigating the dynamic viscoelastic properties of FEAM in various configurations. The tan(δ) of FEAM was determined with a purpose built DMA while varying flock length, density and denier, along with temperature and frequency. These results were validated through batch-to-batch testing and calibration with Sorbothane®. The in-plane shear properties were determined at medium strain rates with a purpose-built double-lap shear jig placed inside a guided weight drop tower. DMA revealed that increasing the frequency of loading on FEAM tends to increase its tan(δ); increasing the aspect ratio of the constituent fibers in FEAM tends to decrease tan(δ); and increasing the density of the fibers tends to increase tan(δ).

13929 | Damage identification and low velocity impact in composite aircraft structures (Dynamics of Composite Materials)

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The aim of this study is to investigate the damage identification analysis and response of a composite of cracked aircraft structures.
The search for increasingly high performances in the field of the aircraft structures to the development of materials having higher rigidities and specific resistances. The use of the composite material offers a good resistance. the use of the finite element method makes to establish dynamic model of the structure. Numerical calculations of the model developed, prove that the Eigen frequencies were decreased after impact in the critical zone, and this reduce is nonlinear; however the stress and strain increased with impact.
Therefore the modal analysis is an important factor for the detection of failure in composite structures.

14349 | A meso-scale model on damping property of 3D woven composite (Dynamics of Composite Materials)

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A meso-scale damping model for 3D woven composite is presented in this paper. Frequency dependent dissipation factor for an epoxy (E51) is measured using dynamic thermal mechanical analysis (DMA) and it then fitted into an empirical function. Based upon this function, damping model for glass fiber/epoxy matrix unidirectional composites is formulated via modified mixture law. The parameters in the formulations of longitudinal, transverse, and in-plane shear dissipation factors for unidirectional composite are calibrated using DMA test on specimens with 0°, 90°and 45°ply angles, respectively. Then, a meso-mechanical damping approach for 3D woven composite with the same material system is modeled. Based on the elastic-viscoelastic correspondence principle, method of complex stiffness is employed to determine its orthogonal damping parameters. The damping properties for the epoxy rich region and fiber bundle in 3D woven composite are estimated by damping models of bulk epoxy and unidirectional composite proposed previously. Flexure vibration tests for 3D woven composites with different weave parameters are conducted and experimental data proves that the proposed damping model works effectively. Results reveal that the bending dissipation factor of 3D woven composite will increase with vibration frequency. With bigger fluctuant angle of fiber bundle, 3D woven composite has larger dissipation factor increment with frequency increasing. Within the frequency range in this study (5Hz~200Hz), the increments are not quite insignificant, and the biggest one is found to be 2.45%. The bending stiffness of 3D woven composites also increases slightly with the frequency in this frequency range. This study exhibits the advantage of the complex stiffness method, for by it calculations of the complex stiffness matrix of 3D textile composites become convenient: their damping properties can be obtained directly from their stiffness prediction model.

14387 | Vibration analysis of a rotating composite beam with transverse loads (Dynamics of Composite Materials)

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The free vibration of rotating laminated composite beams with transverse loads has been investigated. Aerodynamic effects have been considered as a transverse load. Ritz method is used in the formulation. Algebraic polynomials are chosen as displacement field components. Clamped-free boundary conditions are considered. Different deformation theories are used in the formulation including classical and shear deformation beam theories. Effects of external load, rotation speed, hub ratio, orthotropy ratio and length to thickness ratio are analyzed in detail. Results of the present study can be useful in the design of rotors, wind turbine, blades and energy harvesters.

14390 | Dynamics of functionally graded Bresse-Rayleigh-Timoshenko beams (Dynamics of Composite Materials)

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Dynamics of thickness-wise functionally graded Bresse-Rayleigh-Timoshenko (BRT) beams have been studied. Equations of motion and boundary conditions have been obtained by using Hamilton's Principle. Wave propagation in the beam have been studied using Euler-Bernoulli (EB) and BRT theory. It was obtained that axial and transverse deformations are coupled in BRT theory. Three spectrums have been obtained for the BRT theory whereas there are two spectrums for EB theory. Then, simply supported beam vibration problem has been investigated. Validity of the second transverse spectrum of the BRT theory has been investigated in detail.

14435 | A TIME DOMAIN EFFECTIVE YOUNG MODULUS TO ESTIMATE STRESSES IN LAMINATED GLASS BEAMS UNDER DYNAMIC LOADINGS (Dynamics of Composite Materials)

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The mechanical behavior of laminated glass beams is time and temperature dependent because of the polymeric viscoelastic interlayers. In the last years, the concept of effective thickness has been applied to laminated glass elements subject to both static and dynamic loadings, which simplify significantly the calculus in these laminated elements. In this paper, a new method to estimate stresses in laminated glass beams under dynamic loadings using a dynamic effective thickness in the time domain is proposed. The equations have been derived from the frequency domain effective thickness proposed by the authors in previous papers. The results obtained in the analytical equations are compared to those obtained in experimental tests carried out on laminated glass beams with different boundary conditions and at different temperatures.

14436 | STATIC AND DYNAMIC RESPONSE OF MULTILAYERED GLASS PLATES USING THE EFFECTIVE THICKNESS CONCEPT (Dynamics of Composite Materials)

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Multi-layered laminated glass panels are commonly used in applications where a high level of security is required. In general, the polymeric interlayers determine a linear visco-elastic behavior of the laminated structure and consequently the mechanical behavior is temperature and time (or frequency) dependent. In this paper, the static response and the modal parameters of a rectangular multi-layered glass plate (3 glass layers and 2 PVB interlayers) pinned supported at the corners, are predicted using the effective thickness concept. The dynamic effective thickness has been derived from the model proposed by Mead and Yaman to predict the dynamic behavior of sandwich plates with viscoelastic interlayers. The predicted modal parameters of the plate are validated by operational modal tests and also by numerical simulations. The model proposed by Galuppi and Royer-Carfagni to calculate the static response of laminated glass plates with two glass layers is extended to the multilayered case and used to predict the response of static response of the plate subject to a concentrated load at the mid-point of the plate

14496 | Band-structure design of phononic tetrachiral materials for Bloch wave filtering (Dynamics of Composite Materials)

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A large family of chiral and antichiral materials is realized by a cellular microstructure made of a periodic pattern of stiff rings and flexible ligaments [1, 2, 3]. The free propagation of elastic waves through phononic chiral materials can be studied by the analytical formulation of beam lattice models for the elementary cell, in combination with the Floquet-Bloch theory for periodic systems. Within this framework, the present paper deals with the tetrachiral material, which is characterized by a monoatomic periodic cell. Different analytical formulations can be developed to govern the wave propagation in tetrachiral materials. First, continualization-homogenization techniques can be adopted to define micropolar equivalent continua [4, 5], characterized by overall elastic and inertial tensors. Second, high frequency multiparametric techniques can be employed to obtain proper asymptotic approximations of the material band structure [6]. Moreover, valid alternatives are offered by computational methods, suited to account for the model refinements that cannot be included in synthetic formulations. The dispersion curves achievable according to one or the other of these formulations are compared and discussed. Attention is focused on band gaps potentially occurring in the low frequency range, since stop bands can mechanically filter undesired dynamic signals for vibration shielding purposes. In particular, the difficulty to satisfy the conditions related to presence of a band gap in the low frequency range is discussed. Alternatively, the possibility to achieve a band gap at a target frequency either by enlarging the parameter space or by removing some simplifying hypotheses of the synthetic model is analysed. Furthermore, a design alternative of phononic tetrachiral materials for given pairs of band gap amplitude and center frequency is proposed. Finally, the response of a finite dimension cluster of tetrachiral cells subjected to an incident harmonic wave is numerically evaluated to verify the filtering performance.

Keywords: Phononic tetrachiral material, Bloch wave propagation, frequency band gap.

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14508 | Nonlinear Elastic Behavior of PMMA- and polystyrene-based (Nano)Composites (Dynamics of Composite Materials)

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Polymer composites are finding increasingly wide applications in aerospace, marine and automotive industries, where components experience various dynamic loads. Rapidly growing applications of composite materials in industry stimulate analysis of various aspects of their mechanical behavior. However the composite response to intensive dynamic loading is often hard to predict since it may depend drastically not only upon matrix and filler characteristics, but also on filler distribution in the matrix and on resulting mechanical characteristics of the composite, including its nonlinear parameters, 3rd order elastic moduli in particular.

Wave processes in general are good candidates for modeling dynamic loading of materials. Nonlinear elastic strain waves and in particular bulk strain solitary waves (solitons) may be most promising due to their anomalously low decay, stability of wave parameters in homogeneous waveguides and dependence of parameters on waveguide elasticity and geometry. Besides that these waves can be applied for measuring third order elastic moduli of materials which are currently measured by ultrasonic technique with low accuracy.
In this communication we present results on the development of nanocomposite materials on the base of polystyrene and PMMA matrices with different fillers, SiO2 nanoparticles and alumosilicates (Mica ME-100, montmorillonite (MMT-15A) and halloysite nanotubes (HNT)), on measurements of their elastic parameters and on experiments on generation and evolution of bulk strain solitons in these composites. The addition of nanoparticles to the polymer matrices provided noticeable changes in elastic characteristics of the composites as compared to those of the pure matrices and caused well detectable variations in parameters of strain solitons propagating in them.
The results obtained may be of use for understanding, description and prediction of nonlinear mechanical behavior of polymer composites with nano- and micro-sized inclusions.

14521 | Dynamic Response of a Sandwich Beam and Laminate Coated Timoshenko Beam due to a Harmonic Load **(Dynamics of Composite Materials)**

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We study the dynamical response of two models of a damped finite, simply supported beam, under transverse harmonic load. The first model is a laminate coated, Timoshenko beam for which we assume that the outer layers of the beam are reinforced laminates. Vibrations of the Timoshenko beam are described by a set of two differential partial equations. The second model is a classic sandwich beam with a rectangular cross-section consisting of two thick, stiff, elastic sheets and a thick core layer. Vibrations of the sandwich beam are defined by a system of two coupled differential equations, where one is a partial equation and the second is a ordinary equation. The classical solution for the response of both models of the beam has a form of a sum of two infinite series, one of which represents the forced vibrations and the other one free vibrations of the beam. We show that the series which represents aperiodic vibrations of the beam can be presented in a closed form. In order to obtain the effective model of damping, the assumption, that one logarithmic decrement of damping describes both damping of displacements and angles of rotation, has been made. As can be seen from the numerical study the laminate coating of the beam has strong influence on normal and shear stresses in boat models. However both models present different usage of outer layers. For Timoshenko beam outer layers are used to reinforce elements of the construction that already exists, while sandwich beams are assembled as in built or exchanged elements with high mechanical parameters with a relatively low weight of the structural element. In this paper we show that even thou both models are dedicated to elements of different usage, we receive natural frequencies and as well as mode shapes functions.

14529 | Analysis and modelling of the transverse isotropic behaviour of short fibre reinforced composites: Application to short carbon fibre PEEK **(Dynamics of Composite Materials)**

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The use of new thermoplastic matrices in industrial sectors has been promoted due to its attractive mechanical properties, low manufacturing cost and flexibility in terms of manufacturing technologies. However, when a higher strength is desirable and the use of unfilled polymers does not provide the required performance, the use of short fibre reinforced (SFR) composites is a good alternative while retaining its economic and design advantages. In the context of SFR polymers, this type of composites presents an anisotropic mechanical behaviour not observed in unfilled polymers. With the aim of providing tools that permit the analysis of the different mechanical behaviours observed in such materials, we propose a general constitutive mechanics framework for polymers and their corresponding SFR composites. The overall mechanical response of the composite is assumed here as the sum of two contributions: a hyperelastic-viscoelastic/viscoplastic contribution related to the matrix; and a transversely isotropic contribution arising from the fibres distribution. The constitutive formulation is developed within finite deformation kinematics and takes into account: strain rate and temperature dependencies, pressure sensitivity, temperature evolution due to inelastic dissipation and thermal expansion. The general formulation proposed allows for the particularization of the energy potentials and flow equations of each constitutive branch, providing the basis for the formulation of specific constitutive models for a wide variety of polymers and SFR composites. To illustrate the potential of this work, the framework is particularised for polyether-ether-ketone (PEEK) thermoplastics: unfilled matrix and short carbon fibre reinforced PEEK. In both cases, a good correlation has been found between available experimental data and model predictions.

14534 | Strain rate dependent in-plane ply behaviour of fibre reinforced composites- an experimental and numerical investigation **(Dynamics of Composite Materials)**

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Fibre reinforced composites are being increasingly used for aerospace and automotive structural applications. One of the critical loading conditions for such applications is impact, consequently, understanding of the composite behavior under such loads becomes critical for structural design. The analysis and design process for achieving impact-resistant composite structures requires rate-dependent constitutive models, which, in turn, requires material properties of the composite over a range of strain rates. It is, therefore, the objective of the research to experimentally investigate and model the observed strain rate-dependence of the in-plane ply properties of fibre composites for a wide range of fiber orientations. Three different loading rates are considered for the experimental study, designated as quasi-static, medium and high strain rates. Accordingly, three different test setups are utilized, quasi-static universal testing machine, medium rate hydraulic testing machine and Split Hopkinson Pressure Bar system. The stress-strain response of the composite is reported for the different fiber orientations and the strain rates, revealing the rate-dependent characteristics of the carbon fiber reinforced composite. From the test results, it is observed that, the dependency of the fracture strength on the loading rate is significant. Experimental results are summarised in terms of the failure envelopes in the 22-12 material co-ordinate system for the three strain rates.

A high-fidelity anisotropic, strain-rate dependent elastic-viscoplastic constitutive ply level model is developed. Numerical simulations are performed on test coupons at different loading rates and a good agreement is found with experiments for the majority of off-axis tension/compression coupons. The fracture

planes observed in numerical simulations are comparable to those observed in experimental coupons. It is expected that the results and the corresponding modelling technique would yield more accurate prediction of impact behaviour of fibre composites, leading to their optimal design.

14542 | Wave propagation in delaminated thin pretwisted anisotrpoic strip (Dynamics of Composite Materials)

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In this work, delamination in a composite strip is modeled through the sublaminate approach. The pretwisted anisotropic strip is modeled by reducing the original 3D problem into a 2D cross sectional analysis and 1D problem along the length of the strip using the variational asymptotic method. The governing equations of the 1D model are solved using spectral finite element (SFE) method, wherein the structure would be modeled as a wave guide and the dynamic stiffness matrix is derived in frequency domain. The wave response of the delaminated composite structure for different loads and conditions are computed. Further, the model is validated by comparing the result obtained from SFE method with the results obtained from a commercial Finite element (FE) package. The usage of SFE is expected to yield a faster result and lesser computation than the FE method for analyzing and monitoring the delaminated strip exposed to high frequency excitations. Additionally, the SFE based modeling scheme are suitable for the inverse problem of damage detection. Preliminary results from the analysis show that the proposed model is capable of capturing the salient features of coupled wave propagation response in strips. There are however challenges in interpreting results for damage detection since wave reflections from delaminated surface cannot be explicitly considered in the 1D model. The implication of these issues and possible improvements in the model will be discussed in this paper.

14577 | The Effect of Own Weight on Dynamic Analysis of a Pre-Stretched Composite Plate-Strip Containing Twin Circular Inclusions Under Bending Using Finite Element Method (Dynamics of Composite Materials)

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In this paper, the effect of own weight on dynamic behaviors of simply supported composite plate-strip that contains twin circular inclusions subjected to bending load analyzed using the finite element method. Centers of circular inclusions are on a line parallel to the free surface and they made from the same materials. The effects of body forces (own weight) and surface forces (pre-stretching load) on the plate-strip with inclusions are considered together as the initial stresses determined within the linear theory of elasticity. The effects of these initial stresses on the natural and forced vibrations around the inclusions within a plate-strip under additional bending load are examined in the framework of the Three-Dimensional Linearized Theory of Elasticity under the plane strain state. It is shown that the dynamic characteristics of the composite plate-strip with inclusions are significantly affected by taking into consideration the effect of own weight.

Keywords: own weight, circular inclusions, initial stress, composite, forced vibration, natural frequency, finite element method

14611 | Nonlinear vibrations of periodic Euler-Bernoulli beams (Dynamics of Composite Materials)

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The paper describes nonlinear vibrations of Euler-Bernoulli beams with periodic properties. The original model equations with highly oscillating periodic coefficients are transformed to equations with constant coefficients describing macro-dynamics of the beam including the effect of the microstructure size. The main purpose of this paper is to propose an equivalent approximate model describing the nonlinear vibrations of a beam with some periodic properties varying along the beam axis.
In this paper the tolerance averaging technique is applied. This method has wide application and can be used for modelling problems, described by differential equations with highly oscillating coefficients: modelling of dynamic behavior of microstructured thin functionally graded plates and dynamic problems for plates with a periodic structure. Unlike the exact models, the resultant equations have constant coefficients, some of which explicitly depend on the microstructure size. The tolerance averaging technique is based on a set of concepts: tolerance relations, slowly-varying functions and fluctuation shape functions. The micro-macro decomposition is based on the observation that the response of a periodic structure is periodic-like. Thus, the unknown transverse deflection and axial displacement can be decomposed into their slowly-varying and tolerance periodic parts. The new unknowns: averaged transverse deflection, axial displacement and their fluctuation amplitudes are slowly varying functions. The highly oscillating fluctuation shape functions describe the unknown fields oscillations caused by the structure inhomogeneity and have to ensure the l-periodicity constraint, and are proposed a priori for each problem under consideration.
After substitution of micro-macro decompositions into the Lagrangian the averaging over an arbitrary periodicity cell is performed applying the aforementioned approximations. In contrast to the exact formulation, obtained system of partial differential equations for the macrodisplacements and for the fluctuation amplitudes of the axial displacement and of the deflection has constant coefficients.
As an example there is considered a simply supported beam with immovable ends. Various types of periodic cells' structure are considered and the effect of mass and stiffness disproportions in the cell on nonlinear forced vibrations is analyzed. It is assumed that the considered cells are made from a linearly elastic material. In order to solve the problem the Galerkin method was used in the analysis. The solutions of the tolerance model equations, as well as the loads, were assumed in the form of truncated trigonometric series. Free and forced vibrations are then converted into a system of the first order ordinary differential equations and solved by forward numerical integration. The calculations are performed using procedure based on Runge-Kutta-Fehlberg method.
This contribution is supported by the National Science Centre of Poland under grant No. 2014/15/B/STS/03155

14717 | Characterization and evaluation of polyvinyl butyral film for high-speed train windshield glass under impact loading (Dynamics of Composite Materials)

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Background: Composite laminated glass selected as high-speed train windows has become a mainstream trend. Windshield glasses in rail vehicles are fabricated by two or more tempered glass layers bonded with transparent polyvinyl butyral (PVB) films. This designed structure can guarantee safety protection requirements by improving the post-breaking performance of the tempered glass. The post-breaking performance is mainly reflected in retaining the fragments of windshield glass, bearing the larger deformation, avoiding the penetration effect and absorbing the impact energy. Few studies reported the crack propagation and evaluation of PVB laminated glass for high-speed train under impact loading. Nevertheless, there is still a lack of integrated and systematic analysis for PVB laminated glass on rail vehicles, which has higher operating requirements and secure intensity.

Objective: The aim of this work was to study the crack generation and propagation path of PVB laminated glass used for high-speed train windshield. In addition, experimental studies and numerical simulation of the PVB laminated windshield under impact loading were also compared.
Methods: In this study, a series of experiments were conducted to investigate cross-bending mechanical behaviors between the tempered glass and the PVB laminated glass. The tensile tests were performed for PVB films. Then, constitutive model for PVB laminated glass was proposed to ensure accuracy in a finite element (FE) simulation. Finally, a safety hammer impact test was conducted, which was to impact on a PVB laminated windshield specimen of 1.1 m by 0.8 m in dimension. The FE simulation referred to the impact test was performed.

Results: Our experimental results revealed that the PVB film played an important role in energy absorption by comparing the bending tests between the tempered glass and the PVB laminated glass. The tensile stress and elastic modulus of the PVB film were identified. According to the experimental data, it was found that the Johnson-Holmquist Ceramic (JH2) model and Mooney-Rivlin model can better describe mechanical properties of the tempered glass and the PVB film, respectively. The hammer impact test showed that the crack propagated was coexistence two trends between ripple and arborization in diffusion of rail windshield, which is different from automobile glass windows.

Conclusions: This study focused on the mechanical properties and impact response of PVB laminated windshield for high-speed train windshield. The PVB film is an important factor which affect the post-breaking performance of the tempered glass. The results can be used for further design and optimization of the windshield with layered structures for high-speed train application.

14720 | Impact behavior of glass fiber reinforced laminated frontmask for high-speed trains (Dynamics of Composite Materials)

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Background: Driving security is a vital issue in the field of rail transportation. According to the design principle of rolling stock crashworthiness, design for vehicle collision should adopt a multi-stage energy absorption system. This system includes a coupler bumper device, additional energy absorption elements on the end face of vehicle, and a body structure of vehicle. Coupler bumper device is the first level of energy-absorbing device. Glass fiber reinforced plastic (GFRP) is widely used in manufacturing the frontmask for high-speed trains, due to its light weight and high strength. In the process of designing and manufacturing the hood, the strength of the mounting seat is supposed to be higher than that of other parts, and the strength of the frontal collision contact area for the hood should be weaker than other parts.

Objective: The aim of the paper is to study the complicated impact mechanism of the GFRP frontmask of the end caps for high-speed train, and analyze the effect of the size of the thin frontal collision contact area on impact behavior of the GFRP frontmask.

Methods: Low-velocity impact experiments of the GFRP frontmask against the rigid wall are carried out. In addition, the quasi-static tensile, compression and shear experiments are conducted to obtain the mechanical properties and constitutive behaviors of the GFRP frontmask. An accuracy failure finite element model based on the continuum damage mechanism (CDM) is proposed to simulate the failure process of the GFRP frontmask under low-velocity impact using ABAQUS. Define the distance between the point of the end face of frontmask and the cross section of the largest elliptical of the thin frontal collision contact area as L. Based on the verified model, an analysis of the sensitivity of L , i.e. the effect of L on peak force , energy absorption and damage area is performed.

Results: The failure modeling results for GFRP frontmask is well fit with the experiment data. The results indicated that the intra-lamina damage includes fiber fracture, matrix crack, debongding between fiber and matrix, and delamination. The frontal collision contact part of the GFRP frontmask suffers penetration injury and broken into small debris. The debris are peeled from the frontmask so that the coupler behind frontmask can be smoothly and stably linked with another one. In addition, the modeling results showed strong correlations between L and peak force, energy absorption and damage area.

Conclusions: The current study provides an effective modeling method of GFRP frontmask. The simulation and experimental investigation are helpful for improving the possibility of accurate linking of the coupling and capability of energy absorption for the energy absorption system, and further protecting the life and property of passengers and drivers.

14776 | Low velocity impact behaviour of a Glass fiber/Acrylic woven composite laminates: experimental study and multi-scale modelling (Dynamics of Composite Materials)

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For recyclability purposes, an acrylic resin (Elium 150) has been recently developed for the elaboration of laminate composites at room temperature. This new resin is endowed with some interesting mechanical properties that allow them to replace some epoxies in some industrials applications where a high strength is required. In this study, the mechanics of structure genome (MSG) and the finite elements based micromechanics approaches are conducted to evaluate the effective thermomechanical properties of a plane woven glass fiber/acrylic resin composite laminate. Through a two-steps and the asymptotic homogenization approach, the present investigation aims to predict the elastic properties of the glass fiber/Acrylic resin laminated composites. Prior to

numerical simulations, some observations have been performed on the laminate sample in order to accurately represent the geometry of a periodic representative volume element (RVEs). These numerical results were compared with those coming from previous experimental investigations on macroscopic laminate composite. A satisfactory agreement is observed between the numerical predictions and experimental data. In order to test the relevance of the proposed numerical procedure, the effects of the strain rate and the temperature were then discussed. Finally, a finite elements model has been implemented for the simulation of low velocity impacts on the studied laminated composite. Moreover, a multi-scale approach is proposed in order to describe the damage type and evolution during low velocity impact test. The comparison between experimental results and the proposed numerical model are in agreement.

14858 | Numerical and experimental investigations of damping of flax-epoxy laminated composite (Dynamics of Composite Materials)

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Composite structures are present in many areas: The water sport, the naval, the air, railroad transport, the industry of the automobile, but also in the leisure activities or the domain of the renewable energies (for example wind turbines). The advantage of such structures lies in their damping properties of vibrations, and of sound effects and their lightness. Their property of "lightness" offers them an attractive power in industrialization, especially in transport which allows a significant energy saving of energy. There are several types of composites: conventional composites with fiber of carbon, glass, or kevlar, and from now the composites of flax, hemp fibers, that is to say based on natural fibers. It is on these that will be our interest.
The aim of this study is to compute the eigenvalues and damping of natural composites made of flax fibres with an epoxy matrix. Here a modeling of damping of flax-epoxy laminated composite is proposed. The mechanical proprieties of each layer are identified experimentally via tensile tests. Layer's damping (Etak) is introduced in Young's moduli and is considered constant in the following form : Ek = E0 (1 + i Etak). The homogenization technique is applied in order to have the behavior law of the structure. To investigate the vibration problem of these composite structures, a spatial discretization method is applied. A finite isoparametric shell element with eight nodes is used. The resolution of the equation of vibration is carried out using the Asymptotic Numerical Method (ANM) [1]. This method associates a high order perturbation method and a homotopy technique. The initial complex problem is linearized and a set of linear algebraic system is able to be easier solved. The damping (Eta) and damped frequency (Ω) of the structure are defined from the classical formula of [2] : ω2 = Ω2 (1 + i Eta).

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14891 | Uncertainty in Dynamic Characteristics of Pretensioned Concrete Beam Strengthened using Carbon Fiber Reinforced Polymer Laminates (Dynamics of Composite Materials)

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Stochastic finite element (FE) based free vibration analysis of prestressed concrete (PSC) beam with carbon fiber reinforced polymer (CFRP) laminate is conducted. A pretensioned concrete beam with CFRP laminate attached at the soffit is modeled with stochastic material behavior in FE software. Special purpose cohesive interface elements capable of showing debonding failure are used to model the adhesion between the concrete beam and the CFRP laminate at its soffit and numerical validation is completed.

The material uncertainty is considered in the elastic moduli of the CFRP laminate in the longitudinal (E11) and transverse (E22) directions, as well as in the shear modulus (G12). The effect of uncertainty in E11, E22, and G12 individually on the fundamental frequency of the PSC beam with the CFRP laminate is studied. The variation of material properties is assumed Gaussian with mean values and standard deviations of each uncertain parameter considered. The uncertain elastic material parameters are represented using truncated generalized polynomial chaos (gPC) expansions with predefined orthogonal basis. The constructed gPC expansions for the uncertain parameters are used as inputs to the deterministic FE model to realize random frequency responses on a few numbers of collocation points generated in random space. The realizations are then employed to estimate the unknown deterministic functions of the gPC expansion approximating the responses. The impact of composite elastic parameter uncertainty on the modal frequencies of the strengthened PSC beam is investigated.

The probability distributions for natural frequencies, as obtained through the gPC expansion based simulations, are constructed and compared with the Monte Carlo (MC) simulations. Elastic parameters of fiber reinforced composites show significant uncertainty due to their significant structural complexity. The effect of uncertainty in E11, E22, and G12 simultaneously on the first 15 dynamic modes of the PSC structure is studied. From the probability distribution function (PDF) of fundamental frequency due to uncertainty in E11, it is observed that increase in the uncertainty level of E11 from 5% to 40% increases the standard deviation of the output fundamental frequency, skewing the response from the deterministic value making it non-Gaussian. On the other hand, the uncertainty in E22 and G12 doesn't propagate to the output fundamental frequency.

The PDF plots for the frequencies obtained from the gPC and compared with the 5000 MC simulation results and the deterministic values. The mean and standard deviation obtained from the gPC method and MC simulation show good agreement. From the coefficient of variation (CV) for the 15 modes, it is observed that the vertical bending modes are at least three times more sensitive to the uncertainties in the input parameters as compared to the lateral bending and torsional modes. The variation in mean as obtained from the gPC method and MC simulation is less than 0.1%. The gPC method consumes only 0.4% of the computational effort that is required for the MC 5000. The gPC expansion based simulation technique is observed to be an efficient alternative to computationally demanding MC simulation for quantifying uncertainties.

From the uncertainty analysis in the dynamic characteristics of the PSC beam, strengthened using CFRP laminates the following conclusions are drawn:
1. Uncertainty in transverse elastic and shear modulus of the CFRP laminate has no effect on the fundamental frequency of the PSC beam.

2. With increase in uncertainty level, the response becomes skewed and deviates from the deterministic values.
3. The impact of uncertainties on vertical bending modes is much more pronounced as compared to the lateral bending and torsional modes.
4. The collocation based gPC method is an accurate and computationally efficient alternative to MC simulation to quantify the effect of uncertainties in composite properties.

14549 | Dynamic pull-in instability analysis of laminated quadrilateral microplates with FG-CNTs reinforced composite layers based on visco-nonlocal-sinusoidal theories using TW-DQ-Bolotin methods (Electro-thermal properties of composite materials)

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Today, the use of equipped devices with electrical sensors, such as micro and nano switches, has become widespread. The switching of laminated quadrilateral microplates has many applications in the military and medical industry. In this paper, the effect of switching these types of laminated quadrilateral microplates with FG-CNTs reinforced composite layers under electrostatic and intermolecular Casimir forces has been studied. In order to achieve this goal, dynamic pull-in instability analysis of these laminated composite layers based on visco-nonlocal-sinusoidal theories using TW-DQ-Bolotin methods is investigated. The equations of motion based on Sinusoidal shear deformation theory, Viscoelastic properties of the nanoplate(Kelvin-Voigt model) and considering size effects(Eringen's nonlocal theory) are derived. Considering four types of CNT distribution along with three types of FG distributions of CNTs along the thickness direction of a plates are discussed in details. The influences of various parameters such as three boundary conditions (clamped in all edges, simplified in all edges and clamped in two edges in front of each other and free in tow another edges), small scale effect, applied voltage on the pull-in voltage, pull-in deflection are discussed. The achievements of this research are used in various industries as smart controllers and electrical devices.

14332 | Compressive mechanical properties of aluminum foam-polyurethane composites (Porous and cellular materials)

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Aluminum foam has gained much attention thanks to its excellent physical performances combined with good mechanical characteristics. In order to further widen the application fields of aluminum foam, some methods are proposed to improve mechanical properties of aluminum foam. Particle and alloy are introduced to strengthen cell walls of aluminum foam; in addition, composite structures are also used such as sandwich panels, shells and tubes with aluminum foam cores. Recently, an alternative approach is put forward to enhance the mechanical performances of aluminum foam, which focuses on the introduction of polymers. Polymers have been proven to increase properties of aluminum foam by several researchers. However, the characterization of aluminum foam-polymer composites is still limited.
Uniaxial compressive mechanical properties of aluminum foam-polyurethane composites are studied in the present work in order to gain a better understanding of aluminum foam-polymer composites. Open-cell aluminum foam is selected as the matrix, and a type of thermosetting polyurethane as the second filler. Loading velocity and the content of polyurethane are influencing factors, which are used to investigate their influence to plateau stress, absorption energy and specific absorption energy. Meanwhile, the mechanical properties of composites are compared to those of aluminum foam. It is anticipated that polyurethane could increase the mechanical performances of aluminum foam, but the level of improvement is affected by strain rate and the content of polyurethane.

14413 | Particle reinforced themoplastic foam under quasi-static compression (Porous and cellular materials)

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The quasi-static compressive response of Linear Low-Density Polyethylene (LLDPE) foams reinforced by cellular ceramic particles are investigated experimentally and theoretically in this study. The ceramic beads have density 1.6 g/cm3 and the diameter ranging between 1.5 mm and 1.9 mm. For pure LLDPE foams, the diameter of cells vary between 0.5mm and 4 mm. The compression response is governed by the deformation of larger cells (diameter > 2.5 mm). The presence of ceramic particles in the LLDPE foams can increase the stiffness and yield strength of the foam through stabilizing the deformation of large cells. This can significantly increase the energy absorption capacity of the material. A detailed finite element simulation was conducted to facilitate the understanding of the experimental measurement. Both large cells and particle reinforcement were modelled explicitly. The finite element model was generated using Python script under the environment of commercially available software Abaqus to realise the randomness of cells and particle reinforcement embedded in the foams. The numerical model has good agreement with experimental measurement. The research outcome provide important evidence on design of reinforced foams.

14501 | VIBRATION DAMPING IN STEEL FOAM SANDWICH STRUCTURES: AN EXPERIMENTAL STUDY (Porous and cellular materials)

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This research project is an experimental investigation on the structural dynamic properties and vibration damping of steel foam sandwich beam specimens. The sandwich specimens comprise DC01 mild steel plates and steel foam hollow spheres bonded together with a thermosetting epoxy. Specimens included single-phase steel foam core sandwich specimens and two-phase specimens with semi-filled steel foam cores with different volumes of lubricant oil. Three different tests were performed, specifically sine sweep over a range of frequencies, white noise and shock. The results show very good correlations in the estimation of the harmonic frequencies and promising damping ratios for the single-phase cores with further improvements in the presence of two-phase cores.

14524 | Characteristics of porous VO2 thin film for flexible thermochromic smart window fabricated by solution process (Porous and cellular materials)

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Recently, regulations on energy consumption and CO2 emission have been strengthened, and the focus is on the development of technologies that can increase energy efficiency around the world. The energy is mainly consumed to maintain the building's room temperature. Among the technologies developed to save energy, there is a smart window that can selectively block sunlight by coating a functional material on glass. Thermochromic smart window is a passive type that responds to external environment, and VO2 is widely used as a thermochromic material because it enables metal-insulator reversible transition (MIT) near 68 °C. When the crystal structure of VO2 is changed, the infrared rays of the sunlight can be reflected, thereby enabling the room temperature to be maintained. In general, VO2 thin film is manufactured by a deposition process on glass such as quartz or FTO. The deposition process is expensive and difficult to coat with large area. In addition, due to the heat generated during the deposition process, it was limited to application to other fields besides coating on glass. To solve these problems, the VO2 thin film was prepared by a solution process in which a VO2 nanoink was coated on PET substrate, and sintered by intense pulsed light (IPL) process using light energy to prevent damage to the PET substrate by heat. The VO2 nanoink contains a doped VO2 powder prepared by hydrothermal synthesis, and dispersant and binder. Tungsten and titanium are used as doping elements to decrease the transition temperature, and the amount of dopant to be added is based on predictions by results of Macleod software. The VO2 thin film is prepared by spin coating the VO2 nanoink onto PET substrate, followed by drying and IPL sintering. The sintered thin film is in porous state because the dispersant and binder present between VO2 particles are evaporated. Porous thin film can improve the light transmittance in visible light region. The microstructure of VO2 thin films are observed using field emission scanning electron microscopy (FE-SEM), high-resolution transmission electron microscopy (HRTEM). Crystallinity of VO2 thin films were analyzed by X-Ray diffraction (XRD). We succeeded in VO2 coating on PET substrate by solution process. Tungsten doped thin film was more effective in reducing the transition temperature than the titanium doped thin film.

14892 | Evaluation of mechanical properties of Expanded PolyStyrene (EPS) modified with graphene oxide **(Porous and cellular materials)**

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The subject of the research was a composite made of (EPS) Expanded PolyStyrene and graphene oxide (GO) powder of micro- and nanometric sizes. The experiment consisted in the preparation of GO-alcohol suspension and covering it with pre-expanded polystyrene granules. Then, the thus prepared material was formed into blocks from which test samples were cut out in accordance with the applicable standards. The research concerned determination of density ρ, thermal conductivity coefficient λ, compressive stress at 10% deformation σ10, perpendicular tensile strength σTS, bending strength σBS. The cellular structure of cross sections was also examined by means of scanning electron microscopy. The results were compared with the results obtained for EPS unmodified and modified with graphite, in which graphite powder was added to the raw material at the stage of synthesis and beads formation. All test samples had similar density of ρ; 13,35-13,83 kg/m3. The research showed that for EPS+GO samples, λ in the range of 0,0374-0,0378 W/mK was obtained, while EPS samples had λ from 0,0384 to 0,0405 W/mK, and for EPS+graphite λ was constant at 0,0310 W/mK. Investigating the deformation σ10 of EPS+GO composite values from 90 to 102 kPa were obtained, whereas for EPS+ graphite and unmodified EPS, 78-79 kPa and 69-75 kPa respectively. The research of tensile strength σTS showed that the best results were obtained for EPS+GO, from 103 to 139 kPa. Values for EPS+ graphite and EPS were 79 – 80 kPa and 95-96 kPa respectively. Similar results were obtained when testing bending strength σBS. Better mechanical properties of the EPS+GO composite should be associated with a more extensive structure of elementary cells of expanded polystyrene granules. Electron microscopic studies revealed the placement of GO particles inside cells based on spatial suspensions using polystyrene fibers. This creates an additional construction that strengthens individual cells and consequently expanded and agglomerated granules. This mechanism was not observed in the case of EPS + graphite.

14359 | Response of historic brick masonry strengthened with BFRP/GFRP strips **(FRP and Historic Masonry Structures)**

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Historic masonry walls have demonstrated high vulnerability and low shear capacity when exposed to seismic actions. The behaviour of historic unreinforced masonry (HURM) walls under combined compression and shear loading plays a fundamental role in the seismic assessment of masonry buildings. During earthquakes, HURM walls are subjected to shear loads that often lead to the ruin of an entire building. In recent years, the strengthening of masonry walls often foresees external bonded fiber reinforced polymers (FRPs) even if many aspects of this technique are not thoroughly known.
This paper presents the results of an investigation on historic unreinforced masonry wallettes built with historic solid clay bricks in scale 1/3rd. The unreinforced models were tested under diagonal compression both without and with strengthening due to presence of Glass-FRP/Basalt-FRP strips; the strengthening was on one surface of wallette and the angle between bed mortar joints and FRP strips has been varied between 0 and π/2.
Main objectives of investigation have been to determine the influence both of GFRP/BFRP-strips on the shear strength of reinforced historic masonry, delamination mechanisms and the best position of strengthening being the masonry a non homogeneous material but typically orthotropic.
Experimental results have been compared with data obtained by finite element micro- macro modelling performed considering the masonry as an isotropic and orthotropic material.

14552 | DEVELOPMENT OF THIN-WALLED TEXTILE-REINFORCED CONCRETE ELEMENTS FOR FREE-FORM STRUCTURES **(FRP reinforced concrete structures)**

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The innovative composite material "textile reinforced concrete (TRC)" offers a high degree of lightweight potential, compared to the classical building materials. This opens up new fields of application with regard to filigree structures in architecture. Through the use of corrosion-resistant textile reinforcement made of alkali-resistant glass or carbon, the concrete covering can be decimated, so slim concrete components can be implemented permanently and sustainably. For an increment of the application spectrum from textile-reinforced plates to freely-shaped support structures, new methods for material composition and production technology are required.

The paper and the presentation include the development and technological implementation of TRC-shells with integrated functions, such as illumination and light control. In that regard, the establishment of material, structural and technological foundations along the entire value chain is of central importance: From the lightweight design idea to the technological implementation for the transfer of the research results into practice. The development of the material included the requirement-oriented composition of a high-strength fine-grained concrete with an integrated carbon knitted fabrics for reinforcement. The form finding of the textile reinforced concrete shells based on an optimization of the distribution of stress using the tensile triangles according to Claus Mattheck, and is resulting in a harmonious stress flow in radius transitions.
The thin-walled TRC-shells were manufacture with a formwork made of glass-fibre reinforced polymer. An advantage of this formwork is the freedom of design concerning the shape. Moreover, an excellent concrete quality can be achieve. After the production of the new research pavilion - consists of four connected CRC-lightweight-shells - it was installed on the campus of Chemnitz University of Technology.
The developed TRC-shells are distinguish by their high resistance to weathering influences (durability), high surface quality and high load-bearing capacity. With regard to its free formability, this type of construction is particularly suitable for filigree, lightweight buildings. The additional integration of an interactive lighting function allows to further exploiting the potential of the new textile-based construction in terms of functionalization.

Keywords: textile-reinforced concrete; function-integrated lightweight structures; composites, thin-walled shells

14575 | Experimental Investigation on the Effect of Transverse Steel Reinforcement and Slenderness Ratio on FRP Wrapped Eccentrically Loaded Columns **(FRP reinforced concrete structures)**

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This study investigates the effect of internal transverse reinforcement and column slenderness on the behavior of eccentrically loaded circular reinforced concrete columns strengthened with carbon fiber reinforced polymers (CFRP) sheets. A total of thirty two circular columns were tested under compression loading with an eccentricity of 50 mm. All thirty two columns had the same diameter of 192 mm. Test columns were subdivided into two main groups of sixteen columns each: group 1 (C1) with a height of 1175 mm and group 2 (C2) with a height of 800 mm. Both groups (C1 and C2) were further subdivided into two main subgroups Ci-S1 and Ci-S2, eight specimens each, where i indicates the main group number and takes the value of 1 or 2. S1 and S2 differentiate the columns in the two subgroups based on the spacing of the interior transverse reinforcement. Columns in subgroups Ci-S1 and Ci-S2 were reinforced with 6 mm diameter deformed circular ties at a uniform spacing of 125 mm and 187.5 mm, respectively. Each of the four subgroups (Ci-Sj, where j takes the value of 1 or 2) contains eight specimens divided into four identical pairs as follows: Columns Ci-Sj A and B were reserved as control unstrengthened columns and the remaining six columns were strengthened using CFRP sheets. Three different strengthening systems were considered: Columns Ci-Sj-1C A and B were wrapped with a single circumferential CFRP layer. Columns Ci-Sj-1V1C A and B were wrapped with one vertical and one circumferential CFRP layers. Columns Ci-Sj-1V2C A and B were wrapped with one vertical and two circumferential CFRP layers. Test results showed that wrapping the columns with CFRP sheets significantly increased their strength, toughness, axial ductility and axial and lateral deformation capacities. In general, strengthening columns with one vertical and two circumferential FRP layers exhibited superior efficiency compared to other strengthening systems. Compared to columns strengthened with one circumferential layer of FRP sheets the inclusion of another vertical FRP layer did not enhance the column performance. Using larger spacing of the internal transverse reinforcement resulted in lower load resistance, initial stiffness and ductility compared to the columns with smaller tie spacing regardless of column slenderness. The columns with a lower slenderness ratio had a higher load resistance, initial stiffness, toughness, axial ductility, axial and hoop strains compared to the columns with a higher slenderness ratio, except for the control specimens which showed lower axial ductility. The column ductility decreased as the slenderness ratio decreased regardless of the spacing of steel ties. Comparison with the FRP confinement model proposed by the American Concrete Institute indicated that this model neglects the effect of column slenderness on the confinement provided by FRP wraps.

14627 | Evaluation and rehabilitation of a large-scale AASHTO concrete bridge connection detail using a new chemically tunable dynamic covalent bond matrix **(FRP reinforced concrete structures)**

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Considerable damage to the highway bridge system in the United States Gulf Coast region was observed during the 2005 Hurricane Katrina disaster when storm-induced loading caused substantial damage to the substructure-superstructure connection detail, resulting in unseating and drifting of the decks. This research examines the failure modes of the pre-Katrina and post-Katrina details and exploration of an enhanced bridge connection detail under extreme Katrina surge and slamming wave forces using a designable dynamic covalent bond composite. Six girders, their connection details, and dynamic storm forces were reproduced experimentally at 25% scale using inclined loading (surge uplift + lateral wave); connections were as retrofitted using a Carbon-fiber-based (to add strength) reinforced matrix consisting of an Interfacing curing Epoxy/ pre-polymerized Polyurea (C-IEPM). The curing kinetics of C-IEPM are tuned-in via timely hybridization of thermosetting epoxy containing cross-linking functional-group-heavy morphology of epoxide and hydroxyl, and highly reactive pre-polymerized isocyanate-amine polyurea phase. The new-material interface provides design-ability to composite structures by tuning desirable fracture toughness properties under large hurricane surge/ slamming wave forces. Fracture toughness properties of C-IEPM and no-fiber-IEPM (n-IEPM) coupons were investigated using compact tension (CT) testing per ASTM D5045-14, affirming that material ductility and resiliency of C-IEPM and n-IEPM depend primarily on elapsed curing time (tc) of the epoxy network, which affects the dynamicity of epoxide and amine-hardener (polyetheramine) functional groups relative to their partner isocyanate and rate-controlling amine polyurea reactants, and secondarily on polyurea thickness (hp). The C-IEPM-designed connection shows tremendous ductility and composite energy dissipation relative to the as-is detail, allowing the girder to remain intact and safe under dynamic hurricane forces.

14747 | Bond mechanism of innovative anchorage solution for FRP shear-strengthened RC T-beams using CFRP rope **(FRP reinforced concrete structures)**

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Carbon fiber-reinforced polymer (CFRP) rope was a recently developed solution to anchor fiber-reinforced polymers (FRP) shear-strengthened reinforced concrete (RC) T-beams that conventionally uses U-wrap scheme. The rope is a bundle of flexible CFRP strands held together by a thin tissue net. In this technique, holes are drilled through the web at the web-flange intersection of the T-section, and CFRP ropes are inserted through the holes and flared

onto the two free ends of the U-wrap scheme. The technique converts a U-wrap scheme into a full-wrap scheme and thereby offers substantial improvements in bond strength, confinement, as well as ductility.
The objectives of this study are: (i) to investigate the bond behavior of CFRP L-strip plates anchored with CFRP ropes using FRP-to-concrete joints, and (ii) to propose a modification factor for the prediction of the ultimate bond load of FRP-to-concrete joints anchored with CFRP rope.
The experimental program consisted of sixteen bond tests on FRP-to-concrete joints, of which six were unanchored (control specimens) and 10 were anchored using CFRP ropes. Each specimen consisted of two concrete blocks externally bonded with CFRP L-strip plates. The L-strip plates were epoxy-bonded to the concrete blocks in a U-shaped envelope, the two short legs of the L-strip plates were overlapped onto the shorter concrete block (200 mm x 200 mm x 160 mm), and the CFRP rope was inserted into the longer concrete block (200 mm x 200 mm x 250 mm). In this study, the influence of the following parameters on the bond behavior was examined: (i) concrete strength, where three concrete strengths were considered: 17.1 MPa, 27.9 MPa and 57.3 MPa; (ii) CFRP rope length, where three different lengths were used as follows: 1.0R, 1.3R, and 0.7R, where R is the L-strip length (190 mm) along the FRP/concrete interface block. In other words, the CFRP rope was extended or shortened by 30% (60 mm) for L-strip length of 200 mm; and (iii) L-strip plate width, where two widths were considered: 20 and 40 mm. To install the CFRP rope for anchorage, a hole

of 15 mm was drilled for each specimen at the midpoint of the width of the CFRP L-strip plate. A CFRP rope with a diameter of 10 mm was inserted inside each hole and was extended out both sides of the hole. The two ends of the rope were then flared onto the L-strips. Loading was applied by means of a manual hydraulic loading machine by pulling the two concrete blocks apart, producing thereby tension on the FRP L-strips. The test setup was designed to represent an FRP shear-strengthened beam anchored with CFRP rope and experiencing crack opening.
Experimental results showed that the bond performance greatly improved with increasing FRP plate width and rope length. In contrast, concrete strength had a negligible effect on bond performance. This was attributed to high thickness and narrow width of CFRP L-strips used. All the tested specimens experienced debonding failure; failure by CFRP rupture was never reached in any of the specimens, regardless of concrete strength, FRP plate width, or CFRP rope length. For all anchored specimens, the increase in debonding load due to the anchorage was approximately 14 kN. The rate of change in debonding load due to increase or decrease of CFRP bond length was not significant. Therefore, a rope length that only covers the FRP/concrete interface length is recommended. The ultimate bond load increased with plate width; however, the influence of the anchorage became less pronounced. Theoretical formulations provided to account for the ultimate bond load were compared with the experimental results, and a modification factor to estimate the effect of the presence of CFRP rope was suggested. A modification factor of 1.8 was found to yield high accuracy with experimental results. The modification factor is linked to the concrete tensile strength in the bond equations. The factor can be adjusted to fit changes in FRP plate width and CFRP ro

13815 | Buckling analysis of functionally graded dielectric elastomeric hollow cylinders **(Functionally graded materials and structures)**

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The instability of a pressurized soft circular hollow cylinder (or cylindrical shell) composed of functionally graded dielectric elastomeric (FGDE) material is examined. The state-space formalism is developed on the basis of the nonlinear electroelasticity theory of a deformable continuous body with electromechanical coupling as well as the linearized incremental theory for a superimposed infinitesimal deformation. An analytical characteristic equation is derived by invoking the approximate laminate model. Numerical simulations are performed for a pressurized soft FGDE hollow cylinder. The material behavior is described by the generalized incompressible Mooney-Rivlin model. The effects of material gradient and inner pressure are discussed. It is found that the buckling behavior of soft FGDE cylindrical shells can be tuned by tailoring material composition and/or adjusting the pressures acting on the surfaces of the cylinder.

13837 | Torsional Buckling of Functionally Graded Cylindrical Shells Reinforced With Graphene Platelets (GPLs) **(Functionally graded materials and structures)**

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Torsional buckling of functionally graded cylindrical shells reinforced with graphene platelets (GPLs) is studied through finite element analysis (FEA). The functionally graded shell is consisted of a number of layers stacking in the thickness direction. GPLs are uniformly distributed in each layer while the GPL concentration varies from layer to layer according to prescribed distribution patterns. The mechanical properties of the GPL reinforced polymer composites, including Young's modulus and Poisson's ratio, are determined by using modified Halpin-Tsai micromechanics model and rule of mixture. ABAQUS is adopted to conduct the FEA for the cylindrical structures, in which the effects of cutout on the shear buckling is considered. The finite element model is validated by comparing the FEA results for homogeneous cylindrical with the theoretical formula proposed by Donnell. Parametric study is carried out to investigate the effects of the number of layers, the GPL distribution pattern, the dimensions of the shell structure, the weight fraction and aspect ratio of GPLs and the existence of the cutout on the torsional buckling behaviours. The results demonstrate that when the number of layers is sufficiently large, it is accurate enough to use the multilayers to approximate functionally graded structures. A comparison between the shear stress distribution in the thickness direction of 4-layer and 10-layer cylindrical shells reveals that increasing the number of layers could greatly decrease stress mismatch between neighbouring layers. This can significantly reduce the risk of delamination and debonding in the structures. It is found that the critical torsional buckling load decreases with the increase of the shell's length-to-thickness ratio and tends to be a constant while it grows with the increase of the shell's radius-to-thickness ratio. As expected, increasing GPL weight fraction enhances buckling performances of the cylindrical shells. The distribution of GPLs along thickness direction plays a significant role on the torsional buckling performances of the shell structure. Placing more GPLs near the inner and outer surfaces is the most favourable way to improve the buckling behaviours. Thinner GPLs with larger surface area have better reinforcing effects compared to their counterparts with larger thickness and smaller surface area. This can be attributed to improved load transfer between epoxy matrix and GPL nanofillers. Cutouts are sometimes required in the cylindrical structures to accommodate functional components. The existence of the cutout may substantially deteriorate the structural stability of the shells. Therefore, the effects of the cutout on the torsional buckling, which is of great importance for engineering application, are also studied in present work. With the increase of the cutout size, the critical torsional buckling load drops slightly. Meanwhile, the buckling mode transforms from the global buckling to local buckling around the cutout. A remarkable decrease in buckling load is observed when the cutout transforms from circle to slender ellipsoid. The location of the cutout also significantly affects the stability of the structure. The results show that positioning the cutout near the end of the cylinders is preferred to obtain better buckling behaviours compared to putting the cutout in the middle height of the structure. The critical torsional buckling load also depends on the orientation of the cutout. When the angle between the semi-major and horizontal axes is around 45°, the structure has the maximum torsional buckling load. The findings in present work are expected to provide guidelines for the design and optimization of the functionally graded cylindrical shells reinforced with graphene platelets.

14324 | ON THE SOLUTION OF BUCKLING PROBLEM OF FGM THREE-LAYERED CONICAL SHELLS WITH FGM CORE UNDER MIXED BOUNDARY CONDITIONS (Functionally graded materials and structures)

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The three-layer systems are widely used in automotive, nuclear, marine and aerospace industries, which require a strong, rigid and lightweight construction. The traditional three-layer systems consisting of a soft core associated with two thin and tough coatings exhibit delamination problems at the interfaces between the layers [1]. To overcome this problem, FGM three-layered conical shells (FGMTLCSs) proposed in connection with the gradual change in the material properties through the thickness. FGMs are a new class of composite materials made up of a mixture of ceramics and metals that characterized by the smooth and continuous changes of elastic properties [2,3]. The study on the stability and vibration of pure FGM conical shells with mixed boundary conditions within KLT has been proposed recently [4]. The stability and vibration problems of the three-layered conical shells containing an FGM core were first solved by Sofiyev and coauthors [5]. The boundary conditions are freely supports in these studies. In this work, the buckling of FGM three-layered conical shells (FGMTLCSs) with mixed boundary conditions under the uniform lateral pressure is studied. The basic equations of FGMTLCSs are displayed based on the Donnell-type shell theory and solved using by Galerkin's method. The expression for the critical lateral pressure (CLP) for FGMTLCSs within the Kirchoff-Love theory (KLT) is obtained. The influence of FGM core on the CLP for FGMTLCSs is investigated numerically.
Keywords: FGM core, Kirchoff-Love theory (KLT), three-layer system, Critical lateral pressure
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14339 | Post-buckling analysis of relatively thick functionally graded plates containing circular/elliptical holes using plate decomposition technique (Functionally graded materials and structures)

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Functionally graded materials (FGMs) were introduced by a group of material scientists in Japan in 1984. These materials are typically mixture of ceramic and metal and the volume fractions of two or more constituents vary continuously as a function of position along certain dimension of the plate. By gradually varying the volume fraction of constituent materials, their mechanical properties change smoothly and continuously from one surface to the other one. The mixture of ceramic and metal exhibits some outstanding mechanical properties such as high fracture toughness and high degree of temperature resistance by maintaining the desired structural integrity. Thus FGMs have received considerable attention as one of advanced heterogeneous composite materials in many engineering applications by eliminating interface problems and diminishing thermal stress concentrations.
Plates containing cutout are widely used as structural members to further reduce the weight of structures, openings for hardware and wiring to pass through and in case of fuselage windows and doors. However, the presence of holes may cause the plates stability reduces significantly and reallocate the stress distribution in the plates. Thus investigating the buckling of such structures is a necessity. On the other hand, functionally graded plates (FGPs) may sustain additional loads even after buckling takes place and hence the post-buckling behavior of such plates has been of considerable research interest. In such studies, the critical value of load given by linear buckling analysis may not accurately represent the carrying capability of a plate. Alinia and Ghannadpour [1] studied nonlinear analysis of square plates subjected to pressure loading and material properties were calculated by exponential law distribution. Ghannadpour and Mehrparvar [2] carried out a new study on geometric nonlinear behavior of perforated rectangular composite plates subjected to compressive load using an energy method. In the present study, post-buckling analysis and nonlinear behavior of rectangular FGM plates, which contain holes, is investigated. The material properties of functionally graded plates, except the Poisson's ratio, are assumed to vary continuously through the thickness of the plates, according to the simple power law distribution in terms of the volume fractions of constituents and plates with different types of boundary conditions are investigated. In this study, the plate assembly technique is obtained by Penalty method, in which the plate is divided into plate-elements and potential energy for each element calculated individually. The first-order shear deformation plate theory is employed to account for the transverse shear strains, and the Von Kármán-type nonlinear strain–displacement relationship is adopted. The displacement fields are selected such that to satisfy the boundary conditions and the principle of minimum potential energy is applied to obtain a nonlinear equilibrium equations system. It is also noted that the Chebyshev polynomials are used as basis functions for displacement fields. The whole plate potential energy form, which is the summation of the element's potential energy, obtained by above assumptions can be written as quadratic, cubic and quartic energy terms and the related integrals are taken analytically. The obtained nonlinear equations can be solved using an iterative procedure and here it is the Newton-Raphson procedure. The effects of the cutout shape, size and location on post-buckling behavior of rectangular functionally graded plates are examined.
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14341 | Parametric Probabilistic Aproach in the dynamics of porous FGM curved beams (Functionally graded materials and structures)

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This article deals with the stochastic dynamics of curved beams constructed with ceramic and metallic materials that vary in a given functional form. The construction process of this type of structures conducts to the presence of porosity in its domain. The porosity and a non-constant curvature radius may be source of uncertainties in the dynamic behavior.

The beam model is deduced in the context of common variational principles, incorporating shear flexibility, variable curvature. It serves as a mean deterministic approach to the studies on stochastic dynamics and uncertainty quantification, which are the main objective of the present article. The uncertainty quantification procedure considers the employment of random variables to characterize the uncertainty in material or geometric properties such as elasticity moduli and/or density of the material constituents, curvature radius of the beam, porosity parameters, among others. The probability density functions of the random variables are derived appealing to the Maximum Entropy Principle. Then the probabilistic model is constructed with the basis of the deterministic model and both discretized with finite element approaches.
Once the probabilistic model constructed, the Monte Carlo Method is employed to perform statistical realizations.
Numerical studies are carried out to show the main advantages of the modeling schemes employed, as well as to quantify the propagation of the uncertainty in the dynamics of curved FG beams.

14343 | Thermal post-buckling behavior of initially imperfect functionally graded plates containing crack (Functionally graded materials and structures)

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Functionally graded materials (FGMs) are made of advanced composites in which the material properties vary continuously and smoothly from one surface to another. FGMs, which are usually made of metal and ceramic, provide stronger mechanical performance and reduce the possibility of any failure. The main features of its materials are able to withstand high temperature environments and toughness.
In the field of plates without the cracks, extensive research has been done to study the post-buckling behavior of various kinds of plates that is rapidly developing. Many researchers have recently analyzed the buckling, post-buckling and nonlinear behaviors of FGM materials of structures under thermal environment. Javaheri and Eslami [1] that studied the thermal buckling of rectangular functionally graded materials plate. Ovesy et al [2] investigated non-linear analysis of rectangular functionally graded materials plate in the thermal environment by Finite Strip method. Ghannadpour and Karimi [3] worked on modeling the crack with Penalty technique and decomposition the plate into six sub-plate and analyzed post-buckling behavior of cracked composite plate.
In this study, nonlinear and post-buckling behaviors of edge and internally cracked functionally graded material (FGM) plate with or without initial imperfection under thermal loading have been investigated. The nonlinear formulation is based on the First-order Shear Deformation plate Theory (FSDT), in which geometric non-linearity is presented in the way of the Von-Karman assumptions for the strain-displacement equations. Legendre polynomials for the primary variable approximations are used in the Ritz method. The crack is modeled by dividing the entire domain of the laminates into several sub-plates and therefore, a plate decomposition technique is applied. In this study, penalty technique is used to enforce interface continuity between the sub-plates. Some different out-of-plane essential boundary conditions such as clamp, simply support and free conditions will be investigated in this research. The integrals of potential energy are numerically computed by Gauss-Lobatto quadrature formulas to get adequate accuracy. Then, the obtained non-linear system of equations is solved by the Newton–Raphson method. After that, the results are presented for influence of crack length, various locations of crack, boundary conditions and initial imperfection.
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14480 | Nonlocal Nonlinear bending and free vibration analysis of FGM plates using TSDT and Natural Neighbour Galerkin Methods (Functionally graded materials and structures)

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Functionally graded materials (FGM) are the special class of composites in which the volume fractions of two or more materials are varied continuously as a function of position along certain dimension(s) (often, through thickness) of the structure to achieve a required functionality and hence are inhomogeneous at the macroscopic scale. A typical FGM, with a high bending-stretching coupling effect, is an inhomogeneous composite made from different phases of material constituents (e.g., ceramic and metal for thermal barrier structures). FGMs possess a number of advantages, including a reduction of in-plane and transverse through-the-thickness stresses, an improved residual stress distribution, enhanced thermal properties, higher fracture toughness, and reduced stress intensity factors along with high wear resistance.
For large deformation analysis, standard finite element method requires adaptive remeshing, handling interpolation errors due to element distortions, transfer of data from one time step to another, discretization errors, and constraints posed by C0 continuous approximants, in terms of inability to model higher order governing differential equations. To simplify such problems associated with FEM, various meshless methods like SPH [2], EFGM [3], MLPG [4], and method of finite spheres [5] have been proposed by researchers. However these methods lack Kronecker delta property and possibility for exact imposition of boundary conditions. Other meshless methods such as NEM [6] that use natural neighbour coordinates [7] are useful for solid mechanics problems [8].

In this work nonlocal nonlinear bending and free vibration analysis of functionally graded plates has been made using a natural neighbour Galerkin method. The proposal natural neighbour Galerkin method, has many advantages and flexibility compared to other meshless methods. In this method, natural neighbour interpolants are used to construct both the trial and test functions. The natural neighbour interpolants are based on the Voronoi tessellation of the set of nodes N. These interpolants are smooth Ck everywhere, except at the nodes where they are C0. The nonlinear formulation is developed based on the third-order shear deformation theory (TSDT) of Reddy [1]. The von Kármán nonlinear strains are used and the governing equations of the TSDT are derived. The mechanical properties of functionally graded plate are assumed to vary continuously through the thickness and obey a power-law distribution of the volume fraction of the constituents. Numerical examples are presented to demonstrate the efficacy of the present numerical method in calculating defections, frequencies and stresses..
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14554 | Composite structure "Steel 1.2361 – Ti – TiO2" and its production by the contact welding with subsequent induction-heat treatment **(Functionally graded materials and structures)**

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The sphere of application of metal-ceramic materials, e.g. oxide ceramics, is expanding. Many techniques are used to produce functional coatings on cutting and pressing tools, medical and technical products (implants, metal components of endoprostheses). The structure and properties of ceramic coatings is studied using microscopic methods, hardness and wear testing.
Metal-oxide coatings (ZrO2, TiO2, Al2O3, etc.) formed on refractory metals (Ti, Zr) are used in the implant designs. In many studies, modification with nano- or submicrometric particles is used to increase the strength of porous ceramic materials.
Some corrosion resistant steels, e.g. 12Cr18Ni10Ti, 316L and AISI 1.2361, are widely used in many areas, including medicine and metal treatment. To improve the functional characteristics of these steels, especially wear resistance, different techniques are used for the formation of layered structures, films and coatings. Heat treatment, e.g. hardening with high frequency currents (HFC), is one of the ways to improve the mechanical properties. This technique enables the production of a metal oxide coating with high adhesion strength, hardness and biocompatibility, as it was previously shown for titanium.
The purpose of this work is to create effective wear-resistance elements and resource-saving technology for production of a controlled structure on their surface with high adhesion strength, hardness and wear resistance.
Experimental samples were made in the form of 0.5 mm thick titanium (Grade 2) and 3.5 mm thick tool steel (AISI 1.2361) plates. The layered structure "Steel 1.2361–Ti" with a total thickness of 4 mm was obtained by contact welding. The surface of samples was subjected to turning and fine grinding. Further, the it was modified due to the high-temperature effect of HFC at a temperature of 1000-1200 ºC and treatment time not more than 300 s. The HFC treatment consisted of three stages: intensive heating, exposure and cooling together with a ceramic compact chamber.
To analyze the surface morphology scanning electron microscopy was applied. Mechanical properties of metal oxide Ti/TiO2 coatings were evaluated by microindentation and scratch-testing using a mechanical properties tester.
As a result of heat treatment of titanium in the high-temperature range (1000-1200 ºC), a layer of rutile (TiO2) was formed on the surface. The production of the coating included an intensive growth of the crystals, spontaneous scale delamination (up to 50 μm thick) and formation of a submicrometric structure of a hard thin coating (about 0.5-1.5 μm thick).
The microhardness of steel-titanium assembly after the formation of a monolithic sample was characterized by higher values compared to the untreated materials (titanium, steel). This was due to the accelerated heating, local melting and rapid cooling. This thermal cycle was similar to quenching with low- or medium-temperature tempering. The average microhardness of steel reached 450-490 HV, whereas for titanium it increased from 150-180 HV to 300-320 HV. After the strengthening HFC heat treatment, the hardness of steel reached 950-1200 HV, and the titanium layer had a hardness of about 1000 HV.
Cutting tests showed that the resulting coatings of the composite structure "Steel 1.2361 – Ti – TiO2" can be used as tool coatings in the treatment of carbon steel (0.40–0.45 wt.% C) and chromium steel 40Cr13 (0.4 wt.% C, 13 wt.% Cr) with a hardness of 45–46 HRC.
The research was supported by the Ministry of Education and Science of the Russian Federation in the framework of the Program of Scientific Research in Universities (project No. 11.1943.2017/4.6).

14566 | experimental study of FGM of shell induced by thermal effects **(Functionally graded materials and structures)**

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Functionally graded materials represent new opportunities and challenges for many fields of industries from aerospace and automotive to biomedical, electronic and energy. In this paper a new experimental setup is presented to study the dynamic behaviour of a PET shell with a top mass under different harmonic axial loads, subjected to a thermal gradient used to induce linear graded properties in the inner and outer shell surfaces.
A deep experimental campaign has been carried out to identify the modal shapes of the shell under different thermal gradient and results are compared with numerical and mathematical models.
The experiment setup has been built had hoc to allow measurement in a climate chamber of radial displacement of the shell, a rotating periscope, controlled by a stepper motor, has been designed and built ad hoc and a modal characterization under different thermal gradient has been carried out.
The new setup is deeply described.
A linear and nonlinear behaviour has been investigated and results are shown.

14581 | Creep buckling analysis of the functionally graded beam **(Functionally graded materials and structures)**

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Paper presents the buckling analysis of the functionally graded (FG) beam exposed to the creep conditions. Columns under sustained loads are generally unstable in the regime of creep. That means that their stability loss may occur during some final period of exploitation even for loads lower than critical buckling load. In such a context, it is more reasonable, instead of defining the stability by critical buckling load to define it in terms of critical buckling time, the duration of loading at which buckling deflections tends to infinity. Problem is approached through two phases. In first phase a pre-buckling behavior is modeled through load deflection manner to reach appropriate instantaneous response of structure for applied load at zero time while in second phase a time integration scheme is used to reach critical buckling time. The finite element simulations are run out using 3D finite element commercial code. The

simulations were created by dividing the beam into several layers in order to approximate functionally graded material properties distribution. Gradation of material properties is achieved by assigning each layer of different properties. The finite element mash is created using solid finite elements. The creep material behaviour is modelled assuming the creep laws based on experimental data available in literature. The isothermal conditions are adopted for simplicity. The creep is considered under isothermal conditions. Several test examples are run in order to determine critical buckling times for various material parameter. The effects of material distribution on stability state of the beam is considered. The set of the creep buckling, deflection vs time, curves are displayed presenting the responses of different functionally graded material.

14702 | Blast resistance and optimal design of curved sandwich panels with graded metallic foam cores (Functionally graded materials and structures)

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Previous studies show that, the employ of radian or the core gradient can improve the blast resistance of sandwich panels with metallic foam cores. However, the synergy of gradient and radian is complex and lack of investigation. The synergy may improve or reduce the blast resistance of sandwich panels. In this study, finite element numerical simulation method was used to study the co-effect of gradient and radian on the dynamic response of sandwich panels under air blast loading. The numerical methods were validated using experimental data in the literature. Area specific energy absorption (ASEA) and the maximum back panel deformation (MaxD) were taken as performance index. Based on artificial neural network (ANN) metamodels, multi-objective optimization designs of the panel were carried out. The optimized combination of radians and gradients may take advantage of both to improve the blast resistance.

14806 | Finite element analysis of thin-walled functionally graded open section beams exposed to thermal loading (Functionally graded materials and structures)

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Paper presents finite element analysis of thin-walled functionally graded (FG) open section beam type structures exposed to thermal loading. The analysis is performed in a load-deflection manner based on the framework of corotational formulation. The beam model is based on Euler-Bernoulli-Navier theory for bending and Vlasov theory for torsion. Material properties are assumed to be graded through the wall thickness of beam. Various types of FG walls are considered and numerical results are obtained for various types of boundary conditions: simply-supported, clamped-free and clamped-clamped to investigate effects of the power-law index and skin-core-skin thickness ratios on structural behavior at thermal loading.

14380 | Performance evaluation of the smart composite fabrics consisted of carbon fibers and P(VDF-TrFE) ribbon sensors (Health Monitoring Techniques in Composite Structures)

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To investigate the structural integrity of various composite structures under their service conditions, real-time health monitoring techniques using many different type of sensors, such as strain gauges and FBG(Fiber Bragg Grating) optical sensors, have been developed. However, because the conventional sensors only can cover the small area of structures just by responding the local behavior and deformation of structures, many sensors need to be inserted into the composite structures to cover a large-area. As it can lead to deterioration of structural integrity due to load effects, a new method for constructing an efficient large-area monitoring system for composite structures is required. The aim of this study is to develop and evaluate the performance of smart composite fabrics (SCFs) consisted of carbon fibers and poly(vinylidene fluoride–trifluoroethylene) (P(VDF-TrFE)) ribbons as sensors. By replacing some of carbon tows with P(VDF-TrFE) ribbons which have piezoelectric characteristics, the sensor embedded dry fabric can be laminated in composite prepregs during the curing process. As a result, the composite structure can be a smart structure which is able to monitor the real-time status of structural integrity. First of all, a picture frame test was carried out to observe the macroscopic behavior of fabrics that could actually occur during the draping process using SCFs and to determine the limits of shear deformation. Subsequently, several monitoring tests were carried out by using a drop-weight impact machine to evaluate the sensing performance of SCFs and to acquire the impact-induced signal at the different points. Finally, signal analysis was conducted with FFT(Fast Fourier Transform) and WT(Wavelet transform) to correlate the voltage output from the sensors with the corresponding failure modes of composite specimens.

Acknowledgement
This research was supported by the Nano-Material Technology Development Program through the National Research Foundation of Korea funded by the Ministry of Science, ICT and Future Planning (NRF2016M3A7B4910532).

14482 | A fast and efficient approach for simulating ultrasonic waves and their interaction with defects in composite structures (Health Monitoring Techniques in Composite Structures)

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An approach for simulating transient wave propagation in composite waveguides faster than conventional explicit finite element method is presented. The waves in the structure are induced by external excitation and their interaction with structural inhomogeneities is also studied. The problem is formulated using the hybrid wave and finite element (WFE) technique, a method in which only a periodic section of the waveguide is modelled using finite elements. The mass and stiffness matrices of the section are used to set-up the dynamic stiffness matrix from which the propagating modes are extracted. The

section where external excitation is applied is completely modelled using finite elements. A wave solution is imposed on the equation of motion of this section and only the propagating modes are retained for describing the solution. The calculation is carried out in the frequency domain. The external force is also a function of time and it is transformed into frequency domain using Fourier transformation. This is incorporated into the equation of motion of the excitation section which is solved for outgoing amplitudes at a number of different frequencies. The results are then transformed back into the time domain and compared with a conventional finite element solution showing good agreement. A coupling element is modelled by finite elements to simulate the interaction of waves with defects in the structure. The waves impinging on this element are partly transmitted and partly reflected. The amplitude of the reflected wave is calculated and transformed back into time domain. The presented approach is found to accurately simulate the excitation response of periodic waveguides much faster than the conventional explicit finite element method. The work has been done as part of the SAFE-FLY Horizon 2020 project which aims at developing a comprehensive technique for early stage damage detection in aerospace composite structures using ultrasonic guided waves.

14492 | Finite element model updating of uncertain parameters of carbon/epoxy composite plates from experimental modal data (Health Monitoring Techniques in Composite Structures)

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Composite laminates are extensively used in advanced structural engineering, particularly in weight sensitive applications. On the other hand, as these materials have shown a certain susceptibility to impact damage, the topic of efficient techniques to detect damage at an early stage has become an issue of great concern. Among many different methods, the evaluation of changes in modal parameters of the structure, e.g., natural frequencies and mode shapes, between the undamaged and damage states, is used as a good indicator to detect, localize and quantify the damage.
Although a priori Finite Element modelling (FEM), based on theoretical properties of the materials, provides useful information, such a model cannot predict the modal parameters with a high level of accuracy, due to large uncertainties associated with composite material properties. In the present work, the development of a reference numerical model, updated through modal parameters experimentally obtained, that establishes the baseline (initial intact situation) of the dynamic behaviour of a set of carbon/epoxy composite plates is presented.
The methodology starts with the construction of the theoretical FEM of the plates built in ANSYS by using solid elements. Then, a model updating using experimental modal parameters is performed. Such a procedure can be regarded as an optimisation problem, in which the objective function consists of the (weighted) sum of differences between the experimental modal data and the corresponding analytical predictions.
To obtain the modal characteristics of the plates, a modal testing was performed under free boundary conditions (by suspending the plates, alternatively, horizontally and vertically), using a roving hammer exciting the plates at 120 degrees of freedom (DoFs) evenly distributed in both directions, and a mono-axial accelerometer attached to a single DoF reference point. The vibration data are treated by Modal Analysis of Civil Engineering Constructions (MACEC) program, developed by the Structural Mechanics Division of KU Leuven. Twenty-two modes are identified with relatively high values of the Modal Assurance Criteria (MAC) comparing modes shape with those numerically obtained from the theoretical finite element model.
However, considerable discrepancies between the numerically calculated and the corresponding experimentally measured modal characteristics of the plates have been identified. These discrepancies can be considered as mainly due to uncertainties on the theoretical values of physical parameter of the model. Thus, the updating parameters are the global characteristics of the plate for which a certain uncertainty exists (thickness, density and elastic characteristics).
Before developing the updating, a sensitivity analysis that identifies the properties of the material that have the most influence on the modal parameters is performed. Three parameters, thickness, density and elastic modulus in the direction of the fibres, are identified to be influential, and then changed until the objective function is minimised.
Several variants of objective functions are minimised and the results are compared. Best results are obtained by using a function consisting on the sum of differences between the experimental eigenfrequencies and the corresponding analytical predictions, weighted with MAC values.
Two ANSYS gradient-based algorithms are used to solve the optimisation problem: the subproblem approximation method and the first order method.
As a result of the whole process, a physically more correct model is obtained on which discrepancies with the corresponding experimentally measured modal parameters are drastically reduced. This reference model will be applied in future works for the detection and localisation of damage induced in the plates by multi-impact, using vibration-based techniques.

14526 | Simultaneous health monitoring of stiffeners in composite structures through wave scattering analysis: a numerical assessment (Health Monitoring Techniques in Composite Structures)

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Commercial aerospace vehicles have been increasingly designed with composites to meet the high performances requested. However their material properties are accommodated to compensate the effect of unforeseen, sudden and barely visible failures when subjected to low velocity impacts. Structural Health Monitoring is expected to avoid such typical accommodations employed during design and lifetime management, inducing a cost-effective maintenance.
In this context the present paper deals with the simultaneous detection, localization and size assessment of stringers disbondings with monitoring techniques by permanently attached piezoelectric transducers (PZT) capable to excite and sense guided ultrasonic waves. A previous approach efficiently validated on a composite stiffened plate typically designed for wingbox structures is here investigated to simultaneously detect several stringers by changing the operative conditions. The detection technique is capable to predict arrival time of guided waves scattered from stringers detecting, as a consequence, any possible change in a specific scattering area. This area can be furthermore changed depending on typical working parameters.
First, it is shown that processing Lamb wave reflections signals is possible to improve the localization accuracy respect to a general purpose reconstruction algorithm while making use of fewer number of sensors possible. Furthermore, the multimode and multi-frequency working mode allow to efficiently monitor different area with the same cluster of sensors, making use of fewer number of sensors possible.

14528 | A technique for composite materials moisture level detection devoted to health monitoring in Aeronautics (Health Monitoring Techniques in Composite Structures)

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The current trend in aeronautics shows an extended use of composite materials for the design of primary airframe structures. The latest certified large transport and regional aircraft consist of many composite parts: 50% and 53% by weight for the Boeing B787 and Airbus A350 respectively, 26% for the Bombardier CS100. The use of higher allowables (strengths) than the standard practice in the design phase is allowed by the continuous identification (during the operational life of the A/C) of the damage (smaller than typical Barely Visible Impact Damage - BVID) occurring into the composite structure and continuous measuring of the moisture absorption level by means of a dedicated sensor-network. The current designing practice of composite A/C imposes the use of knock-down mechanical allowables to take into account the high sensitivity to environmental exposure (i.e. damages, moisture and temperature) of composite structures. The effect of considering a structure damaged at BVID level with a moisture content reduces drastically the advantage of using such materials that have specific strengths up to 4 times to the quenched and tempered carbon steel. On the other hand, the knowledge of the moisture absorption level of the structure during A/C operations could enable the use of higher design allowables. The aim of this study is to identify a suitable sensor able to measure the moisture quantity absorbed by the structure during the A/C operational life, to be used as a health monitoring evaluation device. The new sensor is based on the idea that a composite laminate can be associated to an equivalent electric circuit (EEC). Some measurable electrical characteristics of this EEC correspond to mechanical characteristics, such as the moisture content of the laminate.
A simple EEC model of the laminate, mainly capacitive, was proposed, with the target to emphasize the laminate electric behaviour with respect to its internal moisture level variation. To detect the laminate electric behavior, some sensing elements (SE) were chosen in accordance with that model. Laminates of 24 plies of Cytec 977-2 reinforced with IMS fiber were used as specimens. The specimens were treated according to moisture absorption procedure ASTM D5229.
An experimental technique, using the chosen SE (namely electrodes) glued onto the specimens, was developed, in order to measure the laminate EEC parameters.
A frequency sweep in the range 20Hz-200kHz was used as an electric stimulus for the electrodes to measure the EEC parameters and the parameters variation was investigated, with respect to an induced moisture content variation.
Then, just a few parameters were selected (related to a substantially capacitive behaviour of the laminate), that had a direct and comfortable variation law with respect to moisture content variation, in terms of ease of measurement (low cost), sensitivity, monotonicity.
The selected parameters variation had a good accordance with the proposed EEC theoretical model of the laminate, showing an increasing dielectric constant with respect of an increasing moisture concentration into the laminate.
The experimental set-up had a good response sensitivity in the stimulus frequency range of typical COTS capacitive meters (1kHz).
Measurement results will be presented.

14576 | A Robust Health Monitoring Framework for Rapid Inspection of a Honeycomb Sandwich Composite Panel with Stiff Core-inserts **(Health Monitoring Techniques in Composite Structures)**

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An ultrasonic guided wave propagation based robust online health monitoring framework is proposed for the rapid inspection of honeycomb sandwich composite panels (HSCPs) in presence of core-inserts of variable elastic material properties. Towards this, an advanced signal difference (SD) algorithm is applied that directly uses the experimental as well as pseudo-experimental sensor signals to image the unknown stiff core-insert locations in the structure. A coordinated theoretical, numerical, and experimental study of Lamb wave propagation in the HSCP have been carried out. It is found that the presence of stiff core-insert regions significantly reduces the amplitude of the fundamental anti-symmetric wave mode. Based on the changes in the modal amplitude, the framework generates SD-coefficients to represent the presence of stiff core-inserts in the HSCP. The proposed framework is applied to identify multiple closely-spaced core-inserts. Finally, in order to verify the robustness of the proposed framework, the influence of elastic modulus and mass density of the core-inserts on the SD-coefficient is analyzed. It is found that the coefficients increase with the increase in elastic modulus and mass density.

Keywords: honeycomb sandwich composite panel; core-inserts; guided wave; piezoelectric wafer transducer; dispersion curve; group-velocity.

14619 | DESIGN AND MANUFACTURING OF ELECTRICALLY CONDUCTIVE COMPOSITES VIA MICROVASCULAR CHANNELS **(Health Monitoring Techniques in Composite Structures)**

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Among numerous types of health-monitoring and damage-sensing sensors that can be integrated into composites, electrically conducting sensors offer a simple, cost-effective, and durable option for structural health monitoring in fiber reinforced composites. The remarkable electrical and mechanical properties of carbon nanotubes (CNTs) render CNT-reinforced nanocomposites as potentially attractive materials for strain-sensing and monitoring purposes. The electrical and mechanical properties CNT nanocomposites are primarily affected by the filler dispersion pattern inside the reinforcing fibers. Any non-uniformity caused by filtration of fillers in dense preform results in a large scatter of the electrical conductivity.
In this study, a novel approach is introduced to create electrical conductive networks in glass fiber reinforced composites. For this purpose, hollow micro-channels were made using vaporization of sacrificial components, here polylactide (PLA). The hollow channels were then filled with CNT-epoxy conductive filler.
Specimens of UD glass fiber reinforced composite laminates were fabricated containing a modified PLA filament (0.8 mm diameter) along the laminate mid-plane. Following the cure, samples were put in a vacuum oven at 200 ºC for 24 hours to vaporize the sacrificial component (PLA filament). A syringe pump was used to inject the CNT/epoxy suspension as an electrically conductive medium into the vascular channel.
The electrical resistance of the samples along their length was measured using two-point-probe technique. The average electrical resistance measured along the channel (diameter 0.8 mm, length 150 mm) for three samples was 18±2 MΩ.
Mechanical characterization of composite laminates with and without a vascular channel showed that tensile strength and elastic moduli of the composite are not affected by making a 0.8 mm vascular channel on its symmetry plane.
The use of such conductive pathways for in situ strain monitoring of a composite specimen was also investigated. For this purpose, the electrical resistance of each sample through their vascular channel was measured during the tensile test. It was found that the strain sensitivity of the prepared conductive channels is nearly two times of conventional strain sensors.

14912 | A methodology based on numerical and experimental analyses: A contribution for SHM systems (Health Monitoring Techniques in Composite Structures)

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Advanced aerospace composite materials are increasingly being used in critical and demanding applications, challenging not only the damage prediction, detection, location and quantification, but also structural residual strength and life estimation. The development of theoretical and experimental studies on residual strength for composite structures, which are damaged by impact loading, aided by a SHM system, which combines different methods, is a strategic approach for overcoming those challenges. For this, it is necessary: to identify, and to localize damage, as well as to calculate the severity of the damage and to predict the residual strength of the composite structure. To achieve these goals, the proposed methodology considers three main steps: (1) Vibration Based Method (VBM); (2) Shearography Speckle (SS) and (3) Flexural After Impact (FAI). In the first step, computational and experimental analyses provide Frequency Response Functions to be analyzed by suitable damage metrics, which are compared in terms of their capability for damage identification and global location. In the second step, the extension of impact damage is determined by using shearography speckle, which is compared to numerical predictions by using damage models. In the third step, flexure after impact (FAI) analysis is used to evaluate its limitations and potentialities as a damage tolerance technique. Thus, the residual flexural strength of damaged specimens is estimated by quasi-static four-point bending simulations and tests. And, a new criterion based on a relationship between damage metric from VBM (Vibration Based Method) and FAI analyses is presented and discussed. Finally, it is discussed the advantages and limitations of the proposed methodology into the context of SHM system (Structural Health Monitoring System).

13816 | Experimental and numerical study of the behavior of hybrid unidirectional/woven composite laminates under impact loading. (Impact Problems)

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In the field of aeronautics, structures are largely made using composite materials, which leads to great weight improvements. A large number of parts are made of thin woven composite laminates. A solution for the improvement of that kind of structures would be to combine, within the same laminate, woven plies and unidirectional plies.
Impacts on composites structures are one of the most damaging load case. Indeed, as composite materials are brittle, impact loadings can lead to numerous degradations (matrix cracks, fiber failures, delamination)[1].
This study focuses on low velocity and medium velocity impact response of hybrid unidirectional/woven composite laminates. It relies on existing studies concerning impacts on woven composite laminates [2]. An experimental study is performed in order to identify the damage mechanisms within hybrid composite laminates during impact. Thus, drop weight and gas-gun impact tests are performed. The tests results are used for the development of a new and specific finite element model. It is based on the semi-continuous modelling strategy set up at the Institut Clément Ader [3-6]. With this strategy, the representation of matrix cracked and the modelling of fiber breakage is separated. This modelling provides results that correlate experimental observations.

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13817 | Study of post-impact damage propagation in thin woven composite laminates (Impact Problems)

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This presentation will focus on the experimental and numerical study of the propagation of post-impact damages within the skin of helicopter blades made with two or three plies of woven composite.
During flight, helicopter blades can be impacted by numerous objects like birds, hailstones, metallic parts from the helicopter, etc… Impact loading is one of the most critical loading for composite structures. The failure scenario of composite laminates is complex, and depends on many parameters like the stacking sequence, the material parameters, the loading or the dimensions of the structure. The damage chronology can be summarized in three steps described in [1] : matrix cracking, delamination and failure of the fibers.
Concerning impact damage modelling for woven composite laminates, a semi-continuous finite element modelling has been developed [2,3,4,5]. It relies

on the separation of the role of the bundles of fibers (represented with rod elements) and of the resin (represented by damageable shell elements). The results provided by this modeling have been validated by comparing with several low and medium velocity impact tests. They are accurate enough to represent the damage scenario.

This presentation concerns the study of the propagation of impact-induced damages during flight. Tensile tests on pre-impacted woven composite laminates have been performed to identify the mechanisms involved in the damage growth. The semi-continuous strategy for the modelling of woven composite laminates has been adapted to represent the propagation observed experimentally. First results are provided.

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14365 | An analytical scaling approach for low-velocity impact on composite structures (Impact Problems)

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For the analysis of low-velocity impact, we provide an analytical scaling approach that permits to analyze structural impact scenario. Thus, numerical damage predictions through high-fidelity methods can be transferred from the coupon to the structural level. For that purpose, we developed an analytical spring-mass model to describe the damage state of a laminate. This model uses an additional spring to capture the laminate's additional compliance by the arising damage. The resulting stiffness value of this spring as a function of the impact energy describes the damage state.
To set up the spring-mass model, the determination of the elastic response and the real impact response are required. This process is commonly performed on a simple reference coupon. An elastic model with finite shell elements is the basis for the determination of the elastic parameters. A high-fidelity simulation or an experiment provides the respective impact response. This reference coupon response is the origin of the impact scaling which can then be applied to an arbitrary structure with the same material and laminate.
On this target structure, the elastic properties have to be determined analogously to the origin. The spring-mass model recombines these elastic properties with the damage behavior of the reference coupon. The reverse evaluation of this spring-mass model enables the scaling of an impact scenario towards the target. Firstly, the impact energy for similar damage can be calculated. The continuous evaluation of this damage similarity provides a curve of equivalent impact energies between the reference coupon and the target structure. Secondly, it is possible to determine the damage state for a given impact energy on the structure. In both cases, a single reference coupon can be valid for large areas of a structure with similar laminates and materials. This validity permits a real prediction of impact damage on the structural level.
The validation of the developed methodology was conducted through experiments in two steps: The spring-mass model is tested for its capability to describe the damage state of a composite laminate. A series of coupon tests confirmed that it suits this need comparable to the projected delamination area. Secondly, the impact scaling itself was validated with experiments on the coupon and the sub-structural level. The respective results confirm that the damage prediction is of high quality.
Beyond the validation, the application to a generic aircraft door structure demonstrates the capabilities of the scaling method in a design process. The analysis effort of impact damage on such a structure gets reduced significantly. Additionally, the areal impact analysis enables to work with the real worst instead of the maximum-sized barely visible impact damage. Accordingly, the damage tolerance assessment can be conducted in a less conservative manner for reducing structural weight.

14420 | Ballistic performance and energy absorption characteristics of lightweight aramid structures (Impact Problems)

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Lightweight structures have an enormous interest in numerous fields such as energy, transport and military industries. The choice of an efficient material and the design of the structure is essential, being currently the main research topic of many groups.
The most commonly used evaluation for the analysis of lightweight structures is the energy absorption capacity under dynamic loads.
Analysis of the energy absorption capacity can be carried out by means of low velocity impacts (when the impact causes penetration) or medium and high velocity impacts (where perforation occurs at the target).
For threats involving low energy penetration such as impacts with small arms or fragments, it is common to use aramid fabrics for body armour or aramid fabrics reinforced with resins for lightweight armour (Doig 1998). Typically, armour systems in military applications under hostile conditions are made of a first protection with high strength steel and of a secondary protection that can also be installed next the exterior armour to protect against high-speed impact. This second armour is known as spall-liners. Spall-liners are normally made of synthetic fibres such as aramid and ultra-high molecular weight polyethylene (UHMWPE).
Experimental impact tests, to cover a wide range of impact energies (20 to 220 J) on thin aramid plates, have been carried out in this work using a weight drop tower and a gas cannon. Assays were performed in the laboratory of the Department of Continuum Mechanics and Structural Analysis of University Carlos III of Madrid. For perforation tests, two projectiles with different geometries were used (spheres and FSP), considered by STANAG 2920 as fragment-simulating projectiles.
ACKNOWLEDGMENTS
The authors acknowledge the Ministry of Economy and Competitiveness of Spain and FEDER program under the Project RTC-2015-3887-8 and the Project DPI2017-88166-R for the financial support for this work.
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14437 | Analysis and simulation of the transient-coupling during soft impact loadings on laminated glass elements (Impact Problems)

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Nowadays a large variety of glass products are increasingly being used in architecture and construction which implies that glass-related standards must be updated and extended to new applications. The study of the response of glass elements subjected to dynamics loadings is of great interest due to the brittle nature of the glass which may cause human injury as a result of glass breakage.
The pendulum test proposed in the European standard EN 12600:2003 can be used to evaluate the dynamic behavior of glass elements subjected to soft impact loadings. Many experimental programs have been conducted following this standard with the objective of studying the mechanical behavior of glass as well as for calibration of numerical models where balance energy methods are usually utilized to obtain the initial impact velocity depending on the height used in the pendulum. However, the dynamic coupling between the impactor and the glass elements must be taken into account for a more realistic simulation.
In this work, the dynamic behavior of a laminated glass beam subjected to different impact conditions is studied. The influence of the hardness and the mass of the impactor head is analysed using the experimental responses recorded with accelerometers during the pendulum tests. The effect of the coupling between the specimen and the impactor is also studied. Finally, a simplified technique to estimate the dynamic response of laminated glass beams combining Operational Modal Analysis and the force of the impactor is proposed in order to improve the predictions obtained with the numerical simulations.

14439 | Dynamic response calibration and validation of lightweight structures of UHMWPE against impact loads (Impact Problems)

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One of the main problems in military engineering is minimizing possible security risks suffered by bodyguards and civil population, thus the improvement of personal protections is a topic that has received considerable attention by researchers in the last few years. The development of numerical models to predict the material behavior, used as armor gears, such as aramids or UHMWPE, has become in one of major focus of interest. A method commonly used for personal protection design is the analysis of its energy absorption capacity.

Military protections, also called “armor-grades”, must be optimized (typology, density, types of fibers, stacking sequence …) to maximize the ballistic limit and to minimize the weight.

The main goal of this study has been the development of a FEM model to predict the impact behavior of UHMWPE personal protections considering different projectiles. The model was calibrated with experimental results of impact tests with FSP (Fragment-Simulation Projectile) [1,2]. Then, the predictive capacity of the model was validated through comparison with experimental tests conducted with FMJ (Full Metal Jacket) projectiles [3,4].

ACKNOWLEDGMENTS

The authors acknowledge the Regional Government of Madrid under the project IND2017/IND-7762, and the Ministry of Economy and Competitiveness of Spain and FEDER program under the Project RTC-2015-3887-8 and the Project DPI2017-88166-R for the financial support for this work.

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14464 | Identification and modeling of Barely Visible Impact Damage (Impact Problems)

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Barely visible impact damages (BVID) are generated by the low velocity impact. Inside the composite material, in the area of impact, a net of delamination and transverse cracks of the layers occur. However, a large areas of fiber failure are not appear. On the impacted surface a small impact mark appear but on the opposite surface the damage area is considerably more extensive. Low velocity impact can be induced by falling tools and equipment during repair or maintenance work, bird strikes, foreign objects thrown from the airplane wheels during take-off or landing, hailstones from under the airplane tires or by raining hail, collisions with other aircraft and ground vehicles on the taxiway or during loading. The object of the analysis are composite profiles made of eight-layer GFRP laminate. The purpose of this work is to analyze the behavior of a composite profile taking into account barely visible impact damage generated by low velocity impact and the damage onset and evolution induced during uniform compression test. The numerical calculations were conducted with the implementation of the progressive failure algorithm, based on the material property degradation method and implementation of the Hashn's criterion as the damage initiation criterion. In all analyzed cases high consistency of numerical and experimental results was achieved and the

failure mechanism included the initiation of the fiber failure in the corner of the columns and its propagation in the direction of the web and the flange of the columns. The occurrence of delamination, and their evolution was modeled in accordance with a bilinear traction-separation law. The obtained results were compared with the results of the experiment.

14530 | IMPACT AND POST-IMPACT ANALYSIS OF REPAIRED COMPOSITE PLATES (Impact Problems)

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Composites structures are finding increasing use in the aeronautical transport sector as a result of their excellent mechanical and specific properties. The use of these structures leads to measurable reduction of the structural weight as well as lower fuel consumption; such operational adjustments increase the efficiency of aircrafts, and reduce pollution emissions.
In order to alleviate the adverse impact to the environment due to air transport operations, the EU has shown great interest in increasing the efficiency and safety of aircrafts. This interest covers the full life-cycle of an aircraft structure (design, production, maintenance, repair, and updating).
Structural elements of aircrafts are susceptible to damage during their service life. Complete replacement of damaged components is not always feasible, due to the high level of integration and the big size of the structural components. Therefore, repair and subsequent put into operation of composite structures, can be cost-effective and less time-consuming. Repair techniques for composite components are related to the objective mentioned above.
Currently, the only certified repairs in air transport sector are bolted repairs. However, bonded repairs can restore greater strength to a damaged composite structure and show some advantages as compared to bolted repairs, such as lower density, improved fatigue behaviour, reduced costs, and excellent formability that allow the manufacturing of patches with complex contours. In addition, external bonded patches are suitable for thin composite laminates. Consequently, the need to gain knowledge about their behaviour under service loading is readily apparent.
The main objective of this work is the analysis of the impact response of adhesively bonded repaired composite structures, and the evaluation of their damage tolerance to low-velocity impact.
Experimental tests will be carried out to characterise the damage and properties of a unrepaired and repaired structure, checking out their main differences. The tests involve pre-damaging both type of structures (by using a drop-weight tower), and then measuring the residual strength by means of a compression test.
The three-dimensional nature of the problem and the material nonlinearities will lead to the use of the finite element method to perform a general analysis, in which the influence of the main parameters of an adhesive bonded repair will be evaluated.
In addition, the influence of the impact energy level on the damage tolerance will be analysed, in terms of characteristics of the impactor and localisation of the impact. For all cases, the behaviour of intact panels will be compared with the behaviour repaired panels.

14608 | NUMERICAL MODELLING AND OPTIMIZATION FOR IMPACT TESTS OF COMPOSITE LAMINATES (Impact Problems)

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One of the most important issues of the use of composite materials, especially in the aerospace field, is to overcome the criticality of their high sensitivity to low energy impact damages. Many uncertainties characterise their behaviour under impact damages, and this forces the current aircraft manufacturers, on behalf of the certification authorities, to oversize the design of the composite structures, in order to avoid long times and high costs necessary to fully understand and predict the actual residual strength of damaged parts. Besides, the behaviour of the structural material is dependent also on the selected material system, the manufacturing process, the layups, etc., and consequently it is mandatory to develop a reliable numerical procedure, able to reduce the current long test campaigns for impact damage characterisation of the composite materials.
The numerical modelling of ASTM tests, according to standard regulations, feed by only a limited number of experimental tests at coupon level, if validated, could allow to predict numerically the tests results. This could reduce consequently costs and times for the execution of the impact tests at coupon level and/or the use of conservative knock-down factors that are commonly used for the BVID (Barely Visible Impact Damage) definition.
In the present work, a methodology that allows simulating an impact test on ASTM D 7136/D 7136M specimens in composite material, of which experimental results are available from tests provided by CIRA, is reported. In particular, the main goal was the generation of FE models that return results, well correlated with the experimental ones, when the layup, thickness and impact energy vary, through:
• the comparison between the numerical and experimental data (i.e. contact force, kinetic energies levels, velocity and impactor translation) in order to validate the FE model;
• the optimisation of the impact numerical model through the comparison of numerical and experimental data, by appropriately setting the MSC NASTRAN SOL 700 solver parameters values (i.e. type of contact, type of elements, etc.);
• comparison of the numerical damage areas with those experimental.
Finally, a trend analysis in order to relate the results of different layups (i.e. number of plies, layups, and thicknesses) at the different energies levels is reported.

14674 | The effect cryogenic temperature has on the high velocity impact response of CFRP laminates: X-ray tomography investigation (Impact Problems)

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Fibre reinforced composites are, at present, one of the most common materials in aerospace and aeronautic industries. Its excellent stiffness/weight and strength/weight ratios make this type of materials one of the best choices to safe weight in structural parts. However, one of the main drawbacks is their

brittleness, which can be accentuated when the structural part is subjected to cryogenic temperatures (as it may occur in satellites orbiting around the Earth). This effect is even more dangerous in case of impact loads, that could promote damages such us: matrix cracking, delamination and fibre breakage reducing significantly the load bearing capacity of the laminate.

In order to study the effect of the temperature under high velocity impact on carbon/epoxy tape laminates, the first step is to perform experimental tests in a wide range of impact velocity (50-450 m/s) and with two different impact angles 0 º and 45º at different temperatures. To perform the impact, a pneumatic launcher which impel a tempered steel sphere of 7.5 mm was employed. In order to control de temperature a climatic chamber fed by liquid nitrogen was used; 3 different temperature ranges were considered: ambient (around 22 ºC), low (-50ºC) and cryogenic temperatures (-150ºC). The composite laminates used in this study were manufactured using AS4 fibres and the epoxy matrix corresponds to the 8552 series, the laminate were composed by 12 plies in a quasi-isotropic configuration (+45/–45/0/90/90/0)s.

The tested specimens were subjected to non-destructive techniques: ultrasonic C-scan measured the damage extension and location, whereas X-ray computed tomography detailed both intra and inter-laminar failures in 3D.

14323 | Fatigue behavior of metal/composites single lap joints at elevated temperatures (Joints)

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The use of composites to repair localized corrosion damage in metallic pipelines has significantly increased in the past years. Repair techniques using polymer-based composites are interesting, since they do not require draining the line and stop operation. However, pipelines conveying liquids may work at elevated temperatures, what can be a limitation for the use of polymeric materials. This work presents the experimental investigations of the fatigue behavior metal/composite bonded single-lap joints used as offshore pipeline composite repair system. Fatigue tests were conducted under tension dominated loading at 50ºC. The adhesion between pipe and composite is the key to the effectiveness of the repair (sleeves or patches), mainly in the case of through-thickness defects. Single-lap joints (SLJ) were fabricated with metal and composite adherends bonded with an epoxy resin reinforced with Aramid fibres. The surface treatment adopted in this study was the same used in the fi eld for repairs. A fatigue criterion for the joint behavior is proposed. It is verified experimentally that, at 50ºC, in load-unload tests with prescribed strain rates and constant maximum load, higher frequencies leads to higher fatigue resistance.

14442 | A microscale finite element model for cold pressure welding in layered metal composites (Joints)

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Multi-layered metal composites produced by cold roll bonding processes have many applications in aerospace, automotive and building industries. In these types of composites, a metallurgical bonding is formed between the metallic layers due to the large plastic deformation. Joining by plastic deformation is recognized as a solid-state welding process, in which two or more metallic layers are joined together by means of a relatively high pressure at a temperature below the melting point. At the microscale level, the process of cold welding for metals can be described using a widely accepted hypothesis known as the film theory. This hypothesis provides an explanation for the mechanism of joining by plastic deformation in metals. In this paper, a microscale finite element model is developed to simulate the bond formation process between metallic layers subjected to large plastic deformation. The presented model accounts for the most important physical micro-mechanisms taking place during the cold welding processes. These microscale mechanisms are (1) the breakage of the brittle oxide layer above the metallic surfaces, (2) the decohesion process occurring between the oxide layer and the metal substrate, (3) the extrusion of the substrate into the created cracks under large plastic deformations, and (4) the bond formation in between the fractured oxide layers. To accomplish this, an interface model is employed which describes both the bond formation and the delamination processes. Finally, it is shown that the model can be used to provide a qualitative description regarding the bond strength evolution. In this framework, the effects of influencing factors, such as the degree of plastic deformation and the thickness of the oxide layer, are numerically investigated.

14596 | Hygrothermal effects on bolted joint strength of NCF composite laminates (Joints)

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Bolted joints are widely used to fasten and/or repair composite structural parts in several industrial applications under various environmental conditions. Hygrothermal effects are a particular class of these environmental conditions and have detrimental consequences on the mechanical properties of composite laminates generally due to the sensitivity of the polymer matrix materials to moisture absorption and elevated temperature levels during operational service life. In this study, hygrothermal effects on the strength and failure mechanisms of bolted joints in non-crimp fabric (NCF) reinforced composite laminates which are used in marine, aerospace, defence and wind turbine industries were investigated. Firstly, a quasi-unidirectional (UD) NCF/epoxy material system was manufactured with vacuum assisted resin transfer moulding method and the through-the-thickness moisture absorption characteristics of the material system were determined according to the ASTM-D5229 standard by using square plates. Then, various cross-ply and quasi-isotropic bolted joint specimens (with constant geometric ratios of e/d=3 and w/d=6) were conditioned by using the data obtained from the moisture absorption tests. Double-lap bolted joint strength of the specimens was determined by using ASTM-D5961 standard. Load-displacement curves, strength values and damage modes were recorded. The results of each layup were compared with the unconditioned counterparts in order to provide relevant knock-down factors for design purposes.

13838 | An improved method of numerical calculation based on unstructured grid for RTM (Advanced Numerical Techniques)

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the authors have a lot researches about numerical simulation of resin transfer molding for resin-based composite materials based on CV/FEM. The energy equation is simplified in discrete process; especially cross-diffusion term is generally ignored. It is correct when the grid is orthogonal, or not. While the mesh distortion is more large, the deviations are bigger. Therefore, this paper conducted a study on the proposed cross-diffusion calculation methods, and validated through case reasonableness and accuracy of the calculation method.

13894 | Three-Dimensional Elasticity Solutions for Functionally Graded Plates by Semi Analytical Approach (Advanced Numerical Techniques)

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Three dimensional (3-D) elasticity solution is presented for a simply supported square functionally graded (FG) material plate using mixed semi analytical approach. The Young's modulus of the plate is assumed to vary exponentially through the thickness, and the Poisson ratio is held constant. The governing equations of a two point boundary value problem (BVP) are written as a set of coupled first order partial differential equations (PDEs) in the thickness direction by algebraically manipulating the equations of 3-D elasticity. These equations are further transformed to ordinary differential equations (ODEs) by using Navier solution technique. The solution is then obtained using a numerical integration technique. Computational model is developed to evaluate displacements and stresses along the thickness of plate.

Results obtained by the present approach are shown to compare very well with other 3-D elasticity solutions available in the literature. The proposed semi-analytical model is very simple, efficient and highly accurate. Further, both displacements and stresses are evaluated simultaneously with the same degree of accuracy, unlike other methods available in the literature.

Key Words:Functionally Graded Material, Three Dimensional Elasticity Solutions, Semi Analytical Approach

14317 | Development DKMT18 shell element in composite structures (Advanced Numerical Techniques)

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Triangular element called DKMT (Discrete Kirchhoff-Mindlin Triangular) element was developed by Katili in 1993. It can take into account the transverse shear strain and it gives a good result in isotropic analysis for thin to thick plate problems without shear locking. The development of DKMT element for composite plate structures has been proposed by Maknun et al. in 2015. It gives the results converge to the reference solution.
Sustainable future will be achieved by using composite as the main materials in engineering constructions. For this reason, it is required a computational method to support the analysis of composite structures. This paper "Development DKMT18 shell element in composite structures" will introduce a new computational method in composite shell structures. The proposed papers will focus on the development of DKMT18 element for composite shell structures. The results proposed by Srinivas, Varadan and Bhaskar and Ren will be used as a standard test to validate the proposed elements.

14368 | PECULIAR CONVERGENCE AND ACCURACY FOR LAMINATED MODERATELY THICK PLATES OF ARBITRARY SHAPE IN FREE VIBRATIONS (Advanced Numerical Techniques)

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As it is well known, engineering theories for plates and shells simplify the three-dimensional (3D) elasticity problem by introducing kinematic hypothesis which lead to simpler mathematical problems. Therefore, such simplified theories have limitations, which are strictly related to the initial hypotheses. The present work is based on the so-called Reissner-Mindlin theory or First-order Shear Deformation, which is used to study "moderately thick" plates. The term "moderately thick" refers to the fact that the plate is not "thin" as in the Classical Laminated Plate Theory (CLPT) or Kirchhoff-Love Theory and not "thick" as in the classical 3D theory of elasticity. Once the physical problem is mathematically well-posed, it is generally solved via numerical methods due to the complexity of finding analytical or semi-analytical solutions. The present work aims to show a peculiar behavior in the solution of such problems by comparing the results obtained using strong and weak form finite element methods when the plates are in free vibrations. In particular, the authors compare the results obtained with two- and three-dimensional theories as a function of the plate thickness.

14385 | Stochastic homogenization in the framework of domain decomposition to evaluate effective elastic properties of random composite materials (Advanced Numerical Techniques)

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Random fibre composites are difficult to model and study. The complexity of their strongly entangled network of fibres leads to technical drawbacks related to the mesh generation. In addition, their study requires the generation of large and numerous RVE during the numerical evaluation of the effective properties. Domain decomposition methods are efficient tools to decrease the calculation time which is important (give a value for example gain of 50% or 30%) in this context. Two adaptations of the homogenization method are proposed: a modified Schur complement method, and a combination of the FETI-1 method, and the method of Schur complement. We present both concepts and provide some relevant results demonstrating their ability in the context of random fiber composites. First, a 2D square RVEs with the help of random parameters describing the morphology of the network of fibres is generated. A meshing process, according to voxelisation approach of RVEs is made: the model with an n-order approximate geometry. Then a finite element study is realized in order to estimate elastic properties with the help of the double-scale homogenization. In order to use the double-scale homogenization method we had to make two main adaptations. First, when generating the RVEswe take care of the continuity of fibers between each sub-domains, secondwe have to eliminate redundant information over the edges. The calculation is performed according to one of two proposed domain decomposition methods. We focus our investigation on the random fibre composites in the elasticity field. First, we present the minimization problem associated to the double-scale

homogenization and describe both modified domain decomposition methods. Second, we provide some numerical results in effective properties.

14450 | Fracture Evaluation by means of Mesoscale Model for CFRP Hydrogen Tank (Advanced Numerical Techniques)

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Introduction
A difficulty of strength evaluation of carbon fiber reinforced plastic (CFRP) is raised from complicated micro structure constituted by resin and carbon fiber. Local stress and strain concentration caused by the micro structure has hindered accurate estimation of the fracture, which is severely required for light weight high pressure hydrogen tank made by filament winding (FW) method for fuel cell vehicle (FCV). We have developed the prediction methodology of burst pressure of CFRP tank in the framework of mesoscale modeling, in which fiber bundle and resin are handled separately [1]. We confirm the validity of proposed methodology through mesoscale finite element analysis compared with bi-axial tensile test of cruciform specimens.

Experiment
The specimens are made by five fiber bundles put in horizontal direction and five fiber bundles in vertical direction via helical FW process to realize similar situation of crossover at right angle. The curing condition of specimen is same with that for tank. The volume fraction of carbon fiber is 55 % for the specimen. Tensile load is statically applied to fiber bundles in vertical direction, while the horizontal fiber bundles are fixed by a fixing jig [2]. The breakage of carbon fiber bundle in vertical direction occurs in the center of the specimen at 1.0 % nominal strain.

Mesoscale analysis
We make up the mesoscale model, where carbon fiber bundles modeled by bars with ellipsoidal cross section are surrounded by resin so as to set the fiber volume fraction as 55 %. The material property of the bundle is set as anisotropic linear elastic body by rule of mixture with the fiber volume fraction of 95 %. That of resin is isotropic linear elastic one.
Stress and strain enhancement caused by crossover are investigated. We set fracture criterion of carbon fiber bundle by 2.1 % of strain along fiber, that is breaking elongation of the carbon fiber itself. We can predict breakage tensile load precisely by means of the employed local strain criterion. We conclude that it is possible to estimate the breaking strength of a high-pressure hydrogen tank exactly by means of mesoscale analysis.

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14465 | Impact-induced damages of auxiliary composite fuel tank on helicopter (Advanced Numerical Techniques)

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In the aerospace industry, the bird strike is very critical and detrimental to the composite parts of aircrafts. Among composite parts of helicopters, especially, the auxiliary composite fuel tank is the one of the critical parts for safety certification because the passengers and aircraft structures can be damaged by explosion or fire of the fuel tanks due to bird strike. Thus, the impact behaviors of the composite fuel tanks should be thoroughly investigated to secure the structural integrity of the helicopters. However, the bird strike tests for aircrafts are very expensive and time consuming. Actually, they can be reduced by performing numerical simulation. Therefore, we conducted the numerical analysis of bird strike-induced damages of auxiliary composite fuel tanks on Korea Utility Helicopter (KUH) series developed by Korea Aerospace Industry (KAI) prior to the bird strike tests. Two-step analysis was performed using ABAQUS/Explicit to save the calculation time: 1) first step is conducted to estimate the impactor velocity after penetration of composite fairing structures due to the bird strike, and 2) second step is undertaken to examine the bird strike-induced damages of the composite fuel tanks due to the bird with the velocity calculated in the first step. A Smoothed Particle Hydrodynamic (SPH) method was applied the impactor model for replicating the behaviors of a bird, and a Coupled Eulerian Lagrangian (CEL) technique was additionally used to reflect the sloshing phenomenon due to the impact into the fuel filled in the composite tanks. Moreover, we analysed the structural failures of the composite tanks considering fiber failure modes in tension and compression, and matrix failure modes in tension and compression using Hashin's failure criteria. We found that the amount of fuel and the shape of the impacted region affect the failure of the composite fuel tanks during the bird strike. As the amount of fuel increased from 50 vol.% to 100 vol.%, the failed area for all failure modes increases. In addition, the failed area for the impacted region with a curved shape was larger than that with a flat shape. The impact behavior of the composite fuel tanks according to the amount of the fuel and the shape of the tanks will be utilized as the basic data for the bird strike tests of KUH series in the future.

Acknowledgement
This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (NO. 2016R 1C1B2010417). This work was also supported by Korea Aerospace Industry, Ltd. Authors are grateful for their support.

14476 | Homogenization in the framework of fictitious domain finite element methods. (Advanced Numerical Techniques)

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Periodic homogenization methods based on a multi-scale asymptotic study can be used to determine the effective behavior of a composite material, via a finite element calculation or via a Fourier space calculation on VER (Elementary Volume representative). One of the difficulties encountered by these methods is the representation of the VERs, which can be present some drawbacks, in cases, for example, where the inclusions are multiple and of varied or very small or very fine forms. In particular, the construction of a conforming mesh for the finite element method can be difficult, expensive or sometimes out of reach, while pixelation (or voxelization) for Fourier transform methods can generate VERs of which the dimensions can be crippling. We propose an original alternative based on a fictitious domain type method, in which the VER is represented by a structured mesh while the inclusions are represented by independent meshes. We present 2D and 3D results on VERs consisting of inclusions of various geometries. We present comparative and performance results compared to the usual methods

14477 | "Current and future Applications of Advanced Simulations techniques to Aerospace Composite structures development in Airbus: From conceptual design to in-service support" (Advanced Numerical Techniques)

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Since earlies seventies, the numerical simulations have been key for the development of aerospace industry. But in the last decade, the role of numerical simulation has taken even more relevance for aircraft development and this relevance will be increased in future developments.

The authors will show how numerical simulation techniques are today applied in the Airframe development in Airbus, focusing on composite structures, during the whole aircraft lifecycle, since the conceptual design phase until in-service support and maintenance activities: Multi-Disciplinary Design Optimization, Global FEM, Global to Detailed FEM interaction, virtual Testing for composites, multibody simulations (MBS) for functional test, Manufacturing Process Simulation or how simulation is being used to support Structural Health Monitoring Systems in Airbus.

The presentation wants to remark whichever current and future challenges and risks of the numerical simulations of composite structures in an industrial environment: Virtual Testing capabilities and limits, industrial application of composite damage and failure models, the role of Verification and Validation, certification by simulation or conditioned based maintenance for aircrafts.

The authors are pushing the reliable usage of numerical simulations for structures inside Airbus, sharing knowledge between different Airbus Business Units with active participation in organizations like NAFEMS or EASN.

14494 | Experimental and numerical analyses of ballistic impact of CFRP fragments. Towards the design of CROR engine debris impact shielding (Advanced Numerical Techniques)

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The reduction of fuel consumption in commercial aircraft is a very important subject, since airlines are responsible of more than 2% of the greenhouse gasses emitted to the atmosphere. The improvement of engines is one of the ways to diminish the consumption, and Counter-Rotative Open Rotor (CROR) engines constitute one of the best promises in order to achieve a relevant efficiency increment. These engines have large composite blades that could, in the event of failure (Blade Off), impact against the fuselage, totally or partially. In this case, the composite fragment acts as a ballistic impactor. In order to design fuselages for this event and adopt CROR engines in the future, it is necessary to understand the impact behaviour of a composite fragment against a deformable structure. Because of the prohibitive costs of a full experimental approach, an efficient test campaign is coupled with high-fidelity simulations in order to generate enough design information.

Experimental tests were performed in which CFRP unidirectional (UD) and woven composite fragments were impacted against 2024-T3 aluminium panels at ballistic speeds. The composite fragments were made using AS4/8552 (UD) and AGP-193PW (woven) plies manufactured by Hexcel Composites, both using AS4 fibres and 8552 epoxy matrix. The impact velocity was varied in order to determine the minimum impact velocity that promotes full perforation of the target (ballistic limit). Three high-speed cameras were used in order to visualize the impact process.

These ballistic tests were numerically simulated by means of finite element analyses in ABAQUS. The aluminium panels were modelled as a monolithic block presenting elastic-plastic behaviour until breakage. The carbon/epoxy impactors were modelled at the meso-level; that is, representing each layer explicitly. The representative physical deformation and damage mechanisms in the CFRP fragments, such as ply failure and delamination, were taken into account explicitly in the finite element discretization by means of a continuum damage mechanic model based on specific failure criteria and a cohesive zone approach, respectively.
The numerical-experimental correlation shows that the models are able to predict with reasonable precision the fragments damage mechanisms and energy dissipated, as well as the failure modes and ballistic curve of the aluminium panel. In this way, the robustness of the modelling approach has been validated. Henceforth, it can be used in the efficient design of impact shields against CROR engine debris.

14512 | Green's functions for unsymmetric composite laminates with holes, cracks, or inclusions (Advanced Numerical Techniques)

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Due to the highly designable characteristics of composite laminates, in practical applications it always has the possibility to design a plate with unsymmetric composite laminates. For such kind of laminates, the material properties is not symmetric with respect to the mid-plane, and the stretching and bending deformation may be coupled together. Unlike the analysis of pure stretching or pure bending in metallic plates or symmetric laminates, the coupled effect would turn the problem from two- to three-dimensional, which complicates the analysis. In order to deal with the coupled stretching-bending deformation, the Stroh-like formalism was developed around fifteen years ago (Hwu, 2003). Since the Stroh-like formalism has been purposely arranged into the form of Stroh formalism for two-dimensional linear anisotropic elasticity (Ting, 1996; Hwu, 2010), almost all the mathematical techniques developed for two-dimensional problems can be transferred to the coupled stretching-bending problems. By taking this advantage, several Green's functions for unsymmetric composite laminates have been obtained. Although the Green's function for the infinite composite laminates has been successfully applied to the boundary element method, its associated solutions for holes, cracks or inclusions cannot be applied correctly due to the discontinuity of some physical quantities, which has not been noticed in the literature.
In the mathematical expression of Green's function, most of discontinuity comes from the complex logarithmic function. Although the discontinuity of complex logarithm, which is a multi-valued function, can be eliminated in all the physical quantities by the identities derived in Stroh-like formalism, the requirement is that the branch cuts for all transformed arguments need to be jumped simultaneously. This may not be difficult for the Green's function of infinite laminates since it is expressed in terms of the standard complex variable. However, the Green's function for holes, cracks and inclusions are expressed in terms of the transformed complex variables, which are variables mapping the ellipse into a unit circle. With these transformed complex variables, a single straight branch cut in the z-domain may turn into four curved branch cuts in the mapped domain and the requirement of simultaneous

jump across the branch should be treated carefully (Hwu, et al., 2017). On the other hand, the discontinuity may also occur due to the neglect of constant terms in the Green's function for inclusion problems. Although the constant term represents rigid body motion and can be neglected for stress analysis, its associated values in matrix and inclusion may be different, and hence the difference between the constant terms of matrix and inclusion should be added in the Green's function to satisfy the continuity requirement of perfect bonding.
By suitable adjustment of branch cuts and adding of the constant terms, the Green's functions for unsymmetric composite laminates with inclusions, published in the literature, have been corrected and verified in this study. By considering an extremely soft inclusion this function can also be used for the cases with holes. Moreover, a straight crack can be approximated by limiting the minor axis of the ellipse to zero.

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14555 | Computation of effective electrical conductivity of composite materials: a novel approach based on analysis of graphs (Advanced Numerical Techniques)

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In this work we continue the investigation of different approaches to conception and modeling of composite materials.

The global method we focus on, is called 'stochastic homogenization'. In this approach, the classical deterministic homogenization techniques and procedures are used to compute the macroscopic parameters of a composite starting from its microscopic properties. The stochastic part is due to averaging over some series of samples, and the fact that these samples fit into the concept of RVE (Representative Volume Element) in order to reduce the variance effect.

In this article, we present a novel method for computation of effective electric properties of composites - it is based on the analysis of the connectivity graph (and the respective adjacency matrix) for each sample of a composite material. We describe how this matrix is constructed in order to take into account complex microscopic geometry. We also explain what we mean by homogenization procedure for electrical conductivity, and how the constructed matrix is related to the problem. The developed method is applied to a test study of the influence of micromorphology of composites materials on their conductivity.

A paper on this subject has just been accepted to Composite Structures.

14612 | Optimization of High-Rise Buildings having Concrete Encased Steel Column using Tree Seed Algorithm (Advanced Numerical Techniques)

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Steel-concrete composite columns consisting steel and concrete material have high tensile and compressive strengths, flexibility, and corrosion resistance. These columns provide cost advantages, especially for the high-rise buildings. One of the most preferred the composite column types is the concrete encased steel column. Due to having enormous design combinations, experience and trial error strategies are not adequate to obtain design high-rise buildings which are economical and satisfy design limitations. Optimization methods are one of the most appropriate tools in order to solve these problems. The primary motivation for the study is to compare the high-rise buildings having composite columns and steel columns with respect the material cost of the structure. For his purpose; optimization program will be developed for the design of the high-rise building having concrete encased steel column. AISC 360-10 and LRFD-AISC standards will be respectively used in order to design composite and steel structural members. A new swarm intelligence based metaheuristic optimization method called Tree Seed algorithm (TSA) will be used in the algorithm. The TSA is developed by adopting behaviors of trees in order to maintain their next generation of through the proliferation of the seeds. The performance of the program will be applied on real-size high-rise structures which are previously designed as steel structures. The design results will also be compared to literature results in order to test performance TSA algorithm for the optimum design of high-rise buildings problem.

14778 | NEW HIGHER ORDER HAAR WAVELET METHOD: APPLICATION TO FGM STRUCTURES (Advanced Numerical Techniques)

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A new high accuracy Haar wavelet method (HWM) has been developed for solving differential and integro-differential equations. Generalized approach has been proposed for wavelet expansion allowing improvement the accuracy and the rate of convergence of the solution. The sample problem considered show that applying the approach proposed allow to improve the order of convergence of the HWM from two to four and to reduce the absolute error by several orders of magnitude (depending on mesh i.e. number of collocation points used). Furthermore, in the case of sample problem considered, the computational and implementation complexities are kept in the same range with widely used HWM.
The research was supported by Estonian Research Council grant PUT1300; Estonian Centre of Excellence in Zero Energy and Resource Efficient Smart Buildings and Districts, ZEBE, TK146 funded by the European Regional Development Fund (grant 2014-2020.4.01.15-0016); Innovative Manufacturing Engineering Systems Competence Centre IMECC (supported by Enterprise Estonia and co-financed by the European Union Regional Development Fund, project EU48685).

14880 | FREE VIBRATION OF VISCOELASTIC PLATES ACCORDING TO FIRST ORDER SHEAR DEFORMATION THEORY (Advanced Numerical Techniques)

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As a structural member, plates are extensively used in all fields of engineering. Therefore, many researchers have carried out extensive studies in the area of plate problem analysis. Based on the changes in structural materials, different plate theories are developed. While the theory of classical or Kirchhoff's plate theory omits the effect of the transverse shear deformation on the deflection of plate, Reissner-Mindlin plate theory considers the influence of it. In many previous discussions of the plates, plate material is assumed as elastic to simplify the analysis. However, real materials show elastic and viscous behavior together and these materials display time-dependent properties due to internal friction. Therefore, viscoelastic constitutive relation is more realistic than the elastic constitutive relation to reflect the certain material behavior. In this research, free vibration frequency of viscoelastic plates is analyzed considering the complete effects of transverse shear and normal stresses. An efficient and systematic procedure based on the Gâteaux differential is developed to construct a new energy functional in the Laplace-Carson domain for the free vibration analysis of first-order-shear deformable linear viscoelastic plates, as mixed-type finite element analysis. The flexural rigidity of the plate is defined by integral operator form, the hereditary integral. For modeling behavior of the viscoelastic plate material, different rheological models are utilized. To convert the obtained solution from the Laplace-Carson domain into the real time domain, methods of numerical Laplace transform inversion are used. The effectiveness of the developed mixed finite element formulation is shown by several numerical examples.

Keywords: rheological model, viscoelastic behavior, mixed finite element formulation, numerical inverse transform technique

14913 | Experimental and finite element analysis of the temperature effect on the behavior of polymers matrix during high pressure torsion process. (Advanced Numerical Techniques)

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The high pressure torsion (HPT) is an efficient process to obtain enhanced microstructures via super-plastic deformation. In view of its optimization, it is of prime importance to assess the relationships between processing conditions and material flow. More precisely, detailed knowledge of the plastic strain distribution in the deformed material in relation to HPT processing variables is very useful. In this context, the present work is focused primarily to highlight the effect of the temperature on the plastic strain distribution into the processed polymers by HPT. The effect of the sample thickness is also studied. To this end, the material parameters of an elasto-viscoplastic phenomenological model were derived from compressive tests at different temperatures and strain rates on a typical thermoplastic polymer (high density polyethylene (HDPE)). The distribution of the equivalent plastic strain and the loading conditions were analysed. Recommendations on process conditions were proclaimed at the end of this work.

13814 | Mechanics of rate-dependent yielding of polymer-based particulate composites (Micromechanics)

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This paper presents the implementation of a virtual testing framework for studying the rate-dependent yielding of a polymer-based particulate composite. The polymer is Polypropylene and the particulate composite is a glass (silica-based) material. The polypropylene is modelled using a Two-process constitutive model for semi-crystalline composites, developed by the authors, which exploits the multi-process viscoelastic relaxation, to capture the rate-dependent yield behaviour of semicrystalline polymers. We showed a framework for generating representative virtual domains of the composites, with a random distribution of spherical inclusions representative of the glass particles. Periodic boundary conditions were imposed on the virtual domain as part of the numerical solution. We have shown an innovative mechanism of imposing periodic boundary conditions using a strategy developed by the authors which involves interpolation functions to match displacements of parallel faces of the virtual domain. The model outputs include effective properties (in the three-dimensional analysis) as well as the yielding behaviour of the particulate. This is the first time the rate-dependence of yielding for a heterogeneous system is shown numerically and we believe outputs from this modelling framework will drive sustainable material design for next-generation particulate composites. The implementation can be adapted to not only composite materials but any heterogeneous system. Although the presentation here has assumed the inclusions to have spherical shapes, the approach has been shown to be extendable to ellipsoids, cuboids, and other random particulate shapes.

13829 | Micromechanical Modeling of Fiber Misalignment on Compressive Response of Fiber-Reinforced Composites (Micromechanics)

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The influence of fiber misalignment on the compressive response of fiber-reinforced composite is investigated in this paper via micromechanical analysis. Augmented finite element method (AFEM) is used to provide high-fidelity data on damage initiation and propagation along with micromechanical analysis. A python program is written to generate the micromechanical model as the input file for Abaqus model. We also discuss the three dimensional AFEM, developed as a Abaqus User Element (UEL). Zero-thickness cohesive elements are inserted on fiber/matrix interface for modelling fiber/matrix interface delamination. Both automatic damage initiation and propagation algorithm is implemented in AFEM to capture discontinuities. Random degree of waviness are considered in different sets of representative volume elements (RVEs). The results show how detrimental is the fiber misalignment to the structural integrity of composite components. It is also seen that the damage initiation and propagation locations are controlled by the degree and location of waviness.

13852 | Thermal and Mechanical Micromechanics Modeling of a Self-Healing Ceramic Matrix Composite (Micromechanics)

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The structure of Ceramic Matrix Composites (CMCs) after oxidation has tremendous effect on the ensuing mechanical and thermal properties of the composite. A self-healing agent, usually in the form of a carbide ceramic, is utilized to observe the structure's temperature distribution after oxidation occurs by means of micromechanics, Finite Element Model FEM. This is accompanied by a depleted layer of the self-healing agents with only the matrix phase present, where a thermal analysis is conducted to recognize the critical points through a thermal stress. Temperature dependent thermal and mechanical properties were obtained elsewhere to observe the mechanical and thermal stress concentrations due to geometrical and material mismatch interfaces between multiple phases. The utilized material domain includes of oxidation product, with depleted ceramic matrix phase from a self-healing agent and the CMC interfaced with the depleted layer. The model is also repeated for multiple volume fractions of the self-healing agent to observe the degree of the strength restoration after oxidation. This approach can be applied for CMCs with self-healing agents under high thermal and mechanical environment.

13853 | Discrete Element Modelling of Sintered Zirconium Diboride Ultra High Temperature Ceramics (Micromechanics)

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Ultra-high temperature ceramics (UHTC) are a class of materials that possess excellent stability, high stiffness, and high strength properties at temperatures exceeding 2000 deg.C. One type of UHTC, zirconium diboride ZrB2, has many applications in the aerospace industry from use as thermostructural materials on nose cones to aircraft engine components. The fabrication of ZrB2 through powder sintering can result in a final microstructure that varies significantly depending on the sintering process parameters used including dwell time, temperature, external pressure, etc. Thus in order to obtain desired properties in sintered ZrB2 it is important to understand the effect of controlling factors and parameters in the sintering process. In this paper, the three dimensional application of DEM to the modeling of solid-state sintering of ZrB2 is described. Using this method, key properties in sintered ceramics are determined such as densification rate, coordination number, and bulk/shear viscosity with results compared to experimental results. Special emphasis is put on the effect of these properties on crack propagation within the sintered ceramic.

14352 | Fully Coupled thermal-chemical-mechanical modeling of cure-induced residual stress in z-pinned fiber composites (Micromechanics)

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The development of residual stresses in composites during cure cycle is one of the most important problems, as they affect the strength and mechanical properties of the final product adversely. Based on the microstructure model of z-pinned composites, local in-plane waviness and uneven volume content of fiber, as well as the change in mechanical properties with the cure degree of resin are investigated. Numerical simulation is utilized to study the development of stresses during curing based on a fully coupled thermal-chemical-mechanical model, involving the effects of chemical and thermal strains as well as viscoelastic material behavior. The new model implemented by combining mesoscopic finite element model (FEM) with periodical boundary conditions is proposed, and the residual stresses in laminates of z-pinned composites in the curing process are analyzed.

14485 | The effect of manufacturing parameters on the stress concentrations in composites with micro-vascular channels under transverse loading (Micromechanics)

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In order to monitor the damage and facilitate self-healing process, composites can be manufactured with vascular channels inside. Such a process is easy to manufacture and does not need many additional tools or materials. However, these channels change the structure of the composite in the vicinity of the channel. They generate not only a low-stiff resin-rich region where pure epoxy exists without fibers, but also stress concentrations around the region. Designers should take care about these issues for the composite to keep its structural integrity under various loading types. Among these loading types, the loading in the direction perpendicular to the axis of these channels are the most critical ones. There are some studies related to the transverse loading in composites with such channels. However, all of these are for specific composite or channel type and do not reveal the relation of stresses to the composite lay-up and channel type.

In this study, the effect of these channels under transverse loading is investigated with finite element modeling considering different lay-up conditions and for channel diameters. First, composite samples are prepared to quantify the resin rich region around the channels. For this, fiber layers are installed in a mold with solid wires in the mid-layer to produce the channeled composite. Then the resin is poured inside the mold and put in the curing owen. After curing, the solid wires are removed and the channeled composite are prepared. Two different stacking conditions [0/90]4s and [90/0]4s are prepared for this purpose with a channel diameter of 1mm. Microscopic images are taken close to the channels and the resin rich region dimensions are determined for both of these types. In [0/90]4s layup, the layer just above the composite is 90° whereas it is 0° in [90/0]4s revealing quite different resin rich region, geometrically.

Finite element models are prepared according to the observed images. Channels with different diameters are modelled by scaling the images of the prepared composites. Lay ups with unidirectional 0° and 90° are modelled as well to analyze the effect of stacking condition, accurately. One quarter of the model is prepared due to the symmetry. Transverse loading is applied on the side of the model. The stress distribution in the resin rich region are determined for various channel diameter and four layup types by scaling with the average stresses generated in the composite.

The results revealed that the channel diameter is more effective in [0/90]4s configuration than in [90/0]4s configuration for the stresses in the interface between resin rich region and layup. The compressive stress observed near the channel are decreased by increasing the channel size. Some extra models are prepared for [0/90]4s with the resin pocket size of [90/0]4s and visa versa to understand if the layup or the pocket size is important. The results indicate that the pocket size is the key factor in the stresses. The results for similar resin-rich pocket dimensions with different layups showed similar stresses where a significant change in the stresses are observed for the same layups but different resin-rich dimensions.

14537 | The role of manufacture-induced defects on the micromechanical fracture mechanisms of fibre reinforced polymers (Micromechanics)

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Defects of very diverse geometries and sizes can be found in all fibre reinforced polymers (FRP) due to different manufacturing procedures. Generally, it is assumed that the main micro-mechanism that causes the failure of a FRP on a matrix dominated loading case is the debonding of the fibre-resin interface. The aim of this numerical study is to ascertain if the defects in the form of circular pores can cause some change in the initial development of the complete failure of a FRP. In order to do so, Representative Volume Elements (RVE) that feature randomly-generated microstructures with different fibre and pore volume fractions are generated to mimic a realistic scenario. Two dimensional numerical simulations of such RVEs with periodic boundary conditions subjected to varying stress states in the transversely isotropic plane are carried out to observe the role of the manufacturing-induced defects on the fracture initiation mechanisms. The constitutive response of the fibres is assumed to be isotropic linear elastic, whereas the matrix, in order to take into account its pressure-dependent behaviour, is modelled using a Drucker-Prager plasticity combined with an isotropic hardening law and a damage-coupled Extended Cockroft-Latham failure criterion. The interface between them is populated with elements with a cohesive zone model-based bilinear traction-separation law, hence allowing for the fibre-matrix interface debonding. To be as accurate as possible in the prediction of the fracture mechanisms the material constants of the matrix will be calibrated using stress-strain curves obtained from tension, shear and compression experiments. The results of the simulations could yield to effective constitutive responses as a function of microstructural defects in the lamina which can in turn be used to model FRP at a structural level.

14622 | Analysis of longitudinal tensile failure of unidirectional composites by means of computational micromechanics (Micromechanics)

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Fibre reinforced polymers (FRP) are widely used in the most transportation sectors, especially in lightweight aerospace structures, mainly thanks to their high specific mechanical properties such as stiffness and strength. However, their low fracture toughness translates into brittle behaviour that often leads to catastrophic failure without prior damage symptoms. This constitutes a serious drawback that added to the lack of reliable predictive models for the design of FRP with mitigated brittleness, limits the application of these materials to a wider engineering space. The development of reliable failure models for FRP is rather challenging due to the complexity of the damage phenomena, as well as due to the difficulties of conducting appropriate experimental validation. Fortunately, the recent increase in available computational resources and advances in computational modelling enabled the development of reliable virtual testing methodologies amenable to study of the mechanisms of failure of FRP.
In this work, a high fidelity three-dimensional finite element modelling approach for unidirectional (UD) composites was developed to predict the phenomena associated with longitudinal tensile deformation and failure in detail. The approach is based on periodic Representative Volume Element (RVE) on a micromechanical scale, with a random distribution of fibres, to capture the progressive damage and interaction between the fibres and the matrix. The carbon/fibre material AS4/8552 was chosen for the purpose of demonstration of the methodology. The fibres were considered transversely isotropic with linear-elastic behaviour. The brittle fracture of carbon fibres was reproduced explicitly by means of a set of fracture planes whose failure is governed by fibre fracture toughness and a statistical Weibull distribution of fibre strengths. A modified elastic-plastic Drucker-Prager model coupled with tensile damage behaviour was used to model the resin matrix. The fibre-matrix debonding and pull-out is simulated by means of a cohesive-frictional model coupled with a surface contact algorithm. This numerical methodology was complemented by extensive in-situ experimental characterization of fibres [1], matrix [2] and fibre-matrix interfaces [3] to generate reliable model inputs.
Besides the detailed simulation of longitudinal fracture mechanisms and their interaction, it will be demonstrated that this modelling approach allows the study of important effects on longitudinal failure, such as dynamic loading and residual thermal stresses. Moreover, it allows the determination of important parameters to the development of lower-fidelity but more efficient analysis tools, such as the Stress Concentration Factor (SCF) caused by the dynamic failure of single fibres, which has a significant effect on the failure probability of adjacent fibres, and the critical fibre cluster.

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14345 | Analysis of the possibility of non-destructive testing to detect defects in multi-layered composites reinforced fibers by optical IR thermography (Modeling, simulation and testing of sandwich and adaptive structures)

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Structural composite materials, especially those made of plastics, are an alternative to traditional construction materials such as metals. Important advantages are their lower weight and the fact that they do not corrode like metals. However, they are not ideal materials because they are also exposed to defects that reduce their technical parameters which can be formed both in the production phase and during operation. It can be concluded based on numerous publications, that IR thermography methods are very useful in non-destructive evaluation of their technical condition. One of the basic methods used in non-destructive testing of composite materials is infrared thermography with optical (various types of heating lamps, lasers) thermal excitation. This method can be applied by either reflection or transmission approaches. The paper analyses the possibilities and effectiveness of using reflection

approach in the case of multilayer composites reinforced fibers. The advantages and limitations of this technique have been demonstrated via composites reinforced with three types of fibers: glass, aramid, and carbon. Depending on application, they are most often multilayer structures consisting of several to a dozen layers of reinforced fibers (fabrics or mats with different orientation of fibers) glued with layers of resin. The most common defects in such structures are: delaminations, fiber cracks, matrix cracks, and separation of fibers from the matrix. ThermoCalcTM-30L computer program was used in order to determine the detection of defects depending on the depth of their location under the front surface of composite material as well as their geometrical dimensions. The ThermoCalc™-30L software is intended for calculating three-dimensional (3D) temperature distributions in anisotropic solids (30-layer) which may contain up thirty anisotropic layers and up to nine subsurface defects. The unique feature of the Program is possibility to introduce a three-component tensor of thermal conductivity, with its principal axes being spatially-tilted in regard each to other, thus modeling composite fibers. The corresponding mathematical heat conduction problem is modeled in Cartesian coordinates and solved by using an implicit finite-difference numerical scheme. The numerical algorithm implemented in ThermoCalc™-30L, unlike available commercial software, enables modeling very thin defects in fairly thick materials without losing computation accuracy. It allows analyzing up to nine defects with a specimen being heated uniformly or non-uniformly with a square or cosine pulse that gives a possibility to study defect cross-influence and lateral 3D heat diffusion.

14428 | A mutil-field coupling finite element model for laminated magnetoelectric composite structure (Modeling, simulation and testing of sandwich and adaptive structures)

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Magnetoelectric (ME) composite structure is a laminated structure consisting of magnetostrictive layers and piezoelectric layers. Based on the magnetostrictive effect in the magnetostrictive materials and the piezoelectric effect in the piezoelectric materials effect, a ME composite structure can generate electric voltage when it is subjected to a magnetic field or vice versa, which makes the ME laminated composites enormous potential applications in magnetic field sensors, gyrators, microwave devices, energy harvesters, and so on. In present work, a coupling three dimensional (3D) finite element model for analyzing the influence of field-orientation and width of the ME composite structure is built, meanwhile, the edge effect and demagnetization effect are considered. The results reveals that the optimal angle is various when the width of the ME structure changes. And an excellent ME performance can be expected in 1-1 configuration composites. Furthermore, the magnetic flux density inside two components and the voltage distribution in piezoelectric material are discussed in detail. Moreover, the stress states of the laminate structure under resonance are demonstrated.

14474 | Numerical study of performance and shape of cork compounds core sandwich plates under blast conditions. (Modeling, simulation and testing of sandwich and adaptive structures)

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Sandwich structures have been used in different industrial applications such as in aerospace or naval structures because of its lightweight and high bending stiffness. This type of structure is composed by thin skins and a lightweight core, its simplicity has made possible to spread its applications and manufacturing for engineering designs. Traditionally, the skins are metallic or made of fibre reinforced plastic (FRP), depending on the sector or applications in which the sandwich is going to be used. This fact allows the designers to use skins depending on the loads that, during its service life, are going to be subjected to. The purpose of the core is usually to isolate thermally and to increase the moment of inertia of the component and therefore its bending stiffness. Moreover it is known its high capability of energy absorption; usually the sandwich core is able to absorb high amounts of energy at a constant load, giving as a result a promising structure for protection or to mitigate impulsive (short duration) loads.

Sandwich skins usually are exposed to impacts and wear, so the range of materials available is narrow, whereas the core is usually protected so there is a higher freedom in the selection of materials. Some authors explore the use of bio-materials such as cork for core applications. These materials present low density, high energy absorption capability and, in addition a low carbon foot print because they are biodegradable. These properties make this type of cores an outstanding option for the industries for its “green" designs.

The cork under impulsive events has been studied by different authors, showing the good performance of this natural cellular material. Some authors studied the cork under high velocity impacts showing how the absorbed energy was strongly augmented by the presence of the cork core [1]. Other researchers explored the use of cork compounds as sandwich core under blast loading; Sousa Martins et al. [2, 3] have presented some experimental promising results of cork cores as an energy absorption component. Therefore, taking into account that cork is a fully bio-degradable material, it is a good candidate to be used as a liner of structures or as a core in sandwich with a low increase of weight.

In this work a numerical model is developed to analyse the performance of aluminium skins and cork core sandwich when subjected to blast loads. Two numerical approaches are used to model the blast loads: an Arbitrary-Lagrangian-Eulerian (ALE) approach and the Load Blast Enhanced (LBE). Both models are validated using the experimental data available in the literature [3]. A detailed analysis of the sandwich behaviour is done for both approaches showing small differences regarding the sandwich behaviour. Numerical models provide relevant information that allows uncovering the absorbing energy mechanisms in the sandwich. Based on these conclusions a new topology is proposed to optimize the energy absorption keeping the mass constant. A wavy cork core was proposed and different geometrical aspects were studied in the absorption energy. After the numerical study an optimized case is obtained in which the absorbed energy increases almost a 40 %. The methodology used could be applied to others configurations and increasing the performance of the structures under blast events.

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14491 | Comparison of modelling approaches of periodic sandwich structures (Modeling, simulation and testing of sandwich and adaptive structures)

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Sandwich structures are certain specific composites made of three layers - outer layers, which are made of materials characterised by high mechanical properties, so as they can be treated as the main bearing part of the structure, and the inner layer, so called core. The core is usually made of light-weight materials, which have two functions: they increase the stiffness of the whole structure, by increasing its thickness, and stand for the thermal and acoustic isolation. Due to the fact, that every each layer of such structures is being modelled and optimized to work best in certain specific conditions, sandwich plates can be characterised by physical and mechanical properties, which are unreachable for 'classic', homogeneous materials. Hence, they have many applications in modern engineering.
There are many different approaches to modelling of sandwich structures. First of all, sandwich structures can be treated as a system of two outer layers modelled as beams, membrane systems, plates or even shells, connected with each other with a certain type of elastic material, such as: one- or multiparametric Winkler's type material, Murakami's type material or Pasternak's type material, among others. Secondly, the whole structure can be treated as a single multilayered plate or shell and then analysed with the use of complicated deformation field hypothesis, such as: broken line hypothesis, Zig-Zag theory or Reissner-Mindlin hypothesis. Eventually, researchers use a vast variety of numerical methods to analyse sandwich structures, such as the finite difference method or the finite element method, which is considered to be the most versatile method of analysis of any type of structures recently. In this work several mentioned modelling approaches will be compared, as the analysis of vibrations of sandwich structures with layers characterised by a periodically varying material properties and/or thickness will be performed. The coefficients of the governing equations of such structures can be periodic, non-continuous and highly-oscillating functions, hence, the modelling process requires a special modelling approach - the tolerance averaging technique, developed by Woźniak et al. [2008, 2010]. Within this approach it is possible to transform the initial partial differential equations with certain specific type of functional coefficients into the constant, averaged form. As a result of this transformation one can obtain governing equations in the form with constant coefficients, which can be solved using methods typical for structural mechanics. Unlike the asymptotic homogenisation method however, the tolerance averaging technique still allows us to investigate the micro-scale fluctuations in the behaviour of considered structures and their influence on the macro-scale overall performance.
The tolerance averaging technique has many different applications in modelling of various thermomechanical problems, for example: buckling of thin periodic plates by Domagalski and Jędrysiak (2015), thermoelasticity of transversally graded laminates by Pazera and Jędrysiak (2015) or dynamic analysis of functionally graded shells by Tomczyk and Szczerba (2018).

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14559 | Experimental and numerical investigations of sound transmission through a double-glazed window (Modeling, simulation and testing of sandwich and adaptive structures)

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The domestic windows in the exterior building facade play a significant role in sound insulation against outdoor airborne noise. The prediction of their acoustic performances is classically carried out in laboratory according to standard ISO 10140. In this work, a 3D elasto-acoustic finite element model (FEM) is proposed to predict the sound reduction index of three different glazing configurations of domestic window, which are compared to laboratory measurements. Two acoustic cavities with rigid-boundaries on both sides of the window are used to simulate respectively the diffuse field on the source side and the pressure field on the receiver side. By using a simplified FEM for the double glazed windows, the sound reduction index is calculated from the difference between the source and receiving sound pressure levels in the one-third octave band from 100 to 400 Hz. The comparison between numerical and experimental results shows a relatively good agreement which highlights the interest of this kind of approaches to avoid expensive experiments.

14600 | The mechanical and thermal loads behavior of exponentially graded sandwich plates in bending test (Modeling, simulation and testing of sandwich and adaptive structures)

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A four-variable refined plate theory is developed to analyze the bending behavior of functionally graded material (FGM) sandwich plates subjected to thermomechanical loads. The sandwich plate faces are FGM, of which the Young's modulus, Poisson's ratio, and thermal expansion coefficient are assumed to vary according to an exponential law distribution in the thickness direction. Two types of FGM sandwich plates, i.e. one with FGM face sheets and homogenous core and the other composed of homogenous face sheets and FGM core are considered. The number of unknown functions involved in the present theory is only four. The governing equations are deduced based on the principle of virtual work and then these equations are solved via Navier approach. Close-form solutions for simply supported FGM sandwich plates are obtained. Comparative studies are conducted to demonstrate the validity and efficiency of the present theory. The effects of significant parameters such as the gradient index, side-to-thickness ratio, layer thickness ratio and loading type on the thermomechanical bending behaviors are discussed in detail.

14614 | The effect of carbon and glass fiber hybridisation on tensile properties of fiber metal laminates (Modeling, simulation and testing of sandwich and adaptive structures)

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Fiber metal laminates (FML) are layered materials which are made of fiber reinforced polymers adhesively bonded with the aluminium alloy. The most known FML is Glass Fiber Reinforced Aluminium Laminates (GLARE) based on the Glass Fiber Reinforced Polymer (GFRP) and Carbon Fiber Reinforced Aluminium Laminates (CARALL) based on high-strength Carbon Fiber Reinforced Polymer (CFRP). However, bonding of the carbon fibers with the aluminium may result in formation of the galvanic cell. One of the ideas for limiting a galvanic cell formation in CARALLs is to separate the metal layer from carbon fibers by the additional layer of a dielectric material, where the usage of two kinds of reinforcing fibers in the FML composite layer creates a new type of FML laminate – the Hybrid FML.
The studies concerning the effect of reinforcing carbon/glass fiber hybridization on the mechanical behavior of FML are very rare, while the fiber hybridisation in classical fiber reinforced plastics are studied widely. One of the most advantages of hybrid laminates is the presence of the post-tensile range in stress-strain curve, which is related above-mentioned failure strain. After the tensile failure of low-elongation (LE) carbon fibers, the high-elongation (HE) glass fibers can still carry some loads. In the hybrid composites the beneficial 'hybrid effect' is also observed, which relies on extension of the carbon fiber failure strain when in comparison to a pure CFRP. Despite numerous studies in this field, there are three hypotheses in the literature explaining the mechanism of the hybrid effect, which can be associated with: the presence of thermal stresses in the hybrid composite; advanced development of the hybrid composite rupture; dynamic stress factors during failure of unidirectional composites. The studies of the fiber hybridization in composites are usually based on thermal stresses hypothesis, where the hybrid effect is associated with the compressive stresses in the carbon fibers and resulting in carbon fibers failure strain increase in hybrid laminate when compared with monolithic CFRP.
The aim of this study was to investigate whether the beneficial hybrid effect would also occur in hybrid by carbon/glass FMLs. The used metal layer is characterized by non-linear elastoplastic stress-strain characteristics, different stiffness and CTE than FRPs. Hence, the equivalent CTE of laminate, is different than for hybrid composite. The hybrid effect in FMLs was investigated based on the hypothesis of thermal stresses and their impact on failure strain of the laminae. Analytical modeling, numerical simulations and experimental tests were performed on GLARE and CARALL, as well as on Hybrid FMLs made of carbon/glass FRPs with different volume proportions.

14648 | Identification of Vibrationg Subsystems of Power Steering System Body **(Modeling, simulation and testing of sandwich and adaptive structures)**

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Identification of Vibrationg Subsystems of Power Steering System Body
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Keywords: Dynamical flexibility, mechanical or Mechatronic Complex Systems, exact and approximate methods of analysis

Introduction

The analysis and synthesis of electrical systems were presented in monograph [1]. This monograph was the assumption to formulating and formalizing of problems of analysis of vibrating beam systems, discrete and discrete-continuous mechanical systems by means of the structural numbers methods [2] modeled by the graphs, hypergraphs, have been investigated in the research Centre in Gliwice (e.g. [3]). The continuous-discrete torsional and transverse vibrating mechatronic systems and transformations of hypergraps of flexibly vibrating beams were presented in [4,5]. To compare the obtained dynamical characteristics – dynamical flexibilities only for mechanical torsional vibrating bar and transverse vibrating beam being a parts of complex mechatronic systems, an exact method and the Galerkin's method were used.
Such formulation can be an introduction to synthesis of vibrating mechatronic systems which will lead to generating the vibrations with require parameters.
Problem and methodology

In this paper for vibrations steering system body:

- frequency - modal analysis of continuous vibrating mechanical subsystem by means exact and approximate methods,
- the supply of necessary formal nations to modeling the considered subsystems by means different category graphs,
- dynamical charcteristics using n synthesis considered class of systems,
- algebraical representation of modeling considered class of mechanical and/or mechatronic systems by means structural numbers,
- the alghoritm of the synthesis of mechanical subsystems of mechatronic systems by continued fraction expansion method distribution of characteristic represented by different category graphs,

have been presented.
Conclusions

Applied method and received results can make up the introduction to the synthesis of considered class systems - torsional vibrating mechatronic ones with constant changeable cross-section. The problems will be presented in future works.
Acknovledgement - This work has been conducted as a part of research project PBS3/B6/37/2015 (PST-41/RMT2/2016) from 2016 until 2018.

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14755 | An efficient prediction of multiple crack in graded sandwich composites using an extended cohesive damage model (Modeling, simulation and testing of sandwich and adaptive structures)

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Graded sandwich composite has drawn massive attention from academics and engineers in the composite society in the last twenty years. The graded sandwich composite consists of two fibre laminates on top and bottom respectively and the foam core between two laminates. The foam core is graded material to have good behavior in failure mechanism. To achieve the best mechanical behaviour, understanding its detailed failure mechanism is essential. It is challenge to predict the multiple crack in the foam core because the core is multilayer graded and weak material. This paper presents an efficient approach in predicting multiple crack of graded sandwich composites using an extended cohesive damage model. Applications in this investigation show that the detailed failure mechanism of graded sandwich composites was studied well by the extended cohesive damage model, and an excellent outcome was achieved through the modelling prediction, which shows the loading capacity of the designed sandwich composite with multiplayer graded foam core is increased by 50% compared to the sandwich composite with single foam core. This investigation also shows that the extended cohesive damage model is a highly efficient approach in predicting mechanical behavior of sandwich composites.

13833 | STUDY OF THE INTERFACIAL BEHAVIOR OF ALFA / PA and ALFA / PE BIO-COMPOSITES (Multiscale Analysis of Natural Fibre Composites)

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The alfa is a typically Mediterranean grass whose large foci spread out over the high plateaus of Algeria. The fibers based on this plant have been the subject of several theoretical and experimental studies on a macroscopic scale. The object of our microscopic study is to see the new behavior of the fiber-matrix interface of the two bio-composites based on fiber alfa, the first having a polyamide (PA) matrix and the second the polyethylene (PE). Our work consists in calculating the apparent and ultimate shear stresses as well as the rate of critical restitution energy as a function of the same radius of this reinforcement.
The analysis of our results shows that the alfa fiber to provide a good mechanical resistance to the different stresses applied on the interface of two alfa / PA and alfa / PE materials. Our numerical simulation shows a good agreement with the experimental study conducted by Le Duigou and showed that natural fibers play a very important role in improving the mechanical properties of composite materials.

13851 | Tensile behaviors of graphene/aluminium nanocomposites (Multi-scale Modeling of Graphene- and Carbon Nanotube-Reinforced Composites)

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Graphene has the perfect two-dimensional lattice of sp2-bonded carbon atoms and therefore possesses excellent mechanical properties such as exceptionally high Young's modulus and strength, making it a promising candidate as the reinforcing nanofillers to improve mechanical properties of conventional metal, polymer and ceramic materials. Graphene reinforced nanocomposites have attracted tremendous interests due to their huge potential applications in various engineering fields to develop advanced light-weight structures. In this study, tensile behaviors of graphene/aluminium nanocomposites are investigated by using molecular dynamics simulations. The effects of the volume fraction of graphene, loading direction, temperature and crystallographic orientation of aluminium matrix are considered. Simulation results show that the inclusion of a small amount of graphene can significantly enhance the Young's modulus of the nanocomposite in the in-plane direction. For example, the modulus is enhanced by 30.0% when graphene's volume fraction is 1.75%. However, the modulus in the out-of-plane direction is decreased, which is lower than that of the aluminium matrix. It is also demonstrated that the modulus decreases with an increase in temperature over a range of 10 K ~ 900 K. Moreover, the mechanical properties of the nanocomposite are influenced by the crystallographic orientation of the matrix due to the fact that different orientations induce the alteration of the interfacial microstructure between graphene and the aluminium matrix. Results presented in this study suggest that both the volume fraction of graphene and crystallographic orientation are important factors for engineering graphene reinforced metal matrix nanocomposites.

14374 | Multiscale asymptotic homogenization analysis of epoxy-based composites reinforced with different hexagonal nanosheets (Multi-scale Modeling of Graphene- and Carbon Nanotube-Reinforced Composites)

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The present work studies the mechanical properties of epoxy-based composites which are reinforced by hexagonal monolayer nanosheets such as graphene, boron nitride (BN), silicon carbide (SiC) and aluminium nitride (AlN), based on a multiscale model using asymptotic homogenization method. Graphene/BN/SiC/AlN nanosheets have great potential in many applications and present special mechanical properties. A brief review of the literature reveals that incorporating these nanosheets into a polymer matrix effectively improves their properties which do not usually follow the rule of mixtures. The mechanical properties naturally depend on the geometry and properties of nanofillers as well as load transferring between nanofillers and matrix. Because of heavy atomistic simulation on the nanostructures, many researchers have been interested in the connection between nanostructures and the continuum mechanics which this paper is in such a category. The repeating unit cell of these honeycomb lattice structures is hexagonal. The discrete

periodic arrangements of the hexagonal nanosheets is suitable to use asymptotic homogenization method. The present model of nanocomposite has a uniformly matrix with long hexagonal nanosheets like a sandwich structure. In this model, the matrix and hexagonal nanosheets are represented as a continuum and atomistic phases, respectively. The hexagonal nanosheet is modeled relevant to its interatomic interactions. Two types of interactions between atoms normally be considered. First, the in-plane interaction is a covalent bonding that consists of bond stretching and bond angle bending. Second, the out-of-plane non-bonded interaction which is the van der Waals force between atoms. Different bond length and force constant associated with bond stretching and bond angle variation is taken from the Tersoff–Brenner potentials for graphene, BN, SiC and AlN sheets [1]. The surrounding matrix could be assumed as a polymer with isotropic properties or a composite with orthotropic properties. This is one of the features of this homogenized model that any orthotropic or isotropic material can be considered as a matrix. The most critical part of modeling is the interphase zone between the atomistic hexagonal nanosheets and the continuum polymer representation while its mechanical properties are derived from the load transferring between the basic composite components. This parametric study on total atomic interactions in the unit cell with the asymptotic homogenization method allows clearly establishing Young's modulus, shear modulus, Poisson's ratios and stiffness coefficients of hexagonal nanosheets and epoxy-based composites reinforced with them as functions of the force constants, bond length, thickness and volume fractions. The unit cell which is proposed here consists of the hexagonal reinforcement, the surrounding polymer, and the interface. The boundary value problem is solved and constitutive equations for the equivalent anisotropic homogeneous shell are derived to define the effective stiffness coefficients which depend on the effective elastic properties. The accuracy of the results have been compared with those available in the literature [1, 2]. Finally, our results are as the same as the trustworthy results of other researchers. This is the fact that the present homogenized sandwich-like model has simplified rules which consider interfacial forces and clears the matrix-reinforcement interface. Thus, it is useful for reasons of using asymptotic homogenization method for nanostructures instead of heavy computational modeling or difficult experiments.

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14497 | Multiscale modeling of the elastic properties of carbon nanocomposites (Multi-scale Modeling of Graphene- and Carbon Nanotube-Reinforced Composites)

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One important issue in carbon polymer nanocomposites is related to the prediction of the mechanical properties, in particular regarding stiffness, strength and fracture energy. They are highly sensitive to four main underlying factors, related to the nanofiller and nanocomposite manufacturing and operation. Carbon nanofiller imperfections substantially reduce its stiffness and strength, whereas nanofiller dispersion quality and misalignment greatly influence the macroscale nanocomposite properties. Furthermore, non-perfect nanofiller-matrix interfacial adhesion results in a strong dependency of the aforementioned properties with the strain state.

An adequate simultaneous modelling of all the above mechanisms is complicated due to the high nonlinearity associated to the interface and the presence of different scales, with the associated meshing and computing performance issues. Few models face the problem of the simultaneous modelling, focusing on particular mechanisms and results.

We have developed a multiscale model able to simultaneously consider all the cited factors in the prediction of the elastic modulus of carbon nanocomposites. At the nanoscale, we have used a cohesive model to evaluate the elastic properties for different strain states. In addition to axial strain, the model simultaneously includes out of plane strain and shear distortion, which we believe is also a novel contribution. Homogenization allows for the creation of stiffness maps for a considerably high number of combinations of strain states, nanofiller sizes, weight fractions and interfacial characteristics. At the macroscale, we have used these maps to update the local elastic properties.

Nanoscale model shows a very good correlation with experimental results performed by means of the measurement of the shift of a strain dependent Raman band. Likewise, macroscale model shows a fabulous correlation with many experimental results from different researchers, for different nanofiller weight fractions and nanofiller and matrix characteristics.

13845 | Investigating the Effect of Silicon Dioxide Substrate on Nanowires/Nanotubes Buckling (Nano-Composites)

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Investigating the Effect of Silicon Dioxide Substrate on Nanowires/Nanotubes Buckling

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Abstract
Silicon Dioxide (SiO2) is the material on which nanotubes and nanowires are placed and used as transistors. SiO2 substrate is modeled as two parameters elastic foundation. To model the elastic substrate, Winkler and Pasternak foundation models are used. Different values of elastic foundation parameters (kw, kp) are taken into consideration to see the effect of these parameters on buckling loads of nanotubes and nanowires. This work aim to highlight the effect of SiO2 substrate on the buckling behavior of nanotubes and nanowires.

The usage of nanomaterials last to the discovery of Carbon nanotube by Iijima [1] in 1991. The discovery of Carbon nanotubes (CNTs) has been composed as a revolutionary point for many areas such as processor technology, biotechnology, gas/chemical sensors, aerospace technology, etc [2-4]. To illustrate, one of major computer processor manufacturer Intel's first processor in 1971 contained only 2300 micro-sized transistor and manufactured by

using “10 μm manufacturing process” [5]. On the other hand, the same company “Intel” has produced and started to sell the next generation processor which manufactured by using “14 nm manufacturing process” and consist of 1.7 billion transistors in 2016. Besides, Moore’s law [6], named after the Intel founder Gordon Moore, predicts that the number of semiconductor transistors will double every 18–24 months [7]. To isolate the transistors, SiO2 is the most used insulator in nanodevices because of its superior isolating performance, stable behavior, and lower cost than alternative isolating materials [8, 9]. After CNT new types of nanotubes have been produced such as boron nitride nanotube (BNNT), silicon carbide nanotube (SiCNT), zinc oxide (ZnO).

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13924 | Thermal buckling analysis of anisotropic nanobeams based on a refined nonlocal model (Nano-Composites)

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Based on the nonlocal elastic theory (NET) and Reissner’s Mixed Variational Theorem (RMVT), the thermal buckling behaviors of anisotropic nanobeams are studied. In the present anisotropic model, a linear zigzag theory is adopted to make the in-plane displacement satisfying the C0 continuity conditions along the thickness. In addition, with the aid of a preprocessing and the RMVT, the interlaminar continuity conditions and free surface conditions are satisfied a priori without shear correction factors. Subsequently, several local and nonlocal beam models are taken as illustrative examples, the problem of the thermal buckling are analytically solved in the simply supported boundary conditions. Illustrative examples indicate that the critical loads agree well with the three-dimensional elasticity solutions which demonstrate the correctness and reliability of present formulation. Finally, the small effects and the effects of different temperature, laminations and geometric sizes are discussed.

14459 | Reinforcement and structure-directing effects of carbon nanoplatelets in microfibrillar composites: Effect of components coupling (Nano-Composites)

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Microfibrillar composites (MFC) are polymer–polymer composites prepared by drawing of suitable polymer blends, where application of various nanofillers (NF) has strong potential for elimination of basic disadvantage of MFC arising from limited parameters of polymer components. The effect of NF does not consist in reinforcement of polymer components and improvement of many materials parameters, like inflammability, only; additional effects on parameters of fibrils and interface, drawing process, etc. are also of importance. Due to complexity of NF acting, both synergistic and antagonistic effects may occur. This work deals with complex effect of carbon nanoplatelets (CNP) on performance of MFC consisting of HDPE matrix and in-situ formed PA6 and PA66 reinforcement. Advantage of CNP in comparison with inorganic, mostly silicate-based nanofillers is higher inherent affinity to polymers, presence of reactive groups capable of reacting with polyamide and potential for further functionalization and/or modification. This allows controlling migration and localization of CNP in MFC, including their presence at the interface. HDPE/PA66 MFC modified with carbon nanoplatelets were prepared by different mixing protocols using masterbatches. CNP influence the dispersed phase size in the original blend negligibly and mostly lead to finer high-aspect-ratio fibrils, i.e. CNP rather support elongation of inclusions than coalescence in the course of drawing. This leads to more favourable melt drawing and represents strong difference from silicates which support coalescence in elongational flow. Favourable mechanical behaviour, exceeding predicted one, was found with low CNP content using the PA66 masterbatch. At the same time, marked differences in properties depending on mixing protocol were found in spite of similar structure and CNP localization in PA66 in all MFC studied. The worst properties found for the HDPE masterbatch indicate that CNP migration between the components causes antagonistic effects. We consider affecting of the HDPE matrix crystallinity at the interphase (surface of PA66 fibrils) by CNP passing from the HDPE to PA66 phase in the course of drawing and subsequent solidification, i. e. by variation in the amount of spherulites in this area and thus modulus of the interphase. Strong impact of such a “soft” interface on modulus of MFC was recently confirmed by finite element analysis. Results achieved confirm complexity of CNP-induced effects in MFC, which may support or reduce dual reinforcement with CNP and PA66 microfibrils and induce necessity of their understanding and harmonization. Migration of CNP between the polymer components and final localization were successfully controlled by CNP/HDPE coupling using aminated CNP and epoxidized polyethylene. The best mechanical properties were achieved in the case of elimination of CNP transfer and/or localization in both polymer components attained by targeted in-situ polymer chains modification. The structure-properties relationship in MFC with different GNP localization and the effect of components reinforcement are discussed.
Acknowledgment
This work was supported by Czech Science Foundation (Grant No 16-03194S)

14469 | The use of the nanomagnetic fluids and the magnetic field to enhance the production of nanomagnetic composite systems (Nano-Composites)

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The researches have started with the idea to exploit the possibility to achieve the new materials in the context of Nanotechnology Constructions, with the aid of the inclusion of Nanomagnetic Fluids. [1] Nanocomposites are composite materials in which the matrix material is reinforced by one or more separate nanomaterials in order to improve performance properties. Nanocomposites are made by dispersing nanofillers (e.g., silicate and ceramic nanoparticles, CNTs, etc.) into matrix (e.g., some polymers, ceramics, metals, etc.). Comparing with conventional composite materials, nanocomposites have numerous advantages such as high mechanical and physical properties, and high reinforcement efficiency.[2] Polymer-embedded nanostructures are potentially useful for a number of technological applications, especially as advanced functional materials (e.g., high-energy radiation shielding materials, microwave absorbers, optical limiters, polarisers, sensors, hydrogen storage systems, etc.) [3-5] The potential of introducing significant changes in material properties with low contents of Nano sized functional additives justifies the attention given to research of nanocomposites. The paper presents the possibility of creating a new category of nanocomposites, magnetic nanocomposite materials, using magnetic nanofluids (MNF) and resins. [6,7]. MNF, also known as Ferro fluids, are ultra-stable colloidal suspensions of ferri/or ferromagnetic particles – e.g. magnetite (Fe_3O_4) – in various carrier liquids. [8]. The target of our research is to obtain new materials having magnetic and mechanical controllable properties. [9-11]. 1. 6. N. Crainic, A. Torres Marques, Nano - Composites – a state of the art review - Mareriais'2001 – 1 ISBN 0-87849-905-9; 2. Hurang Hua, Landon Onyebueke, Ayo Abatan, Characterizing and Modeling Mechanical Properties of Nanocomposites-Review and Evaluation, Journal of Minerals & Materials Characterization & Engineering, Vol. 9, 2010; 3. G. Carotenuto and L. Nicolais, nanocomposites, Metal-Filled, in the Encyclopedia of Polymer Science and Technology, Wiley, New York (2003); W. Caseri, Macromol. Rapid Commun. 21, (2000); 4. Metal-Polymer nanocomposites, Edited by Luigi Nicolais and Gianfranco Carotenuto ISBN 0-471-47131- 3 2005; 5. Banert, T. and Peuker, U.A., Preparation of highly field super-paramagnetic PMMA-magnetite nano composites using the solution method, Journal of Materials Sciencem, Vol. 41, (2006); 6 N. Crainic, A. T. Marques, D. Bica, L. Vekas, P. J. Novoa, C. P. Moreira de Sa, The Use of the nanomagnetic Fluids and the Magnetic Field to Enhance the Production of Composite by RTM – MNF, Mol. Cryst. Liq. Cryst., Vol. 418 (2004), ; 7. A.T. Marques, N. Crainic, D. Bica, L. Vekas, P. J. Novoa, Control of nanomagnetic fluids during the production of composite parts components in EC-_SF, workshop on Nanotechnology (2002), Grenoble, France; 8. Avdeev, M.V., Aksenov, V.L., Bica, D., Vékás, L, et al. (2006), Journal of Colloid and Interface Science, Vol. 295; 9. N. Crainic, Doina Bica, A. T. Marques, C.C. Popa, P. J. Novoa, Nuno Correia, Oana Marinica, C. P. Moreira de Sa, and L. Vekas, Magnetic nanocomposites obtained using high evaporation rate magnetic nanofluids, International Journal of Nanomanufacturing, Issue: Volume 1, Number 6, (2007) ISSN 1746 – 9392; 10. N. Crainic, D. Bica, N. C. Popa, L. Vékás, A. Torres Marques, P. J. Nóvoa, N. Correia, C. P. Moreira de Sa, Magnetic nanocomposite materials obtained using magnetic fluids and resins, International Journal of Nanomanufacturing,, Vol 6, Nr. 1-4, 2010, ISSN 1746 – 9392); 11. N. Crainic, A. Torres Marques, L. Vekas, P. J. Novoa, N. C. Popa, N. Correia, Oana Marinica, P. Vieira, Particularities concerning the utilization of the magnetic nanofluids with different concentration of nanoparticles to obtain the nanocomposite materials, MECHCOMP2014, Stony Brook University, USA, 2014, BOOK OF ABSTARCT, Edited by A.J.M. Ferreira, Fu-Pen Chiang, Robert V. Kukta;

14486 | Fabrication of Ag-MWCNT composite circuit sintered by Intense pulsed light at room temperature (Nano-Composites)

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There has been much research regarding direct printing on flexible substrates because it is environmentally friendly and is a low cost process compared to conventional vacuum deposition and photolithography. Furthermore, Nanojoining technology with silver nanoparticles has been widely used as alternatives to the conventional bonding processes including soldering and adhesive bonding process due to high working temperature and reliability of sintered Ag joints.
However, high sintering temperature (typically 200 ~ 300 °C) and sufficient sintering time are required to achieve denser structures between nanoparticles. Furthermore, the nanoparticle based circuit generally shows the poor mechanical properties. To overcome these concerns, design of filler nanomaterials and low-temperature sintering process are considered in this work. Intense pulsed light (IPL) sintering is a promising alternative to conventional heating due to its applicability to large-area and short-time processing at room temperature. The microstructural evolution shows that silver nanoparticles form network with sintering at higher pulse power and longer pulse widths. The adhesion and flexibility properties of the IPL sintered silver film were evaluated by a roll-type 90° peel test and IPC sliding test, respectively. The failure mode was analyzed by fracture observation with an optical microscopy (OM) and field emission scanning electron microscope (FE-SEM). The peel strength of Ag composite circuit on polyimide increased up to 32 N/m when the Ag-MWCNT composition was 2 wt.%. It is assumed that MWCNTs enhanced the peel strength and flexibility of composite Ag circuits because MWCNTs act as bridge role between Ag nanoparticles.

14689 | Thermoelectric response of polyethylene terephtalate based composites with multi-walled carbon nanotubes (Nano-Composites)

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Thermolectric behaviour of materials gains increasing attractiveness in the context of sustainable energy management system. Although most perspective presently known materials, used for conversion of waste heat to energy, are based on rear earth metal compounds and their nanostructures, their application is somewhat limited due to toxicity and limited availability of raw materials. Consequently, considerable interest is devoted to the development of alternative materials with thermo-electric effect, capable to replace the existing rear earth metal based compounds in some applications. Especial interest should be devoted to the systems based on engineering polymers due to their increased use in almost every field of national economy. Based on these considerations, the current research is devoted to evaluation of thermo-electric properties of melt compounded polyethylene terephthalate (PET) nanocomposites with various contents (up to 5 wt.%) of multi-walled carbon nanotubes (MWCNTs). Apart from thermoelectric behaviour, thermal, electrical and mechanical properties of the manufactured PET/MWCNT nanocomposites are also revealed depending on the structural peculiarities at the nanofiller surface, polymer-nanofiller interface as well as within the polymer matrix. It is demonstrated that i) storage modulus of the PET nanocomposites increases along with growing MWCNTs content, especially at nanofiller contents above 2 wt.%, ii) glass transition temperature of the polymer matrix increases but the respective cold crystallization temperature decreases as a result of interaction of MWCNTs with both amorphous and crystalline phases of PET, iii) increment of thermal conductivity of the PET nanocomposites with growing MWCNTs content is comparatively smaller than the rise in electrical

conductivity, iv) measured parameters of thermoelectric characteristics (S, PF, ZT) of the investigated PET nanocomposites also increase to certain extent along with rising the nanofiller content.

14789 | Efficient mechanical loading of multilayer graphene sheets (Nano-Composites)

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Model polymer composites based on multilayer graphene flakes can be mechanically stretched to large deformations by adopting a particular ladder-like morphology consisting of consecutively mono-, bi-, tri- and four-layer graphene units. In this type of flake architecture all the layers adhere to the surrounding polymer inducing similar deformation on the individual graphene layers, preventing interlayer sliding and optimizing the strain transfer efficiency. We have utilized Raman spectroscopy to quantify fully this effect. We have subjected to tension various mechanical exfoliated single-, bi-, tri- and few-layer graphene flakes, embedded into the upper surface of a PMMA bar and covered by a polymeric film, while their mechanical response is monitored simultaneously by the shift of the G and 2D Raman modes with strain, using the 514.5 nm (2.41 eV) excitation wavelength. The results suggest that a step pyramid-like architecture of a flake can be ideal for efficient loading of layered materials. This work opens new perspectives in numerous applications including high volume fraction composites, flexible electronics and straintronic devices.

Acknowledgements: The work is part of the project gRaFID funded by the Management Authority of Western Greece Region in the frame of RIS3 "Microelectronics and aAdvanced Materials"

13803 | A Review: Nanomaterials as a Filler in Natural Fiber Reinforced Composites (Natural Fibre Composites)

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Composite reinforcement is defined as a technique to improve the engineering characteristics of composite and a fiber reinforced composite (FRC) is a composite material consisting of a polymer matrix imbedded with high-strength fibers, synthetic fibers or natural fibers. Natural fibers have recently become attractive to researchers, engineers and scientists as an alternative reinforcement for fiber reinforced composites (FRCs). Nanocomposite shows considerable applications in different fields because of larger surface area, and greater aspect ratio, with fascinating properties. Being environmentally friendly, applications of nanocomposites offer new technology and business opportunities for several sectors, such as aerospace, automotive, electronics, and biotechnology industries. Hybrid bio-based composites that exploit the synergy between natural fibers in a nano-reinforced bio-based polymer can lead to improved properties along with maintaining environmental appeal. This review article intended to investigate natural fiber/nanofiller-based hybrid composite with specific concern to their physical and mechanical properties.

13834 | Study of the effect of poly (butylene succinate) (PBS) and poly (hydroxybutyrate-co-hydroxyhexanoate) (PHB) matrix on the interface damage of the Biocomposites (Natural Fibre Composites)

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The alfa fiber has considerable resistance in their natural environment. The objective of our study is to simulate the damage of the fiber-matrix interface of bio-composites based on this alfa fiber and the two poly (butylene succinate) (PBS) and poly (hydroxybutyrate-co-hydroxyhexanoate) (PHB) matrix. Our modeling is based on the calculation of various constraints such as the apparent shear stress and the ultimate stresses and the restitution energy.

The analysis of the results showed us that the shear rate of the interface of the two bio-composites materials based on the natural alfa fiber has been decreased comparing with other composite materials based on carbon fiber and base of the two matrix used poly butylene succinate (PBS) and polyhydroxybutyrate (PHB).

These results confirm that natural fibers actively improve the mechanical properties of composite materials.

13847 | Dynamic tensile properties of natural fibers composites with different components (Natural Fibre Composites)

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There are many type of natural fibers exist in nature. And the components of them are typical different as the raw material plants growing up in different environments. For example, the fibers of swedish pine forests with needle litter are quite different from that of straw. The former has higher density and hardness, but latter has larger ductibility. Therefore, the mechanical properties of them have noticable difference. For the composites which made from those natural fibers, the mechanical properties of the composites are also highly affected by the type of fibers. In this research, the dynamic tensile properties of natural fibers composites are studied with different components at different stress rates by using SHTB. The related stress-strain relationships at different stress rates have been revealed and the macroscopic failure morphology and microscopic failure mechanism have been researched and discussed as well. It could find that the proportion and component are the mainly influencing factors for the natural fibers composites, and the dynamic mechanical properties of the natual fibers composites are very different from that of static mechanical properties.

14337 | Alkali treatment leading to an enhancement of the mechanical properties of a new lignocellulosic fibre (Juncus effusus L.) subjected to tensile loading (Natural Fibre Composites)

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Since the global warming potential and environmental toxicity are increasing in recent years, which has led the scientific and industrial communities to focus their interests on the use of materials of natural and ecological origin focusing their research topics on recyclable, renewable and sustainable materials with less impact on nature. It would be better to take nature into account and try to make the most of it. It is not by coincidence that the year of 2009 has been designated by the United Nations as the International Year of Natural Fibres, to highlight the role of these fibres in the world and to raise public awareness and governing bodies to respect the environment and human health. This has the impact of increasing the demand for products made from natural fibres. The development of the next generation of materials and processes will be strongly influenced by the principles of sustainability, eco-efficiency and green chemistry.

This research concerns the effect of the NaOH chemical treatment, concentration and immersion time of the specimens, on the physicochemical and mechanical properties of a new fibre from a wild plant called Jancus Effussus (JE) and to establish the groundwork for future research related to the development of this fibre as a potential reinforcement in bio-composite materials. The JE fibre, which is prevalent in many parts of the globe, including Algeria, and despite the good toughness and strength properties, it remains unknown industrially but used artisanally. Parts of the roots and marrow of JE have been used as medicinal plants in oriental medicine. The JE rod is formerly used for manufacturing, mats, ottomans and baskets.

In this research, the morphology and diameter of the technical JE fibres treated and untreated were analyzed by optical and scanning electron microscopy, their functional groups were studied by FTIR, their thermal degradation behaviour was examined and deepened from the TG, DTA curves and the degree of crystallinity is determined using X-ray technique. In addition, a mechanical characterization is carried out using the tensile tests of the technical fibre in order to evaluate these mechanical properties, namely the stress and the strain at failure and the Young's modulus. The JE fibres extracted from the plant stem were treated with different concentrations of NaOH from 0.5% to 5% and with an immersion times from 30 min to 72 h. It has been found that an adequate treatment of the fibres could lead to an increase in its ultimate stress and Young modulus by 93% and 150% respectively, while the strain decrease by 12%. In view of the dispersion in the results obtained, the latter were analyzed using the two and three parameters Weibull statistical laws.

Key words: Lignocellulosic fibre, Juncus effusus L., tensile loading, Weibull

14347 | Effect of Benzoylation Surface Treatment on Tensile Properties of Sugar Palm/Glass Fibre Hybrid Composites (Natural Fibre Composites)

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In the last decade, the awareness in using Arenga Pinnata or Sugar Palm fibre in biocomposites has developed since they are low cost, low density and lightweight. However, natural fibre has a weak interfacial adhesion and poor resistance to moisture absorption. This weaknesses can be improved by using surface treatment on the fibre. Surface treatment can produce fibre with cleaner surface, and increase the fibre surface roughness because the treatment will remove non-cellulosic compounds of the natural fibre. Sugar Palm fibre were chemically modified using benzoylation treatment. The tensile properties of the composites were investigated according to ASTM standards. The tensile properties of the Sugar Palm/Glass Fibre hybrid composites were investigated by comparing the tensile properties of both treated and untreated Sugar Palm fibre. Sugar palm fibre were chemically treated with benzoyl chloride before being hybridized with glass fibre. The findings conclude that sugar palm fibre treated with benzoylation treatment resulting improvement in tensile properties of the fibres.

14369 | Morphological study and physico-chemical characterization of natural palm-phœnix dactylifera fibers intended as insulation material (Natural Fibre Composites)

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Energy efficiency has quickly become one of the major issues of our time, and buildings are one of the leading component. They consume more energy than any other sector, and thus contribute to a large extent to climate change. The building sector is the largest consumer of energy as it represents between 30 and 40% of the global final consumption, and 41% of final consumption in Algeria.

The choice of an insulating material is important as a wide range of these are available. However, its selection lies on diverse factors including initial cost, effectiveness, durability, and environment. Inorganic insulating materials have long been used mainly because of their long-term financial benefit. However, they may be harmful to human health and body and may also cause environmental pollution, such as emissions of toxic gas and particle. Moreover, production of these materials is highly energy intensive and the eventual disposal is an environmental hazard.

Therefore, alternative materials having the same or even better properties as the conventional ones need to be explored as they can offer lower cost. This need has prompted research in the direction of renewable fibrous thermal insulation made from trees and plants. The natural fiber is very easy to acquire and it is cheap. It has the ability to regenerate itself, requires less energy for production and biodegrade easily when disposed of as waste leading to a significant reduction of negative environmental impact.

In many countries, increased interest in the use of agro-fibers as building thermal insulation is being researched. Each country tries to take advantage of the natural resources it possesses. In Algeria, the date palm is very widespread and represents a very important natural renewable resource. It has a lifetime that usually exceeds a century in which it remains productive of fruits (dates) and fiber waste (fruit branches, leaves, leafs, etc.). More than 20

million date palms (phoenix dactylifera) produce an average 600 tons of these fibers, including those positioned around the trunk and contributing to its thermal insulation against high temperatures that take place in the Sahara desert where more than 100,000 farms are located.

The present investigation is mainly concerned with the extraction of the by-products selected from three types of date palm trees (known locally as 'deglet el-ghares', 'deglet Nour' and 'Mech deglet'). They have been extracted from the date palm leafs that cover the trunk of these trees. An examination of their morphology (length and cross-section) along with their physiochemical characterization are performed.

The collected fibers were mainly divided into raw fibers, and those chemically treated to clear their surface from impurities, and roughening it in order to improve the adherence fiber-matrix. Sodium hydroxide-NaOH at different concentrations and immersion times is used. The fibers were then immersed into sulfuric acid-H2SO4 before being washed with water and immersed into distilled water. Finally the fibers were dried at 70oC for 6 hours.

The characterization has been carried out using diverse techniques. The Thermal Gravimetric Spectroscopy Analysis-TGA was performed from ambient up to 600oC whereas the Fourier Transform Infrared Spectroscopy Analysis-FTIR led to an identification of the spectra between 500 and 4000 cm-1. Finally, Differential Scanning Calorimetry-DSC tests were performed.

The results obtained were compared to those available in the specialized literature.

Key-words: Date palm fibers, Insulation, SEM, TGA, DSC, FTIR

14375 | Mechanical properties of composite material reinforced with short natural Alfa fibers (Natural Fibre Composites)

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This paper presents an experimental study of mechanical characterization of composite materials reinforced with short Alfa fibers, obtained by extraction of stems raw Alfa. An alkaline chemical treatment under different durations applied to the fibers and a mechanical behavior analysis was studied of PP/Alfa samples with different volume fiber fractions. An SEM observation affected to the fracture surface samples PP/Alfa to improve the interfacial adhesion morphology of the material. There're important increases of the Young module of PP/Alfa with deferent volume fraction compared to Neat PP.

14394 | Mechanical properties and damage behavior of polyamide 6/basalt fabric composite laminates (Natural Fibre Composites)

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Thermoplastic composites have gained an outstanding interest because of their higher mechanical properties and damage tolerance, chemical resistance, infinite shop life, intrinsic recyclability and shorter manufacturing cycles compared to their competitor based on thermosets. On the other hand, the growing sensitivity towards environmental concerns have strongly promoted the replacement of traditional reinforcements as glass or carbon fibers with natural ones demonstrating great potential for use of so-called natural fiber composites (NFCs). In this frame, recently a special attention is ever more dedicated to systems involving basalt fibers (BF) [1] because of their high strength and elastic modulus with respect to glass fibers [2] as well as their higher impact performances and wider application temperature range if compared with Kevlar ones. Basalt fibers, derived from a natural volcanic rock, have been successfully included in many thermosets and thermoplastic resins giving rise to products with very interesting performances as witnessed by a significant number of evidences available in the literature [3,4].
This research was focused on basalt composite laminates based on a commercial polyamide 6 (PA6) matrix. PA6 is a semicrystalline thermoplastic resin widely used in several engineering applications due to its outstanding mechanical properties, processability, good resistance to solvents, high strength and high wear resistance. However, with the aim to overcome some disadvantages as the low heat deflection temperature, high water absorption and dimensional instability and to further expand its applications, the inclusion of reinforcing fibers results to be a common and appealing strategy. In more details, symmetric plaques [(0/90)9]s based on a neat polyamide 6 (PA6) films and a commercial plain wave basalt fabric are obtained by conventional film-stacking technique and adequately cut to produce specimens for flexural and low-velocity impact tests. Results are averaged on at least 5 determinations and compared with typical mechanical parameters of the matrix processed under the same conditions.
Preliminary flexural tests showed that the presence of the basalt fibers induces a significant rise of the mechanical parameters with the modulus increasing of an order of magnitude and the flexural strength which is almost quadrupled.
Work is in progress to investigate the mechanical behavior of PA6/basalt composite laminates under low-velocity impact loading and to highlight involved damage mechanisms by both non-destructive and morphological observations.

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14404 | Low velocity impact tests on Basalt Fibre Laminates at Room and Low Temperatures (Natural Fibre Composites)

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Basalt fibre are nowadays under attention for applications in civil, naval and automotive fields, potentially replacing glass ones. The main reason of the interest is the increasing importance of the environmental aspect that has promoted the use of natural fibres as reinforcement in polymer matrices. Since their very good mechanical properties, in static and dynamic conditions, the application of basalt laminates like structural components is under investigation.
The dynamic behaviour and the impact damage represent a major threat in the field of composite materials and basalt fibres laminates have already shown some potential in terms of energy absorption, as detailed in [1], and so of the damage.
All the most common aspects and the criticities related to their inhomogeneity and anisotropy nature were observed, in particular about the damage formation and the interaction between the different failure modes. These aspects are further exacerbated when considering applications on marine vessels, where extreme temperatures, in some cases, and the fluid-structure interaction, must be taken into account.
Basalt woven fabrics (0, 90) were stacked in 16, 22 and 30 layers and impregnated by vinylester resin by resin infusion fabrication technology. From the obtained laminates, rectangular specimens were cut and impacted at low velocity at increasing energy levels up to penetration, at room and low temperature of -50°C. The commonly used ultrasound non-destructive technique, UT, was used to investigate the internal damage onset and propagation. A low delamination extension was, in general, noted at room temperature and it was confirmed in extreme temperature too. Respect to what observed on CFRP laminates, the internal damage seems to be confined in a limited area under the impactor/material surface contact point. Lower absorbed energy and lower delaminated areas were measured at low temperature.
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14429 | Influence of drill point angle on the drilling of biocomposites (Natural Fibre Composites)

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Nowadays, biocomposites have been considered promising materials to replace traditional composites in specific applications. Normally, these biodegradable composites are manufactured with synthetic matrices (epoxy, polyethylene...) and natural fibers as reinforcement. However, in order to obtain 100% biodegradable composites, synthetic matrices can be replaced by natural matrices, being those of polylactic acid (PLA) the most used. The use of these 100% biodegradable materials reduces the impact on the environment. Moreover, the replacement of traditional composites by biocomposites means a reductions of health hazards. In addition, it allows to reuse waste from mills and farms, which in turn can be reused after the life cycle of the biocomposite.

Although the composite materials are manufactured with geometries very close to the required final size, assembly operations are necessary to joint different components. The joints between elements of composite material can be adhesives or fastened joints that need a pre-machining process, being drilling the most common.

The studies related to the drilling processes on 100% biodegradable composite material are almost non-existent, and generally are focused on the establishment of optimal cutting parameters for the reduction of the damage generated during the process, mostly fraying. The geometry of the drill as well as the feed in conjunction with the cutting speed are the most influential parameters during the drilling of biodegradable composites. Taking into account the geometry of the drill, one of the most critical elements in the generation of damage during the processing of the composite material is the point angle of the drill, a parameter that has not been analysed in previous studies related to the biodegradable composite.

The aim of this work is to analyse the influence of the point angle of the drill on the damage generated during the drilling of the 100% biodegradable composite material. The samples were manufactured from flax fiber as reinforcement and polylactic acid (PLA 10361D) as matrix in different thicknesses. Moreover, the effect of the point angle in relation to the optimal cutting parameters on the thrust forces was analysed. The 6 mm diameter HSS twist drill analysed have point angles of 118°, 100°, 90°, 80° and 70°. The influence of point angle was studied by means of a FEM model developed in ABAQUS/Explicit that was validated through comparison with experimental data.

14466 | Biocomposites based on polypropylene and spent coffee grounds: Production and properties. (Natural Fibre Composites)

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The main focus of this study is to elaborate a new bio-composite by compounding polypropylene (PP) as a matrix and spend coffee ground particles (SCG) residue, after soluble coffee preparation, as reinforcement. In this work, we performed firstly a bio-composites containing several black SCG particles contents (5, 10, 15 and 20 wt.%) in order to investigate the effect of particles loading on thermal rheological and mechanical properties.Then, the effect of bleaching treatments and the use of compatibilizers (silane and styrene-ethylene-butene-styrene-graft-maleic anhydride) on the biocomposites properties at 15 wt. % was examined. In this purpose, extrusion and injection techniques were used to prepare the different bio-composites. SEM micrographs show a good dispersion and distribution of SCG particles into PP matrix leading to good performances of the bio-composites. After treatments micrographs reveal an enhancement of PP/SCG treated particles adhesion, which furthermore increase with the addition of coupling agent. As a consequence, the tensile and torsional properties enhance to achieve a maximum for bio-composite at 15 wt.%. Moreover, chemical treatments and coupling agent enhance also bio-composite's properties compared to bio-composite with black (raw) SCG particles.

14484 | Tooth bending fatigue strength of birch fiber reinforced composite gear (Natural Fibre Composites)

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Natural fiber composites present mechanical properties that are comparable to those of some non-degradable materials. With there interested mechanical

properties they can compete with technical plastics according to Mejri et al. . However, the use of this type of composites for the design and manufacturing mechanical components requires a prior evaluation of its mechanical behavior. The engineer who designs a mechanical component must dimension it with respect to the following perspectives: considering the maximum load to which the component is subjected, which is referred to as static dimensioning, and considering the evolution of load along service, which is referred to as fatigue analysis. Following the environmental advantages of bio-composite, the application to low torque gearing must go through a fundamental to application chain. The present step follows the more fundamental tension and 3-points flexion tests and is prior to the rotation fatigue test.
The current work implies gear samples tested in bending fatigue mode on a single tooth. The aim is to quantify the fatigue life of birch fiber reinforced high-density polyethylene (HDPE). The custom-made bench test for single tooth testing is presented with the used material. The expected results include evolution of the fatigue life according to the imposed displacement.
The short fibers used are yellow birch fibers with mean length of 0.49 mm and 24.7 μm mean diameter. The HDPE is HDPE Clair 2909 by NOVA Chemicals. A coupling agent, Maleated polyethylene (MAPE) (G2010) was also used to enhance the fiber to matrix cohesion. The fiber percentage of the reinforced samples is fixed to 40%, with 3% MAPE. The materials are mixed with hot rollers, grind into small chunks then melted and pressed into a three pieces mold. The choice of fiber rate (40%wt) is based on results obtained by Bravo and al. . They have notably shown that using 40%wt of short birch fibers as reinforcement brings about mechanical properties that are similar to those of some plastic materials such as Polyamide (PA6 and PA11) better known under its industrial name “Nylon”.
The test bench was designed using reviews of the SAE J1619 norm. It was designed around 3 inches pitch diameter, 0.25-inch-wide and diametral pitch of 10 gear samples, but is adjustable to fit larger and smaller gear samples. It provides a vertical linear tangential action on a single tooth. The gear is prevented from rotating by an anvil at the root of the second tooth from the tested one, ensuring that the tooth loaded in flexion breaks first. The contact point is adjustable through the gear angle by the height of the anvil.
Experimental variables were fixed based on previous work on the same material, allowing for easier analysis and comparison. The loading frequency is fixed at 10 Hz. Controlled variable is the displacement due to the low value of recorded force during static tests. Five displacement levels will be used to get a complete view of the fatigue curve.
Preliminary results show a diminution in the ultimate static force with the addition of birch fibers, from 682 N to 400 N for samples as described above. The displacement at failure is reduced from 3.6 mm to 1.02 mm. That implies an increase in the tooth stiffness from 286 N/mm to 390 N/mm with the fibers. The major difference between the sample types resides in the behavior. The 40% reinforced samples exhibit brittle fracture with a little plastic deformation area. As for the unreinforced gear, they present ductile fracture with a large plastic deformation. Expected results include fatigue curve and distribution at each imposed displacement. Relative standard variation comparison between the reinforced and unreinforced samples will confirm or infirm the observed quasi-static behavior. Furthermore, the evolution of fatigue life will be studied to justify the utilization of birch fiber in gear application.

14495 | A study of the impact of fiber content on the durability of flax fiber-reinforced epoxy composites (Natural Fibre Composites)

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Due to the current environment issues awareness, public authorities are looking for new ways to make the cities more appealing to the population. Therefore, the demand for ecological solutions for urban outdoor equipment is rising. Academic and industrial researches have a growing interest for bio-composites, in particular plant fiber-reinforced composites. This makes them a good alternative to the usual fossil resource-consuming composite materials.
One major issue with plant fiber-reinforced composites, along with obtaining high fiber content, is their durability when exposed to water or moisture. In a previous work, losses in mechanical properties after water vapor sorption were observed. A change in the tensile behavior was also noted, in accordance with the observations on the plant fibers.
As for immersion in distilled water at 23°C, some authors observed these losses of properties, but also some contradictory results, highlighting the need of more investigations. In their works, Munoz and Garcia-Manrique observed an increase of the ultimate tensile strength by around 30 %, but Scida et al. observed a decrease of the ultimate tensile strength by around 10 %.
The purpose of this work is to analyze the impact of water sorption at 70°C in distilled water on the mechanical behavior of unidirectional flax fiber-reinforced composites obtained by thermocompression of 20 plies of 110 g/m2 UD flax fibers (FlaxTape™ from Lineo©) manually impregnated by a DGEBA epoxy resin (SR 8500 with SZ 8525 hardener from Sicomin©). This study, which concerns two composites with different fiber contents, addresses the evolution of their microstructural and mechanical properties during and after saturation in distilled water at 70°C.
The properties of the two composites were measured under ambient conditions (23°C, 50 %RH) as the reference state. The first composite material, called “1 bar” as a reference to the processing pressure applied, exhibits a 37.7% volumetric fiber content. The second one, called “3 bars”, has a 51.1% volumetric fiber content. Parallelepiped samples of these two materials were immersed in distilled water at 70°C until the moisture equilibrium was reached. This equilibrium was achieved after 26 days of Fickian sorption and the water uptakes were around 12 % for “1 bar” and 15% for “3bars” (compared to samples stored at 23°C and 50 %RH).
In order to follow the evolution of stiffness and damping through the sorption process, modal analyses in free vibrations (through impulse response) were conducted at specific times of immersion. Tensile tests have been conducted (before and after immersion) on 3 kinds of unidirectional samples: 0° oriented fibers, 90° oriented fibers and 45° oriented fibers.
The first noticeable result of this work is the linear dependency between the modulus and the gain of mass of the samples. Indeed, the modulus decreases linearly with moisture uptake to half its original value at saturation, with the same rate for “1 bar” and “3 bars” composites. Also, the vibration damping ratio increases linearly with the water sorption and is more than doubled.
Then, it was found that the difference of stiffness between “1bar” and “3bars” composites before immersion, mostly due to difference in volumetric fiber content, disappears after immersion. Also, water sorption vastly reduces the stiffness and strength of the composites and non-linear tensile behavior appears. This non-linear behavior seems to be fiber-dependent since the “3 bars” composite was more affected.
The results in all fiber directions give a clear state of how these composites evolve with water sorption. However, work is in progress to complete these results through quasi-static tensile tests with unloads in order to characterize the visco-elasto-plastic behavior and through fatigue tests on immersed samples. Also, a numerical model is currently being developed in order to use these composites in structural urban outdoors applications.

14535 | The Effect of Fibre Length on the Tensile and Sorption Properties of Natural Fibre Composites (Natural Fibre Composites)

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Critical fibre length affects the integrity of the mechanical properties of a composite, in particular, the tensile strength. Predicting the critical fibre length using theoretical relations becomes complex when dealing with discontinuous, randomly oriented natural fibres which are subject to microscopic flaws and structural variations. Kenaf and flax fibre reinforced polypropylene composites were investigated where fibres were cut to 5, 10, 20 and 30 mm mean fibre length (MFL). Chemical modification was conducted in three phases of alkanisation, neutralisation and silanisation to increase the interfacial adhesion between the hydrophilic fibres and hydrophobic matrix. The prepared natural fibres were mixed with polypropylene fibres in fibre weight fractions of 15, 20, 25 and 30 percent and were processed into nonwovens using two cycles of carding and needlepunching. Composite plates were then manufactured by compression moulding 10 layers of nonwovens. Tensile specimens were prepared in accordance to ASTM-D638. There is a large difference (up to 60% in some cases) between yield and ultimate tensile strength (UTS) due to the ductility of the polypropylene fibre. The peak tensile strength occurs at an MFL of 10 mm for flax samples and between an MFL of 10 mm and 20 mm for kenaf samples. The maximum UTS achieved was 81.8 MPa and 77.3 MPa for flax and kenaf samples respectively. The maximum yield strength was 62.1 MPa for flax and 50.8 MPa for kenaf samples. An ‘effective fibre length’ was used to describe the actual fibre length subject to tensile testing as the initial prepared MFL was limited by the gauge dimensions of a test specimen being 13 mm x 50 mm. A software code was written to analytically estimate the effective fibre length. Using this model, it was deduced that the critical fibre length for flax and kenaf samples manufactured using the prescribed methodology was 11.4 and 10.2 mm respectively. Water absorption was conducted under the specifications of ASTM-D570 where samples were cut into discs, 50.8 mm in diameter, and submersed into distilled water. Three additional specimens were cut per batch and covered with 1 micron thick adhesive polypropylene film on both circular surfaces to ensure that diffusion predominantly occurred through the circumference of the specimen. Specimens were weighed after 1 hour and 24 hours of submersion, with weekly weigh-in intervals thereafter. Sorption results reveal that on average, sorption increases with MFL and fibre weight fraction. The covered samples, unintuitively, saturated at a higher mass percentage than uncovered samples. This may have resulted due to degraded fibre build-up being confined by the polypropylene adhesive film on the samples. Samples between 5 and 10 mm MFL absorbed the least amount of water, saturating at 6.5 and 7.8% for covered kenaf and flax respectively. The effective fibre length was similarly analytically determined to be 8.9 mm for flax and 9.1 mm for kenaf water absorption samples. Design points are discussed, exploring the optimum effective fibre length and fibre loading in discontinuous, randomly oriented natural fibre composites. To achieve the highest water resistance whilst being the strongest in tension, it is deduced that prepared fibres of approximately 10 mm MFL are optimal. Since discontinuous, randomly oriented natural fibre composites are cut to limiting dimensions given by the relevant standard, it is suggested that standardised testing in these cases are rig dependent. Furthermore, such a result would infer that scaling data to meet design dimensions would be inaccurate as the effective fibre length would change in every case.

14757 | Development of a new green concrete made of recycled aggregate and natural fibers (Natural Fibre Composites)

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Green concrete has drawn more and more attention worldwide in recent years, due to the ever increasing demand for concrete, the exhaustion of resources and the environmental impact of building materials. Recycled aggregate (RA) is obtained by crushing the concrete components of construction and demolition waste (CDW), which is recyclable. However, concrete with RA (RAC) has usually a lower quality than the natural aggregate concrete (NAC) because of the weak interfacial transition zone (ITZ) between RA and new cement mortar. Natural fibers (NF) such as hemp, coir or bamboo are generated from agricultural and industrial residues and are known to have high specific strength and stiffness. They are also cheap and renewable, making them the ideal candidates to create green composite materials. In this study, NFs are used as reinforcements, in order to increase the crack resistance, the toughness and the ductility of RAC, especially in ITZ. Then, the development of a new natural fibers reinforced recycled concrete (NFRRAC) with 100% RA (both coarse and fine aggregate) replacement is investigated. Different types and volumes of NFs will be introduced to dry mortar mixes and the mechanical and physical properties of the new material are studied.

14765 | Mechanical characterization of Andean natural fiber: Furcraea Andina (Natural Fibre Composites)

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In these report mechanical properties of natural fibers extracted from the Furcraea Andina is presented. The Furcraea Andina, commonly called Cabuya, is a plant that grows in the Andean region from 2200 to 2800 m.a.s.l. Single fibers were tested according to the ASTM C1557 and D 3822 and properties like strength, failure strain, modulus of elasticity were determined. The effects of fiber length, test speed, and alkali treatment on the mechanical behavior were determined as well using two parameters Weibull statistics. Results shows a slight reduction in stress and strain values with length increment and the testing speed doesn’t shows significant effect on the mechanical properties; furthermore, improvement of mechanical properties with the alkali treatment were observed. Finally, average strength of 600 MPa, modulus of 22 GPa, and failure strain of 4% were obtained.

14473 | Sparse representation based approach for acoustic emission signal identification in glass-epoxy composites (Non-destructive Inspection Techniques for Composite Materials and Structures)

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In this work, a new approach for the damage mechanism identification in glass fiber reinforced polymer composites (GFRP) was introduced. This approach is based on the sparse representation (SR) technique applied on recorded acoustic emission (AE) signals. The SR is trained to offer a novel representation of signal; it consists to approximate the signal by selecting a small number of elements in over complete dictionary. The proposed technique used a redundant dictionary specific to various damage mechanisms, which could appear in composites. Experiences were carried out on model specimens of GFRP composite in order to produce particular damage modes. These latter were used for the learning process leading to establish the redundant dictionary. The proposed classification procedure was examined on the signals of learning as well as on the test signals. This study has revealed the interest provided by the SR of signal to follow the damage mechanisms in composites.

14541 | A multi-function programmable system for damage detection (Non-destructive Inspection Techniques for Composite Materials and Structures)

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Structural health monitoring (SHM) based on guided waves allows assessing the health of a structure due to the sensitivity to the occurrence of delamination. However, wave propagation presents several complexities for effective damage identification in composite structures. An efficient implementation of a guided wavebased SHM system requires an accurate analysis of collected data to obtain a useful detection. Non-destructive measurements of an electromechanical impedance allow for the effective assessment of the state of mechanical structures. Piezoelectric transducers, which are distributed in monitored structures, introduce coupling between mechanical properties and directly measured electric entities. Therefore incipient mechanical damage can be detected and its growth followed. This work presents an hybrid damage detection system based on both electromechanical impedance method and a statistical damage index approach, useful to reconstruct the damage appearance. Experimental tests carried out on a composite laminate demonstrated the effectiveness of the developed multi-function system.

14744 | A Comparison Between Portable Raspberry Pi based Digital Shearography and Laboratory Based Digital Shearography for Defect Detection in Composites (Non-destructive Inspection Techniques for Composite Materials and Structures)

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Digital shearography is a non-destructive inspection and evaluation technique and can be used among other for the detection of defects in manufactured composite materials and parts such as aircraft components, composite yacht hulls and masts, wind turbine blades and composite pressure vessels to name but a few.
The inspection method employs a monochromatic laser light to illuminate an object under inspection. For testing purposes, the object is stressed using either thermal, mechanical or vibratory methods and the resultant interferometry based speckle patterns of the object's geometric response to the low level induced stresses are recorded. Suitable image processing of the acquired speckle images is applied to yield fringe patterns representing the object's displacement gradients due to the applied stress. Should the inspected part contain a material defect, its presence can be identified by localized fringe anomalies present in the produced fringe patterns.
Due to the large capital outlay of dedicated digital shearography inspection systems, the authors have been developing a low cost digital shearography system which should be better suited for portable in-situ inspection applications, or in instances where the capital outlay of a dedicated system is not justifiable. The system is based on the Raspberry Pi credit card sized PC which is coupled to a regular USB3 based digital camera. Python based software is used to control the image acquisition, processing and fringe generation requirements of the inspection method.
In order to evaluate the feasibility of this low cost prototype and in particular to determine the defect detection capability of this system, a project was put in place which investigates the defect detection ability of the prototype in comparison with the department's laboratory based digital shearography inspection system. Three composite panel samples manufactured out of carbon fiber and Nomex, fiberglass and balsa wood, and carbon fiber and foam were prepared with man-made defects which included internal delaminations, internal cracks and outer skin removal.
The samples were first inspected using the laboratory based digital shearography system. The samples were then inspected using the Raspberry Pi based prototype digital shearography inspection system. For both inspection procedures the same object stressing methods and intensities were applied to the prepared samples. The results obtained from both inspection systems are presented. The defect detectability, fringe visibility, fringe density and image refresh rate are some of the results that are compared between both systems in order to determine whether the Raspberry Pi based prototype can be considered as an viable digital shearography inspection system.

14490 | Optimization of variable stiffness laminates using differential evolution. (Optimization techniques and methods)

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To take full advantage of the mechanical properties of fibrous composite materials, fiber orientation within the material can be tailored for custom purposes. Fiber orientation and geometry can influence the mechanical behavior of composite parts, including its behavior under dynamic loading. The stacking sequence of a laminate can then be optimized in order to meet stiffness and strength criteria [1].
To solve the optimization problem the differential evolution (DE) optimization technique is used. DE is a stochastic optimization technique developed by Storn and Price [2]. It is a population based, stochastic function minimizer that may be initialized by sampling the objective function at multiple, randomly chosen initial points.
In order to evaluate the objective function, a numerical meshless method is used. The RBF meshless method is simple to implement and capable of producing accurate results.
AKNOWLEDGEMENTS
The support of Ministério da Ciência Tecnologia e do Ensino Superior and Fundo Social Europeu (MCTES and FSE) under programs POPH-QREN and Investigador FCT and grant SFRH/BPD/111846/2015 from FSE are gratefully acknowledged.
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14502 | The role of laminate stiffness matrices in the ballistic limit of composite laminates subjected to high velocity impact: An analysis using FEM and Artificial Neural Networks (ANN) (Optimization techniques and methods)

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From the 80s, the behavior of composite materials subjected to high velocity impacts has been studying through experimental tests, mainly gas gun impacts. At the same time, researchers have developed different material models implemented in explicit finite elements codes which have been able to reproduce the experimental behavior of composite subjected to this type of dynamic loading. The use of this combined methodology has revealed the different failure mechanisms promoted during the impact, and the influence of the impact and laminate parameters in the problem. Nevertheless, these techniques are not appropriate to analyze the wide range of possibilities in the design of laminates (a great amount of time and economic resources are required); therefore, more efficient methods would be desirable.
This work presents the capability of an ANN approach to study the influence of specific laminate parameters in composite plates subjected to certain loading cases. In particular, it has been analyze the role of laminates stiffness matrices ([A] and [D]) in the change of the laminate ballistic limit when subjected to high velocity impacts. For this purpose, it has been obtained the ballistic limit of different ply stacking sequence laminates, therefore varying the laminate stiffness matrices between them, using an appropriate ANN. Afterwards the post process of the relation between laminates stiffness matrices ([A] and [D]) and the ballistic limit have uncovered its influence on the laminate impact behavior.
In order to obtain a refined ANN tool, a combined methodology of experimental and finite element method has been used. First it has been developed a numerical FEM model in the commercial explicit FEM code LS-DYNA to reproduce the impact phenomenon. The material model for the laminate takes into account different intralaminar failure mechanisms and the use of cohesive interactions allows reproducing the interlaminar damage. The results of the FEM model are compared with experimental data to proof its validity. Once validated, the FEM model is used to provide data for the ANN for the training process. Finally the trained ANN is able to predict accurately the ballistic limit of composite laminates studied.
In this study, it has been used 12 plies of AS4/8552 squared plates (110mm side) subjected to a 7.5mm tempered steel sphere impact. The velocity has been varied in a range of 70-200 m/s in order to obtain the ballistic limit for the plate. The ply stacking sequences analyzed has restrained to symmetrical cases with conventional ply orientation (0, 90, +45, -45), in order to obtain recommendations for industrial applications. The ANN allows studying very efficiently the whole possibilities of laminate stacking sequence using the common orientations, in symmetric 12 plies laminates (4096 cases). Conclusions obtained of the role of laminate stiffness matrices can be used by composite design engineers to improve ballistic performance of composite plates.

14504 | Design Optimization of Composite Blade Stiffened Panel using Genetic Algorithm (Optimization techniques and methods)

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This paper explains the design optimization of blade stiffened panel made of composite materials using Genetic Algorithm (GA). Structural break down method is used to simplify the stiffened panel model into plates with certain boundary conditions. Objective function of GA optimization process is constructed analytically from composite plate buckling equations. A numerical study using Finite Element Method is presented to check the design optimization result. Two cases of compressive load design point are studied to compare the optimization results. Optimization process shows that the formulation of the objective function, structural breakdown boundary conditions and the magnitude of buckling load design are influential on the validity of the optimization. Final design optimization results show that the solutions are not unique. The higher compressive load input will have more variety of solutions which are close to the design point. The error between the optimization results and the design point could be less than 5%, meanwhile the maximum error between the finite element analysis and the design point is less than 16%. MATLAB is used intensively for the design optimization process.

14634 | Achievable Bounds in Frequency Domain for Frequency Response Optimization of Laminated Composite Materials (Optimization techniques and methods)

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The frequency response of a fiber reinforced composite plate in various fiber angles in different layers is investigated. A parametric finite element model for a carbon fiber reinforced epoxy laminated plate is created and a harmonic load is applied on the middle of the plate. The analyses are done at multiple harmonic frequencies with different fiber angles. The vibration magnitudes are obtained as the excitation frequency changes for given fiber angle sets. Thus, different plots are evaluated accordingly and the effect of fiber angles is considered. For a given material, it is desired that the vibration magnitude is low around working conditions and high around natural frequency. In other words, frequency response magnitude curves are desired to be flat around working frequencies and steep around natural frequencies. The upper and lower limitations of such conditions such as the flatness of magnitude curves around working frequencies and steepness of magnitude curves around natural frequencies can be obtained by using Nevanlinna-Pick interpolation equations. Accordingly, Nevanlinna-Pick interpolation equations were applied to achieve reachable flatness of magnitude curves around working frequencies and steepness of magnitude curves around natural frequencies. Once the physical limits are known, it is possible to make a correlation between fiber configuration and performance under harmonic load and the load frequency. Mathematical formulations of the associated optimization problem, corresponding Nevanlinna-Pick interpolation equations and numerical results are presented for a sample laminated plate.

14672 | Design of a damping system for smart FGM beam by PDSO (Optimization techniques and methods)

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The employment of Functionally Graded Material (FGM) was introduced in order to mitigate the problems that arise at the interface between two joined different materials. The FGM are characterized by properties that vary microscopically in a predetermined manner (Swaminathan et al., 2015). The use of piezoelectric materials, on the other hand, has growing up due to their inherent capability to react to external stimuli or input and to sense any modification to either their own state or modification of host structure, see Gaudenzi (2009). The properties of piezoelectric materials, able to couple electrical field and elastic deformation, have been widely integrated with structures to control deformations and vibrations. These intrinsic characteristics have opened effective applications of these materials in the framework of active and passive vibration control (Hagood and von Flotow, 1991; Vasques and Rodrigues, 2006). In particular, the reduction of structural vibration can be achieved by both active (Gaudenzi et al., 2000) and passive control (Thomas et al., 2012). Several studies have been performed to analyse the FGM structures coupled with piezoelectric patches (Bian et al., 2006; Bruant and Proslier, 2015). To assemble a damping system based on active control it is necessary to bond on the host structure at least two piezoelectric devices, a sensor and an actuator, conversely the passive damping of the vibrations requires a piezoelectric device shunted to a suitable external electrical circuit that represents a

simpler and cheaper technique. On the afore-mentioned basis, a finite element design approach for a damping system to be applied in functionally graded beams integrated with surface piezoelectric devices is presented in this paper. Finite Element model, developed by the authors, implements the first-order shear deformation beam theory and is based on the preliminary analytical condensation of the electric state to the mechanical state. This allows to establish an effective mechanical beam kinematically equivalent to the original smart beam including the effects of electro-elastic couplings. The contributions of the external electric loads are included in both the equivalent stiffness properties and the equivalent mechanical boundary conditions. The state space representation is invoked for the assembled smart beam finite element model to favour its implementation in a block diagram environment for multi-domain simulation. Population Decline Swarm Optimization (PDSO) procedure is used to select the optimal parameters in order to optimize the damping system performance. The PDSO procedure is based on a decline demographic model and implements an high global minimum search capability and reduced computational efforts to obtain the optimal selection. Results and solutions for different circuitry arrangements are considered to show the versatility and effectiveness of the proposed model in simulating vibration damping of active systems.
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14460 | Metamodel-based uncertainty quantification for braided composites with manufacturing considerations **(Probabilistic modeling and reliability of composites)**

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Stochastic analysis in engineering sciences takes into account the uncertainties that may exist and affect a certain physical system in an a priori unknown manner. As the design of structures gets increasingly complex over the years, the impact of those uncertainties onto the system response has to be studied in order to implement numerical procedures for virtual testing platforms.
Braided composites are of special interest for the aerospace and the automotive industry, due to their excellent performance in terms of stiffness/strength-to-weight ratio, delamination resistance, impact properties etc. The complexity of such materials sets a computational challenge when it comes to robust and reliable simulations. Efficiency also plays an important role for probabilistic assessments since the response variability needs repetitive procedures in order to be calculated (e.g. Monte Carlo simulations). Hence, the aim of this work is to present an uncertainty quantification framework for braided composites simulation, dealing with the stochastic stiffness and strength prediction via numerical multiscale analysis. The computational burden of Monte Carlo analysis is bypassed with various metamodeling techniques, such as Neural Networks, Polynomial Chaos expansion and Kriging modeling. Uncertainties accounting for material properties randomness, geometric randomness but also for random spatial variations caused by manufacturing aspects (e.g. fabric compaction during molding, jamming actions during braiding), are propagating through the scales to the final scatter of the mechanical properties of the macroscale.
Results offer a perspective on the variability influence of the random parameters, an overview of the performance of several surrogate models and also highlight the importance of realistic uncertainty quantification. Furthermore, this work provides a useful guidance for uncertainty propagation assessment with advanced non-intrusive metamodeling techniques.

14525 | Reliability of three-layer beams under stochastic excitation **(Probabilistic modeling and reliability of composites)**

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The paper presents the assessment of the reliability of three-layer beams subjected to a random dynamic load. Two beam models are considered: a classic sandwich beam with a rectangular cross-section consisting of two thick, stiff facesheets and a thick core, and also a Flügge beam that is reinforced with laminates. A static model of a simply supported beam subjected to various models of dynamic loads was assumed for both beams. The vibrations of both beam models are described by a set of two differential equations, one of which is a partial equation and the second an ordinary differential equation. Multilayer constructions are now widely used, and despite many strength attributes, they are characterized by the multitude and variety of forms of destruction, including: 1) global buckling of a structure, 2) delamination combined with local buckling of laminates, 3) shearing of the core, 4) local depression of the surface or buckling of a single cell (applies only to structures with a core with a reticular structure). Determination of the most probable form of destruction is a very important issue and is the basis of a lot of scientific research. The Cornell reliability index was adopted in the paper as a measure of the safety of a structural element.
The aim of the work is to present a computational algorithm that can be used to calculate such an index for bended layer beams. The use of the adopted models of sandwich beams in real conditions is completely different - sandwich beams are mainly used as new structural elements, while Flügge beams that are reinforced with laminates increase the strength of an existing element. Due to coherent elements in the equations that describe the vibrations of both beams, the authors decided to conduct a comparative analysis.
The paper evaluates the reliability of three-layer beams with respect to the possible mechanism of destruction, type of load, material characteristics and the geometry of the beam's element.

14527 | Reliability Based Design optimization of composite repair structure for gas corroded pipeline **(Probabilistic modeling and reliability of composites)**

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One of the most important challenges in engineering design is uncertainty. Most of the input parameters in structural design have a random nature.

Structural design would need accurate and efficient methods to consider uncertainty in loading, geometry, material properties, fabrication process and functional conditions of the structure. The commondesign method is allowable stress/strain with determinestic parameter approach. In this study, an investigation into the design of rehabilitated pipelines under reliability constraint is conducted. The limitstate function is defined based on ASMEPCC-2, and reliability analysis is conducted using the FORM method. target reliability index is described in ISO 2394. The method presented in this paper, taking into account the uncertainties, offers a high lifetime composite repair and high reliability for corroded gas pipelines.

13831 | Design of imperfection-insensitive hierarchical cylindrical shells enhanced by hybrid fibers (Stability of Nano, Micro and Macro Composite Structures)

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Due to the high specific stiffness and strength, composite cylindrical shells have been widely used in the fuel tanks and inter-stages of launch vehicles. As the shell structures are relatively sensitive to the actual geometric imperfections, there is a large knockdown factor for the actual buckling load by compared with the theoretical buckling load. In the nature, many biological structures show an excellent resistance to structure imperfections due to their hierarchical characteristics. Inspired by this, we develop and design a novel imperfection-insensitive composite shell from the point-of-view of increasing its material hierarchy, by introducing the long and short hybrid fibers into the composites. Firstly, the novel numerical implementation of asymptotic homogenization (NIAH) method is derived and used for the numerical prediction of the effective stiffness coefficients for composite RVE with hybrid fibers, indicating a higher prediction accuracy than other equivalent methods. Then, the explicit dynamic method is employed to calculate the collapsed load of the perfect composite shell and the Single Perturbation Load Approach (SPLA) is chosen as an effective method to evaluate the knockdown factor (KDF) for the imperfect model. Furthermore, an optimization framework is established for the design of imperfection-insensitive hierarchical cylindrical shells. Among the optimization process, the volume fractions of long and short fibers in the composite RVE, together with the layer thickness are set as optimization variables. The optimization objective is to maximize the KDF of the hierarchical cylindrical shell. The larger the KDF is, the more imperfection-insensitive the structure is. The constraint condition is that the perfect collapse load is not smaller than the design load and structural weight is not larger than the design weight. By means of an illustrative example, the effectiveness of the proposed design and optimization framework is validated. In comparison to the traditional composite shell, the hierarchical composite shell with optimal volume fractions of hybrid fibers behaves less imperfection-sensitive and can be regarded as one robust design. In particular, the high bending stiffness caused by hybrid fibers is considered to be a key point for the hierarchical composite shell to resist the imperfection, which is an interesting conclusion for the design of hierarchical composite shells.

14448 | Experimental and numerical investigation of warpage in particle loaded thin composite plates (Stability of Nano, Micro and Macro Composite Structures)

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Fibre-reinforced composites loaded with micro/nano particles are being employed in different areas for their functional properties. But, the behaviour of such composites is different while fabrication is due to the presence of particles. The presence of filler particles not only affects the process parameters bur also the product characteristics. One major parameter that needs to be investigated in particle loaded composites is the process-induced residual stress which cause warpage in the thin composite plates. Mainly, these stresses are generated due to the mismatch of thermal expansion behaviour between the plies, resulting in shape distortion of the composite part.
The aim of this study was to determine the effect of silica micro-particles loading on the mechanical properties and shape distortion of thin composite plates. Laminated composite plates (3 mm thick) were fabricated using unidirectional (UD) glass fabric as reinforcement and vinylester (Epovia Optimum by Polynt composites) as the matrix material, both with and without the addition of fillers. After curing, it was found that the curvature was produced in both the plates. Furthermore, it was revealed that the warpage in thin plate was reduced by the addition of fillers (silica micro-particles) to the composite material.
For numerical study of the results, it was required to determine the properties of the constituent materials. Therefore, the resin samples reinforced with 0, 2, 4, 5 and 6% (vol%) of silica particles were prepared and their thermal expansion coefficients (CTE) were determined using Dilatometer. The fillers tend to decrease the CTE of reinforced resin and increase its modulus, as determined using UTM. These properties were used as input to investigate the shape distortion numerically using COMSOL Multiphysics (v 5.3). The numerical results were found to be in close correlation with the experimental values.

Keywords
Thin composite plates, Finite-element analysis (FEA), Shape distortion, Warpage

13860 | Residual Crushing Performance of Square carbon fiber reinforced plastic (CFRP) Composite Tubes after Transverse Low-Velocity Impact (Failure of Composites)

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With the increasing demand of light-weight for vehicles, carbon fiber reinforced plastic (CFRP) composite, which has a better strength to weight ratio, has been widely used as energy absorption structures, such as crash boxes for progressive folding energy absorption under axial compressive loads. During its whole life time, various impact cases may happen, such as drop out of tools or collision of stones. While CFRP are usually rather sensitive to dynamic impact loadings and even minor, invisible damage could cause the performance reduction. However, studies existed on residual properties of CFRP tubes mainly considered the impact in axial direction, limited studies were available to evaluate the effect of transverse impact on residual axial compression characteristic. This work aims to study the residual crushing performance of square CFRP tubes after transverse low-velocity impact with experimental and numerical methods.
Firstly, serials of low-velocity impact tests were conducted to examine the damage modes with the increase of impact energy. Then the quasi-static axial compression tests were carried out to characterize the degradation of residual crushing performance induced by the impact. The main damage modes are matrix cracking for lower impact energies, delamination and fiber breakage for high impact energies. Peak forces of impact force-displacement curves increase with the increase of impact energy. It is also found that the degradation of residual compression properties could be divided into different regions. Different with the progressive crushing mode seen in the un-impacted tubes, collapse and unstable local buckling were observed in the axial crushing tests. The peak load and specific energy absorption of the performed tubes were also analyzed with un-impacted tubes finally. Together with cross-section

views in impact position, the performance reduction during axial compression caused by impact were explored, which showed a shear failure mode. Finally, a finite element model was established for describe the dynamic behavior of CFRP tubes and validated with experimental results with a user-defined material subroutine VUMAT.

14506 | Hybrid repair of Steel Micro-bolt and Adhesive for Composite Laminate with Delamination (Failure of Composites)

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Since the composite material is generally produced by laminating thin prepregs, the in-plane stiffness and strength in which the reinforcing fibers are disposed are high, but the reinforcing fibers are not disposed in the thickness direction, so that the strength and stiffness are relatively low. Therefore, when the impact is applied from the outside, delamination that separates the layer and the layer easily occurs. If delamination occurs in the composite laminated structure, it is particularly vulnerable to buckling under the compressive load. Therefore, the problem of effectively repairing delamination of composite laminated structures has become a concern of many researchers. The method of repairing the composite structure can be divided into mechanical fastening method and bonding method. Mechanical fastening means repairing the damaged area using fastener. The work process has an advantage of being simple, but the stress concentration due to hole and the weight increase due to the fastener are unavoidable. Adhesive bonding is mainly used to replace damaged part with composite scarf patch. It can minimize stress concentration and weight increase, but it has a complicated repair process and low fatigue strength recovery rate.
Recently results of the studies have been reported on methods for repairing delamination using bolts with micrometer-sized diameters instead of conventional fasteners. This study is based on the fact that the tensile strength of laminate with multiple holes smaller than one large hole is higher if the total area of the holes in the laminates is the same. The authors have shown that it is possible to recover the buckling load up to 90% after repairing the delamination of the laminate using various arrangements of brass micro-bolts. In addition, the pre-tension applied to the bolt produces a compressive load in the thickness direction of the laminate, resulting in the effect of suppressing the crack growth. But the strength of the bolt is not sufficient, so the pre-tension can not be applied. Therefore, the authors have recognized the necessity of research on the delamination repair method using high strength and stiffness bolts through previous research results. In addition, when delamination occurs, not only the mechanical properties are degraded but also functional problems such as leakage of fuel or pressure through the delamination region may occur. Particularly, in case of an aircraft wing in recent years, an integrated fuel tank using a structure is often used. In this case, delamination may cause fuel leakage. Therefore, even if the delamination is repaired mechanically and the structural strength is restored, it is desirable to adhere the delamination area again with an adhesive.
In this study, the delamination of composite laminates was repaired by a hybrid method using 303 stainless steel micro-bolts and adhesive having higher strength and stiffness than brass, and then buckling test was performed. It is also possible to prevent the leakage of fuel or pressure through the delamination area by using the adhesive together with the bolt, and to transfer the load more smoothly by filling the gap between the fastener and the hole with adhesive. In order to examine the effect of the number and layout of bolts on the buckling load after repair, tests were performed on the laminate with various bolt number and layouts. Strain gauges were attached to all specimens to confirm the exact load that buckling occurred.
Acknowledgement:This work was supported by the National Research Foundation of Korea (NRF) Grant funded by the Ministry of Science and ICT (NRF-2017R1A5A1015311). This work was also supported by the Technology Innovation Program (or Industrial Strategic Technology Development Program) (10074270, Development of Manufacturing Core Technology for 3-Dimensional Woven Integrated Composite Wing Structure of 5,000 Pound VLJ Aircraft) funded By the Ministry of Trade, Industry & Energy(MOTIE, Korea)

14507 | A Study on Bending Characteristics of Scarf Joint Laminates Reinforced with Microbolt (Failure of Composites)

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As the application of composites to aircraft has increased, research on the repair method for the damage of composite structures are actively being conducted. A typical repair method for local damage is a scarf joint method in which a damaged area is partially removed and a scarf-shaped patch is placed in that area. When repairing composite structures using scarf joint repair method, it is possible to obtain a high tensile strength recovery rate, however, there is a problem that failure due to peel stress at the end of the scarf easily occurs when the bending load is applied.
Therefore, in this study, we proposed a new repair method that can improve the bending characteristics of the scarf joint while maintaining the tensile strength recovery rate to the same level as the scarf joint repair method. The key idea is to prevent the de-bonding by fastening microbolts at the end of bondline of scarf joint which are vulnerable to bending load. Since microbolts with small diameters are used instead of conventional fasteners, it can be implemented with minimizing the weight increase due to the fastener and the decrease of the in-plane strength due to the fastener hole.
The scarf joint specimens used for the test were made using the secondary bonding method. The scarf ratio is 1/30, and the stacking sequence is [45/0/-45/90]2S. The laminate were made using a unidirectional carbon-epoxy prepreg tape USN-200A (SK Chemical) and the film adhesive FM300-2M (Cytec) was used for bonding.
First, open-hole tensile tests were conducted by drilling 3, 6, and 9 holes of 0.6 mm diameter, respectively, in order to examine the effect of bolt hole on the tensile strength of the scarf joint specimen. The total number of specimens was 20 (5 specimens for each shape), including scarf joint specimens with no holes. As a result of the open-hole tensile test, we found that the difference in tensile strength between the scarf joint specimens with and without holes was not distinct. Therefore, it was concluded that the stress concentration due to the bolt holes does not significantly affect the tensile strength of the scarf joint even when several small holes are machined.
Based on this conclusion, 4-point bending tests were conducted to analyze the bending characteristics of the scarf joint reinforced with microbolts. The specimens used in the bending tests were made by machining 3, 6, and 9 holes of 0.6 mm diameter in the same positions as the open-hole tensile test specimens, and then brass microbolts were fastened having the same diameter as the holes. The total number of specimens was 20 including unreinforced scarf joint specimens
As a result of the test, we found that the bending strength of the specimen reinforced with microbolts was higher than the scarf joint specimen without microbolt-reinforcement. These results indicate that microbolts initially prevented crack propagation due to peeling stress at the end of the scarf.

Acknowledgement : This work was supported by the National Research Foundation of Korea (NRF) Grant funded by the Ministry of Science and ICT(NRF-2017R1A5A1015311). Also this work was supported by the Technology Innovation Program (10077320, Development of 700bar hydrogen storage vessel manufacturing technology for FCEV using high speed filament winding method) funded By the Ministry of Trade, Industry & Energy(MOTIE, Korea)

14509 | Cohesive zone method for failure analysis of scarf-patch repaired composite laminates under bending load

(Failure of Composites)

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Failure of scarf-patch repaired laminates under three-point bending load was experimentally and numerically investigated. A total of 40 repaired composite laminates with different scarf angles and patch lengths were tested. The distance between the two lower rolling pins were changed to examine its influences on the failure of the laminates. Three-dimensional finite element analyses using cohesive zone models were performed to predict both failure load and mode of the repaired laminates. Several cohesive parameters such as interface strength, interface stiffness, and cohesive zone length were examined to investigate their effect on the analysis results. The analysis results showed that the interface strengths have a significant effect of the prediction of failure load A good agreement between the predicted results and experimental data were obtained, revealing that cohesive zone method is an efficient tool for prediction of failure of the repaired laminates.

14545 | Flexural Behavior of Delaminated Composite Laminate after Micro-bolt Repair **(Failure of Composites)**

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As the mechanical properties of composite materials are improved and composite structural design techniques are developed, composite materials are being applied not only to secondary structures of aircraft but also to primary structures. In addition, due to the development of composite structure manufacturing technology, the composite structure of aircraft has been integrated and becoming larger. For example, in case of Boeing 787, a wing skin of 32 m in length and 6 m in width is manufactured in one piece by co-curing method.
A typical problem of a composite structure as compared with a conventional metal material is that delamination, which is a phenomenon in which a layer and a layer are separated, easily occurs. Once the delamination is found, the repair method depends on its size. If the damage is so large that local repair is difficult, the laminates between the frames can be cut and other laminates replaced using rivets or bolts. However, in this case, stress concentration occurs due to the fastener holes, and the continuity of the laminate plate is destroyed, and as a result, the load-supporting ability of the structure is remarkably decreased. There is a method of attaching another laminate to the outside of the damaged part and mechanically fastening it, but this method has a disadvantage that the weight is greatly increased.
Another way in which researchers have a lot of interest is scarf patch repair. The original structure is removed in the form of a scarf around the damaged area, and a patch of the same shape is prepared and adhered with an adhesive. This method can be used to minimize discontinuity in stress and increase in weight. However, there is a disadvantage that the original structure to be removed is large compared to the size of the damage, and the manufacturing process is complicated.
Therefore, in this paper, we propose a micro-bolt repair method using bolt with micrometer-sized diameter for repairing composite laminates with delamination. This technology is a technique that can demonstrate the advantages of mechanical fastening and simultaneously solve the shortcomings. Since the micro-bolt is used, the weight increase of the structure after the repair hardly occurs. The diameter of the hole is very small so that the in-plane property degradation of the composite laminate due to the fastener hole can be minimized.
The micro-bolt used in the repair is made of 303 stainless steel and the diameter of the bolt is 600 μm. The bending strength of laminates after repair was evaluated by performing three-point bending tests on a total of 40 specimens, changing the number and arrangement of micro-bolts. In order to analyze the test results, the changes of strain energy release rate in the crack tip with different number and arrangement of the repair bolts were examined by finite element method. The results of the test and analysis showed that the micro-bolt repair method has the effect of increasing the failure strength of the composite laminate by preventing the progress of the delamination under the bending load.

Acknowledgement : This work was supported by the National Research Foundation of Korea (NRF) Grant funded by the Ministry of Science and ICT(NRF-2017R1A5A1015311). This research was also supported by Korea Aerospace Industries, Ltd.

14558 | Surface treatment method for improving bonding strength of composite-to-titanium joint **(Failure of Composites)**

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Composite materials are applied to various structures such as aircraft due to their excellent mechanical properties, but they are vulnerable to impact load due to the brittleness of the matrix. Especially, high-speed rotating structures are exposed to various debris collision risks such as hail and bird. In preparation for this, the leading edge or trailing edge of the structure is reinforced with a shock-resistant metal material.
What is important here is a technique of combining a reinforcing metal strip with a composite material, such as bonding or riveting. Mechanical fastening using rivets is the most reliable, but the manufacturing process is complicated and there is a high risk of local damage to the composite structure. In addition, in the case of a thin structure, it may not be possible to use the rivet without changing the OML (outer mold line). A recent trend is to adopt a bonding method. In this case, it is a key technology to increase the bonding strength between the metal material and the composite material and secure the fatigue life. In the case of metals, aluminum is generally used, but titanium is sometimes used.
The bonding strength depends on the type of adhesive, the bonding environment, and the surface treatment condition. Once the adhesive is determined, the environmental conditions for bonding, such as the curing cycle, are determined accordingly. However, even if the adhesive is determined, the bonding strength varies greatly depending on the surface treatment conditions of the structure. For example, if impurities such as oil or peel ply residue are present on the surface, the bonding strength is greatly reduced.
There are three major surface treatment methods for bonding. The first method is to grind the surface with sandpaper or to increase the roughness of the surface by a method such as grit blasting. The second method is to change the chemical properties of the surface using chemicals. The last method is to increase the surface tension using plasma, corona discharge or laser treatment. It is necessary to select an appropriate method depending on the kind of the material of the adhesive and the structure and the service environment. In addition, even when the specific method is used, the detailed parameters may vary depending on the design requirements.
In this study, we have studied the surface treatment method to improve the bonding strength between carbon-epoxy composites and titanium strips. For various surface treatments of composite laminates and titanium strips, double lap shear tests and peel tests were conducted to investigate the effect of the surface treatment method on the bond strength. The shear test and peel test were conducted according to ASTM D3528 and D1876, respectively.

Acknowledgement: This work was supported by the Technology Innovation Program (or Industrial Strategic Technology Development Program) (10084659, Core technology development of an efficiency 90% composite fan and performance test for 10,000 lbf aero turbofan engine) funded By the

Ministry of Trade, Industry & Energy (MOTIE, Korea).

14787 | An In-Situ Digital Image Correlation Based Framework to Understand the Failure Mechanisms in Metal Matrix Composites (Failure of Composites)

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Precise measure of strain/stress fields in vicinity of a propagating crack is difficult by using conventional fracture testing. The evolution of microcracks and distribution of heterogeneities all influence the strain field and in turn determine the activation of failure mechanisms. The objective of this study is to develop an in-situ Digital Image Correlation (DIC) framework which not only tracks the crack evolution but also resolves the microstructure details and the failure mechanisms during the failure process. A cohesive finite element based computational model is developed to track the crack propagation. Based on the DIC analysis and simulation results, a semi-analytical model which quantifies the competition between different failure mechanisms is developed. The conclusions are potentially useful for designing high toughness metal matrix composite through microstructure tailoring.

13875 | Study of hybrid composites with chemically treated lignocellulosic fibers and organophilic clay. (Analysis of Wood and Natural Fibre Composites)

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Study of hybrid composites with chemically treated lignocellulosic fibers and organophilic clay.

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Abstract

The use of composite materials with lignocellulosic fibers (extracted from plants which is renewable resources) as reinforcing agents replacing synthetic ones goes towards sustainability as well as creating new sources of employment in the field where the lower income population lives. In this work an evaluation of epoxy resin composites and curauá fibers is carried out, whose fibers are extracted from the leaves of a plant of the Amazonian region called Ananas (Ananas erectifolius). This lignocellulosic fiber is among the ones having greater mechanical resistance and lower density. The objectives of this work were to study the influence of chemical treatments of the fiber and the amount of organophilic clay on the mechanical properties of the composite. In order to improve the wettability of the fibers, they have been treated using a solution of sodium hydroxide (NaOH) by varying its concentration and the immersion time. The morphology of the treated and untreated fibers is studied using Scanning Electron Microscope (SEM), the results show the good effectiveness of the treatments performed in relation to the fibril separation and the surface roughness of the fibers. The chemical composition and the crystallinity of the fibers were studied using FTIR and X-ray diffraction respectively. The composite laminate specimens were performed in a closed mold with the dimensions of the specimens according to the corresponding norms for tensile and Izod impact tests. The fracture zone was observed after the tensile tests using SEM and Transmission electron microscope (TEM), confirming the wettability effectiveness of the fiber treatments and a correct dispersion of the clay within the matrix, improving the properties of the composites. The results of this work showed that, on one hand, the inclusion of 5% of the clay in the epoxy resin leads to an increase of 74.8 % in the tensile stress, while 10% of clay improves the impact resistance by 348.5 %. On the other hand, the epoxy resin reinforcement by 20% of curauá fibers treated by 5% of NaOH for 4 hours immersion time and an inclusion of 5% of clay lead to the best tensile stress by an improvement of 176.7 % compared to the resin alone. While, the best impact resistance, with an improvement of 1100.2% compared to the resin alone, is obtained for the composite having 20% of curauá fibers treated by 5% of NaOH for 2 hours and 10% of clay.

Keywords: Composites, Curauá, Organophilic clay, Epoxy Resin.

14338 | Effect of water absorption on the Weibull distribution of fatigue test in jute reinforced polyester composites (Analysis of Wood and Natural Fibre Composites)

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Composite materials have been manufactured using bidirectional jute fibre in a polyester matrix. Static bending tests have been conducted to establish the static properties of the composites which have been used to calculate the maximum loads used during the three point fatigue testing. The manufactured composite have been subjected a water ageing for various time of immersion (90, 180 and 270 days). Significant fatigue strength decrease has been observed during water ageing. The number of cycles to failure of the aged and no aged specimens were correlated using the two parameters Weibull distribution function to introduce the probability of failure and to plot the S–N curves for different reliability levels (Ps = 10, Ps = 36,8, Ps = 50, Ps = 90 and Ps = 99%). The results have shown that the two-parameter Weibull distribution describes the fatigue life probability distributions of jute reinforced polyester composite material with quite high statistical correlation coefficients.

14340 | Physical and Thermal Properties of Treated Sugar Palm /Glass Fiber Reinforced Thermoplastic Polyurethane

Hybrid Composites (Analysis of Wood and Natural Fibre Composites)

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Lignocellulosic/natural fibre and glass fiber based hybrid composites are considered as a high performance composites but very limited numbers of researchers worked on substituting sugar palm fiber with glass fiber in hybrid composites. Fiber modification of natural fiber improved interaction between fiber and polymer matrix in composites. In this study, the effect of various treatment such as 6% alkaline, 2% silane and combined 6% alkaline- 2% silane on physical and thermal properties of sugar palm/glass/thermoplastic polyurethane hybrid composites were carried out. The combined alkaline-silane treated hybrid composites showed the lowest density, thickness swelling, and water absorption as compared to other composites. The good thermal stability and the chemical changes were discovered for treated as compared to untreated sugar palm fiber based composites. Overall, the treated sugar palm/glass/thermoplastic polyurethane hybrid composites suitable for fabrication of automotive components.

14406 | Laboratory test and numerical investigation of the adhesive layer in sandwich composites (Analysis of Wood and Natural Fibre Composites)

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Paper presents a finite element method attempt to predict progressive delamination of glue laminated timber beam through cohesive layer strength. There were used cohesive finite elements, quadratic stress damage initiation criterion and mixed mode energy release rate failure model. Finite element damage was equal to complete element stiffness degradation. Timber material was considered to be orthotropic with plastic behaviour after reaching bending limit. Progressive delamination in real structures has a significant impact on the construction. It may lead to stiffness and composite strength reduction or on the contrary may cause stress relief and delay of the total failure of the composite. It confirms the importance of choosing a suitable glue for each laminated structure. To present a specific example of the problem, in the paper there was performed finite element method analysis of three layer glue laminated timber beam. Numerical analyses were done in Simulia Abaqus/Standard solver.
Double lap shear tests were performed on MTS 809 machine. Experiments were carried out on 5 specimens in dimensions of 140 x 120 x 80 mm. Force and the displacement of the gauge was recorded by the machine software. Energy release rate calculated basing on the test results was applied to the FEM model.
The paper presented more complicated approach of numerical modelling double lap shear connections in glue laminated timber than it was presented in currently accessible publications. Timber material was considered to be highly orthotropic and the cohesive joint was modelled basing on the traction separation law. The numerical simulation procedures of the interface layer behaviour were adopted from epoxy-carbon/glass composites models which was a relatively original idea. There was proposed supplementing laboratory tests using numerical simulations in some cases when laboratory tests require very complicated accessories. Numerical analyses showed that stress state in the glulam joints was much more complicated than it had been assumed in cited publications. There was stated the need of developing more precise numerical description of the shear stresses in such connections.

14756 | Evaluation and optimization of coir fibres/cement interface (Analysis of Wood and Natural Fibre Composites)

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Spruce and poplar wood have been almost exclusively used in the processing of wood-wood cement boards (WWCB), mostly because of their good compatibility with cement. Alternative fibres such as coir, extracted from the husk of the coconut, do not inhibit the cement hydration and could be a good candidate to replace wood. However, studies have shown that despite their good physical properties and great cement compatibility, coir fibres cement boards have poor mechanical performances. It is mainly due to the poor interface between the cement and the fibre, leading to a very week fibre/matrix load transfer. The objective of the present study is to evaluate the interfacial properties between the coir fibres and the cement by pull-out tests and microscopy and to optimize this interface by modifying the surface of the coir fibres by pre-treatment. In overall, this study aims to improve coir/cement interface in order to make stronger and more sustainable fibre cement boards.

13841 | Influence of the stack composition of composite combat helmets on the ballistic trauma (Design and application of composite structures)

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The latest improvements of personal armor systems have led to lighter protective structures with optimised strength-to-weight characteristics. However, the trauma caused by the great deformation suffered from composite materials, the Behind Helmet Blunt Trauma (BHBT), is still a concern.

In this work, several stack configurations for a combat helmet have been tested against ballistic impact through explicit finite element analysis (FEA). To measure the biomechanical consequences of this non-penetrating impact, a numerical model of a human head with the main living tissues has been developed. The amunittion employed for the simulations is a 9 mm FMJ bullet, with an initial velocity of 530 m/s.
The following stack configurations were applied to the helmet model:

#S1: 16 aramid-fabric layers, all with the same orientations, with a total thickness of 8 mm. The mass of the whole helmet shell is 1.03 kg.
#S2: 16 aramid-fabric layers, with alternating orientations of 0º/90º and 45º/-45º between adjacent plies, with a total thickness of 8 mm and the same mass as #S1.
#S3: a hybrid configuration of 8 plies of aramid fabric in the striking surface (total thickness 1.6 mm) and 16 of UHMWPE (total thickness 3.84 mm). The mass of the whole helmet shell is 590 g.

#S4: a hybrid configuration of 12 plies of aramid fabric in the striking surface (total thickness 2.4 mm) and 16 of UHMWPE (total thickness 3.84 mm). The mass of the whole helmet shell is 695 g.
#S5: the same material configuration as #S3 leaving an air gap of 2 mm between the two different materials.

The energy absorbed by the helmet shell and the trauma suffered in the head model are recorded in all the simulations. The amount of energy absorbed by the helmet configurations #S1 and #S2 is almost the same, whereas a basilar skull fracture is obtained with #S1 while no skull fracture is observed when using #S2. This difference arises in the different deformation patterns suffered by the helmet. In #S1, the diameter of the deformed area is approximately 7.4 mm, while in #S2 it increases to 11 mm. As for the hybrid configurations, #S3 scarcely prevents bullet perforation, and the resulting injury on the head model is a depressed fracture in the site of impact. This fracture pattern generates greater strains in the brain tissue, thus leading to a greater probability of neuronal damage. All the helmet deformation is concentrated around the projectile, so little energy distribution along the plies is obtained. The amount of energy absorbed by the aramid layers is a 15% lower than the corresponding to the UHMWPE. However, when including the air gap between both materials (#S5) the energy absorbed by the aramid layers increases, and thus the resulting depressed skull fracture has a lower diameter diminishing the risk of brain injury. Increasing the number of aramid layers at the sriking surface (#S4) improves the energy absorbing by a 20%. However, the helmet shell deformation remains localized close to the bullet, and a linear skull fracture is obtained.

In conclusion, in this work we obtained that, between the five configurations tested, the 16-ply aramid fabric configuration #S2 offers superior performance in terms of protection against head trauma. Therefore weight reduction achieved with the hybrid configuration is restricted by the safety requirements, and a compromise between the heavier (aramid) and the lighter (UHMWPE) material has to be made or other stack configurations should be explored.

14321 | A COMPARATIVE STRESS ANALYZE OF ALUMINUM AND WOVEN GLASS FIBER REINFORCED EPOXY COMPOSITE PANEL FOR SHIP SUPERSTRUCTURE **(Design and application of composite structures)**

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The applications of aluminum as a structural material in marine industry, has diminished because of problems with cracking and maintenance cost in superstructures bonded to steel hull. Alternatively, fiber-reinforced plastic (FRP) has been studied as an advantageous option. Since the mid-1980s the use of composites has increased considerably to improve the structural and operational performance and reduce the maintenance costs of the ship. The present work compares aluminum and glass fiber-reinforced polymer (GFRP) panel used in a ship superstructure in terms of the strength and weight characteristics, based on laboratory tests and classification societies rule. In this study, a cross ply mats (e-glass fiber orientation 0° / 90° with 326 g/cm² weight) are mixture of epoxy resin (RR15 from SILAEX® based on diglycidyl ether bisphenol A and an aliphatic amine hardener). They are used to manufacture the GFRP by hand lay-up method. An overall description dealing with the composite panel design is given. Standard test method for compressive properties of polymer matrix composite materials is performed. Rule expressions to predict the modulus of elasticity (E), critical buckling stresses (σc) and breaking stresses (σbrt) are compared with experimental data in order to analyze and suggest safety factors. The mechanical characteristics of the GFRP and the aluminum are compared showing the advantage in use of composite panel.

14346 | Carbonyl iron/natural rubber composite elastomer with magnetic gamma-ferrite particle additive and its magnetorheological behaviors **(Design and application of composite structures)**

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Magneto-responsive smart magnetorheological (MR) elastomers have received much attention not only for their reversibly controllable rheological characters but also high mechanical properties with increasing magnetic field strength in addition to MR fluids. Addition of carbonyl iron (CI) particles to elastomeric matrix is one of the typical methods for producing MR elastomers (1). To improve MR effect of MR elastomer which is consisting of CI and natural rubber (NR), the rod-like shaped hard magnet gamma-ferrite (γ-Fe2O3) particles were added to MR elastomer similar to the case for the MR fluid (2). When fabricating the isotropic MR elastomer, the magnetic field was appiled to both sides to align the CI/ γ-Fe2O3 particles in the uniform direction. Morphology and rheological properties of the MR elastomer based on CI/ γ-Fe2O3 particles were compared with those of pure CI MR elastomer. To confirm the morphology and alignment of two MR elastomers, high resolution scannig electrom microscopy was used. Rheological properties of MR elastomers were measured by using a rotational rheometer with external magnetic fields. The results showed that the strain sweep and the angular frequency sweep tests confirmed that the storage modulus increased with increasing magnetic field strength. Furthermore, these results showed that MR elastomer with CI/ γ-Fe2O3 added had higher modulus and MR efficiency than MR elastomer with only CI particles based on both Payne and MR effects.

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Keywords: Magnetorheological elastomer, Natural rubber, Carbonyl iron, gamma Ferrite

14351 | The analysis of sensitivity of thin-walled compressed composite columns on eccentricity load **(Design and application of composite structures)**

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The study investigates the problem of the critical and postcritical states of thin-walled carbon/epoxy composite columns under axial and eccentric loads. The objective of the study is to determine the effect of eccentricity of compressive load on the buckling mode and critical load of the columns. The above problems are investigated via numerical simulations based on the finite element method. The problem of stability loss is solved as a linear eigenproblem. The postcritical states are analysed as a geometrically nonlinear problem and solved by the Newton-Raphson method. Composite material effort is measured by two failure initiation criteria for composite materials: the Tsai-Wu failure criterion and the Hashin criterion. The numerical simulations are performed using ABAQUS®, a FEM-based commercial simulation tool. The developed numerical models are the verified by experimental rig tests performed on physical models of the structures. The rig tests are conducted at room temperature on a universal testing machine. The following are measured: compressive load variations, column shortening, deflections perpendicular to column walls at selected points on the structure. In addition,

strains are measured at the point of highest expected column web deflections as determined by the numerical analysis. As a result of the measurements, the postcritical paths describing the relationship between load force and deflection, and the postcritical paths describing the relationship between load force and column shortening are determined. The experimental critical load is estimated based on the determined characteristics of the structure by approximation methods. The postcritical characteristics of the composite structure serve as a basis for validation of the developed numerical models. Qualitative and quantitative analyses are performed to determine the effect of load eccentricity on the buckling and performance of composite columns in the postcritical state. The research reported in the paper was conducted under the project UMO-2015/19/B/ST8/02800 financed by the National Science Centre Poland.

14382 | Design of fastening inserts for mechanical joining of composite structures made of long fiber prepreg sheet (LFPS) (Design and application of composite structures)

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Long Fiber Prepreg Sheet (LFPS) has the advantages of excellent production efficiency and formability of complex shapes compared to conventional continuous fiber reinforced composite materials because it can be thermoformed by conventional compression molding for mass production. For the case of highly complicated structures, net-shape molding is hard so adhesive bonding or mechanical joining of parts separately fabricated are required. When maintenance and regular replacement of some of the assembly are needed, mechanical joining with appropriate fasteners like inserts and screws can be alternative. Conventional mechanical fasteners cause a decrease in the structural strength of fibrous composites because of holes for installing inserts. To avoid fiber cutting or additional machining of fibrous composites, the inserts may be installed during the composite forming process by co-cure method. Co-cured inserts can simplify the production process without machining such as drilling and additional bonding processes. Conventional metal inserts for screw fastening has cylinder shape so only the shear force may resist the external pulling-out forces. On the other hand, the proposed insert has wings to increase the contact area between the insert and the LFPS inducing high bonding strength. The wings spread during the forming process act as anchors to resist pulling-out forces generating not only bonding force but also mechanical wedging effect. X-ray was used to estimate the spreading status of the wings in the composite substrate. The static and dynamic pull-out test were performed according to design variables like wing length, wing width, and surface roughness. Bonding strength according to the design variables were experimentally investigated and the optimal condition was determined.

Acknowledgement This research was supported by Ministry of Trade, Industry and Energy and Defense Acquisition Program Administration (Development of long fiber reinforced thermoset sheets manufacturing and part forming technology for draping, 15-CM-MA-15)

14388 | Investigation of the structure and properties of self-reinfoced UHMWPE composites (Design and application of composite structures)

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In recent years, self-reinforced composites (SRCs) which represent composites in which a polymer matrix is reinforced with oriented fibers and tapes, or particles of the same polymer, attract particular attention of researches. The advantages of such composites are high compatibility of the matrix and the reinforcing elements, the ability to achieve a good interfacial interaction between the components of the composite and higher recyclability as compared to composites composed of different classes of components. The aim of this work is study of the structure and properties of self-reinforced composite materials based on UHMWPE fibers. For composite production compression molding method which results in only partial surface melting of UHMWPE fibers was used, during cooling the molten part formed a matrix of composite material. Self-reinforced composite materials at pressures of 0.1, 25, 50 and 75 MPa, and at temperatures 145, 155, 165 °C were obtained, the molding time for all the obtained materials was 2 minutes. It was found that the maximum values of tensile strength and Young's modulus (267 MPa and 12.6 GPa, respectively) shows the composite materials obtained at 155 °C and pressure of 50 MPa. Lower temperature of compression molding (145 °C) results in lower values of the tensile strength and Young's modulus (223 MPa and 8.9 GPa), and higher temperature of compression molding (165 °C) results in only 43 MPa and 3 GPa, respectively. It was found that increase in compression molding temperature results in increase in fraction of the melted fibers which is accompanied by loss of unique mechanical properties of UHMWPE fibers.
Comparative studies of mechanical and tribological properties of isotropic UHMWPE and obtained composite materials were carried out. Preservation of the oriented structure of the initial fibers allows to obtain composite materials with improved properties in comparison with isotropic UHMWPE. It was found, that obtained composites shows more than 2 times lower friction coefficient and wear rate in comparison with isotropic UHMWPE. The studies showed that for isotropic UHMWPE the creep strain rate at a stress of 10 MPa was 11%, and for composites, even at a load of 150 MPa it was only 4.2%. Due to its high strength, low values of friction coefficient and wear rate, high creep resistance and biocompatibility, the developed self-reinforced composite materials can be used in various kinds of applications.

14425 | Prediction of the collapse load of axially compressed thin-walled composite beam (Design and application of composite structures)

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In many cases, aircraft structures are stiffened with thin walled section of various shapes to support compression loads. The initial buckling of thin walled structures does not result in immediate failure. This post buckling capability is used to achieve light weight design. And final failure of thin walled structure is called crippling. To predict the failure load, empirical methods are often used for thin walled structures in design stage. But empirical method accuracy is depend on geometry. In this study, experimental, empirical and numerical study of the crippling behavior of I-section beam made of carbon-epoxy are performed. The progressive failure analysis model to simulate the crippling failure is evaluated using the test results. In this study, commercial software LS-DYNA is utilized to compute the collapse load of composite specimen. Six kinds of specimens were tested in axial compression. Correlation between analytical and experimental results has performed. From the results, we can know that the flange width-to-thickness ratio is found to influence the accuracy of empirical and numerical method.

14427 | Tunability of Lamb wave band structures in a two-dimensional magnetostrictive phononic stubbed plate (Design

and application of composite structures)

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Phononic crystal (PC) consisting of the periodic arrays of elastic inclusion in matrix, has been already attracted extensive research efforts of researchers due to the band gap characteristics that wave cannot propagate in some frequency ranges. Besides the bulk wave propagation in infinite PC and surface wave localized at a semi-infinite PC, the tunability of Lamb wave propagation in finite thickness PC plates has been attracted much more attention of physics and engineering communities. Meanwhile, in the magneto-elastic PCs with magnetostrictive materials, band gap characteristics can be tuned by the physical parameters of constituent materials under external stimuli.
In this paper, considering the nonlinear magneto-elastic coupling constitutive behavior of magnetostrictive material, the tunability of Lamb wave band gaps of phononic stubbed plates with magnetostrictive material is investigated under the stress and magnetic field loadings. The Lamb wave band characteristics of two Schemes, that the magneto-elastic phononic stubbed plates with holes (Scheme-I) or without holes (Scheme-II) are studied respectively. The dependence of Lamb wave band gaps on magnetic field, pre-stress and geometric parameters are discussed. In the low magnetic field, For Scheme-I, phononic stubbed plate possesses two band gaps in the normalized frequency range from 0 to 2.5. However, the two new (the third and the fourth) band gaps can be generated and decreases monotonically until disappears with the rise of magnetic field for Scheme-II. In the moderate and high magnetic field, with the increase of magnetic field, band gaps of two Schemes gradually move toward the high frequency area, while the compressive pre-stress has an opposite effect. The phenomena may be caused by the competitive relation of compressive stress and magnetic field on magnetic domain. In addition, the height of the stub is a key parameter for generating or vanishing of band gaps and the appearance of the holes can also regulate the location and width of band gap. In summary, numerical results show the complex relationships among Lamb wave band gaps, magnetic field, pre-stress and geometric parameters, which provide guidance for intelligent regulation and active control of Lamb wave propagation in phononic plate devices.

14510 | Study on the design and manufacturing of carbon fiber reinforced composite by tailored non-crimp fabric technology with local reinforcement for complex automotive part applications. **(Design and application of composite structures)**

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The homogeneous knitted structure results in a homogeneous drapability, which leads to strong shear stresses and textile defects (gaps, folds) on geometries with complex and non-complex areas. Therefore the use of the conventional NCF technology for production of complex varying components is not economically viable. The application of TNCF technology allows the manufacturing of complex tailored textile preforms with local reinforcements and local drapability properties, avoiding additional preforming process steps for several geometries.
The SUV tailgate part is one of the most complex components of a car. Due to their complexity, we use the tailored non-crimp fabric technology(TNCF). This technology allows a high productivity with local reinforcements, locally adjusted drapability and a high amount of fiber layer to reduce the number of processing step in the subsequent preforming process. The positive effect of the stitching pattern on drapability has been demonstrated by a component which is geometrically similar to the complex side area of tailgate. Complex areas can be realized without any textile defects ensuring the fiber orientation. And Comparing to the current metal sheet production(7 parts, weight of 15kg), using the TNCF technology we were able to reduce the number of components by 70% and the weight by about 35%.

14523 | Comparative Study On Quasi-static and Impact Load Performance of Cubic, Pyramidal, and Hexagonal Cell Shaped Carbon Fiber/ Polypropylene Thermoplastic Composite Truss Lattice Core Sandwich Structures with Carbon Fiber/Polypropylene Laminated Composite Face Sheets **(Design and application of composite structures)**

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In the presented study, fully recyclable and lightweight all thermoplastic composites lattice truss core sandwich panels were developed and measured mechanical performances under quasi-static and impact compression and bending experiments. The lattice truss cores constructed of cubic, pyramidal and hexagonal prisms shaped unit cells. A pyramidal, hexagonal and cubic lattice truss unit cells constructed of thermoplastic EVA hot melt adhesive joining of continuous carbon fiber reinforced thermoplastic Polypropylene (PP) matrix composite monofilament beams. These units combined sequentially to produce core structures. The carbon fiber/PP laminated thermoplastic composite plates were used as face sheets. The combination of the lattice truss cores and thermoplastic composite layers joined by hot-melt thermoplastic EVA adhesives. The structural response of all-composite lattice truss core sandwich beams was carried out by flatwise compression and three-point bending under quasi-static and impact loads. Euler micro-buckling, core shear micro-buckling, face sheet micro-buckling, face sheet wrinkling, face sheet crushing and other failure types were discussed. Always node rupture is fatal to carbon fiber reinforced/PP thermoplastic composite pyramidal truss core, and shear deformation for hexagonal and cubic lattice cores sandwiches. Fracture of the node joints is the weakness of the bent structure. Consequently, the pyramidal lattice core sandwich panels show higher specific strength and stiffness than the hexagonal and cubic unit cell lattice cores. However, when the truss members are sufficiently slender, the lattice core sandwich panels collapse in compression predominantly by the elastic or inelastic buckling of truss members.

14694 | Ballistic penetration of soft structures with fiber layers and fluid container **(Design and application of composite structures)**

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Explosion experiments using TNT explosive with premade fragments were performed on soft composite structures that were composed of water sheet and high-performance fiber fabrics. The structures were proved to efficiently mitigate the blast pressure and reduce the fragments velocity, which are potentially promising for disposing of suspected explosives with advantages of light weight and producing limited secondary hazards.
In this study, ball-bearing impact tests were performed on five different configurations of targets, (i) water sheet, (ii) fiber layers, (iii) fiber layers/water sheet, (iv) water sheet/fiber layers and (v) fiber layers/water sheet/fiber layers. The water sheet was encased in a thin polyvinyl chloride (PVC) container; two different fiber fabrics, aramid fiber plain-woven layers and ultra-high molecular weight polyethylene (UHWMPE) fiber cross-ply layers, were tested. The results of ballistic limits were compared to investigate the influence of the arrangement order of the fiber layers on the ballistic resistance of the composite targets. Localized and global failure and deformation characteristics of the composite targets were determined and compared to find ground for the different ballistic resistances. This study provides fundamental understanding of mechanisms by which the soft composite structures with fiber layers and fluid container resist the fragments, and can help in further modification of the structures for resisting the combined effects of blast and fragment loading.

14696 | Design and ballistic penetration of metal-ceramic hybrid composite structures **(Design and application of composite structures)**

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To examine the performance of different composite structures and guide the designation of lightweight and high-performance structure, a series of metal-ceramic sandwich hybrid structures were designed by changing the panel structures, SIC ceramic shapes, Ti6AL4V frame structures and compound pattern. The composite structures were subjected to impact tests using 12.7 mm diameter hard steel projectiles over the velocity of 820 m/s. A combination of high-speed video imaging and cross sectioning of impacted samples was used to investigate the performance and penetration mechanisms of each structure. Moreover, ANSYS/LS-DYNA software was used to simulate the penetration processes and explore the underlying mechanisms of these hybrid structures. The results were analysis in detail to obtain the effect law of each influence factor and guide the designation and optimizing of the structure.

13836 | Beam and Column Finite Element Model For FRP Concrete Composite Members under Multiaxial Constitutive Laws **(FRP in concrete, steel and composite steel/concrete structures)**

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INTRODUCTION
Fiber reinforced composites have many advantages as retrofitting and strengthening material to the existing reinforced concrete structures (Cho, et al. 2005, 2008). In concrete structural members, fiber reinforced polymer (FRP) with glass fibers, carbon fibers, and any other types of fibers can improve the strength and ductility of concrete by providing confinement. This research is aim to develop beam and column finite element formulation for FRP reinforced concrete structural members. The finite element was formulated with a force-based method and the proposed solution algorithm was particularly suitable to predict local nonlinear flexural deformations in plastic hinge region with softening behaviors.

FORCE-BASED FINITE ELEMENT FOR FRP CONCRETE MEMBERS
This section contains the formulation of the force-based beam and column finite element without rigid body modes. Only two iterations are conducted inside the element, in order to speed up the overall convergence process. The residual deformations can be seen as the linear approximation to the deformation error made in the linearization of the section force-deformation relation. The selection of the interpolation functions is computed from the assumption of constant axial force and linear bending distributions within the element. In final, the determination of the element equilibrium equation can be accomplished by inversion of the element flexibility equation. The element state determination is satisfied by the conversion of the element residual deformation which cannot be applied at the element nodes because it violates node compatibility. The main advantage of the force-based formulation is that during the iterations the element force and deformation fields are adjusted until the section constitutive relations are satisfied, while always satisfying equilibrium along the element.
The element formulation relies on the fiber section discretization to compute section force and section flexibility matrix corresponds to section deformation. As the uniaxial law, the newly proposed model by Cho et al. (2005, 2008) is adopted to predict the confining effect by FRP jackets. This model is based on the multi-axial constitutive relations, which will be described precisely on following section. Under the tri-axial stress state, the strength and ductility of concrete depend on the confinement provided by the FRP jacket. Therefore, it is necessary to compute the strains of the FRP from classical lamination theory. The multiaxial strain-stress relation of concrete is based on an orthotropic hypoelastic formulation and is expressed through the incremental law. If it is assumed that no slip between the concrete and the FRP shell, that is, if the interfaces are perfectly bonded, the compatibility and equilibrium in the cross-section should be satisfied. Combining arrangement of these conditions, the increment of radial stress in concrete, the increment of longitudinal stress in the FRP jacket, and the increment of concrete radial strain can be derived.
Based on the multiaxial constitutive laws of concrete and FRP composite, a force-based beam and column finite element for reinforced concrete flexural members wrapped by FRP composite has been developed. In this procedure, the number of jacket layers, the direction of each layer, the layer stiffness and the layer thicknesses are included in the calculation of the equivalent material properties of the FRP laminate.

CONCLUSIONS
Some experimental results on FRP concrete structural members were compared with the current finite element analysis, and it demonstrated that the current finite element prediction was well suitable not only to estimate the global behavior of load-displacement relationship of the member but also to estimate inelastic local behaviors such as curvature and strain distributions in the region of plastic hinges.

14802 | Strengthening of Reinforced Concrete beams using Textile Reinforced Mortars **(FRP in concrete, steel and composite steel/concrete structures)**

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A structure may need repair or strengthening for various reasons: the structures may have to carry larger loads; damage due to accident; errors made during design or construction phase; or corrosion damage of the structural members. Various methods have been used to repair/strengthen reinforced

concrete members. The study included testing of fifteen reinforced concrete beams (150 x 100 x 2700 mm): one control beam (without strengthening); one beam strengthened with one layer of textile bonded with epoxy to the tension side of the beam; while the remaining beams were strengthened with one layer, two layers and three layers of textile bonded with mortar. Three different schemes of strengthening were used. In Scheme 1, the textile layer(s) were bonded to the bottom of the beam along the beam axis at the tension side only. Scheme 2 consisted of bonding the textile layer(s) along the bottom of the beam in addition to attaching U-shaped textile strips around the beam cross section spaced @ 480 mm C/C. The third scheme, Scheme 3, is similar to Scheme 2 except the U-shaped textile were applied continuously at the outer one-third of the beam span. Three different mortars were used to bond the textile fabrics. The test results indicated that epoxy bonded textile performed better in terms of strength enhancement as the bond was perfect compared to mortar bonded textile where the bond was the main cause of failure. However, the ductility or deformability was slightly better in beams strengthened with mortar bonded textiles. The test results also showed that as the number of layers increases, there is no significant increase in strength due to bond failure. When the U- shaped strips were used along with increasing number of textile fiber layers, the gain in flexure strength and gain in ductility was observed.

14890 | A simplified 3D finite element modelling approach for reinforced concrete beams (FRP in concrete, steel and composite steel/concrete structures)

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Numerical simulation of reinforced concrete structures requires the explicit representation of both the concrete and the reinforcement bars, where the two materials are modelled separately using appropriate constitutive laws including damage variables for concrete in compression and tension. Even if this way of modelling is convenient and satisfactory, it requires a huge computational effort especially in the case of large scale applications. The aim of this paper is to develop an alternative model dedicated for the simulation of large scale reinforced concrete structures with no need to represent explicitly the steel reinforcements. Based on the literature review, the authors developed a fictitious stress-strain relationship for reinforced concrete under tension. The model is based on the shape of the slip-adhesion curve between steel and concrete proposed by the European Committee for Concrete (C.E.B.) to estimate the crack opening widths. Relationships covering the cracked stage up to the yield point of the steel are proposed depending on the material properties of concrete and steel, on the reinforcement ratio, as well as on the crack widths. The developed model was successfully implemented in the ABAQUS commercial software. The effectiveness and computational efficiency are demonstrated through some examples under tensile and bending loadings.

14914 | Evaluation of existing bond-slip approaches for steel-FRP joints (FRP in concrete, steel and composite steel/concrete structures)

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The use of fibre-reinforced polymer (FRP) in strengthening steel structures has attracted world-wide attention. The bond between a FRP laminate and steel substrate plays a significant role in ensuring the effectiveness of the FRP strengthening system. Various bond-slip relations for FRP-steel joints have been developed in the previous studies. An accurate bond-slip relation can deliver more accurate predictions of steel-FRP joint strengths. Especially, in all numerical simulation for the CFRP strengthening steel structures, the bond-slip model should be accurate enough to produce proper results. This paper provides an insightful and comprehensive evaluation of the existing bond-slip relations using finite elements method. The proposed numerical model is able to capture all failure modes that may occur in the case of FRP-steel joints. The results obtained from the numerical model are compared with those collected from experimental database of the previous research studies. It has been found by applying these relations that the bond-slip relations display a significant scatter and often a quite irregular value of joint strengths compared to the corresponding experimental data.

14522 | Effect of Carbon nanotube addition on interlaminar fracture toughness of fiber reinforced composites using carbon/glass hybrid non-crimp fabrics (Laminated composites with material uncertainties)

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The growing demand for lighter and superior performance materials, especially in the area of aerospace, automobile, and defence applications has attracted the interest of many towards woven and unidirectional CFRP composites. However, in spite of very good in-plane strength, they have poor resistance to interlaminar fracture under different loading conditions.
Carbon nanotubes (CNTs) are introduced as a multiscale reinforcement into the fiber reinforced composites to suppress the delamination phenomenon. In order to overcome the high cost and the crimp problem caused by the carbon fiber fabric, hybrid non-crimp fabrics (NCF) with carbon fiber and glass fiber was used. And CNTs dispersed epoxy resin was used to improve resistance to interlaminar fracture. Hybrid composites were compared with carbon fiber NCF composites and glass fiber NCF composites in terms of interlaminar fracture toughness with CNTs added.

14358 | On the modelling of thermoelasticity issue in transversally graded laminates (Thermal problems on Composite structures)

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In this work, the problem of thermoelasticity in a laminate with non-periodic distribution of the ingredients is presented. This laminate is made of two different materials. The macroscopic properties of this structure are changing continuously along one direction, perpendicular to the laminas. The thickness of the cells of considered composite is constant and called a microstructure parameter. This type of structures can be called the functionally/transversally graded laminates. In the analysis of various issues concerning these composites, the same approaches can be used as for composites with periodic structures so thermoelastic phenomenon can be considered in relation to micromechanical models with idealized geometry, because the basic cell in reference to these laminates cannot be defined in a simple way. Unfortunately, most of the proposed models do not take into account the effect of the microstructure size on the overall behaviour of the functionally graded laminates. In order to obtain the averaged equations,

taking into account this impact, the tolerance averaging technique is used. This technique was used in many studies to derive equations for various cases of periodic structures and to describe various thermomechanical problems in this type of composites. Recently, this way of modelling is modified and adopted for problems of composites and structures with functional gradation of properties. The tolerance averaging technique is related to the introductory concepts such as the tolerance-periodic, the slowly-varying and highly-oscillating functions and the averaging operation. The basic aim of the application of this technique is to replace the system of differential equations with the highly oscillating, tolerance-periodic and discontinuous coefficients, by the differential equations where the coefficients are slowly-varying. The tolerance modelling is based on some assumptions. The first is the micro-macro decomposition, where it is assumed that the fundamental unknowns (the displacements field and the temperature field in this work) can be taken as a sum of the averaged part and the oscillating part. Furthermore, it is assumed that the oscillating part can be expressed as a product of the known fluctuation shape functions, and the new unknowns - the fluctuation amplitudes. The new basic unknowns, averaged fields and fluctuation amplitudes, are assumed to be slowly-varying functions of that coordinate which parameterizes the perpendicular direction to the laminas. The second assumption is the tolerance averaging approximation, in which it is assumed that some terms are negligible small. The main aim of this work is to obtain and present the differantial equations of two models - the tolerance and the asymptotic model, describing the thermoelasticity problems of considered laminates with transversally graded properties. Substituting the micro-macro decomposition to the main equations of thermoelasticity problems, using the orthogonalization method, doing the appropriate averaging and transformations, the final equations of the tolerance model were received. The equations of this model give a possibility to take into account the effect of the microstructure size. Directly from the equations of the tolerance model, by omitting the terms dependent on the microstructure parameter, the equations of the asymptotic model can be obtained. These equations describe the thermomechanical problems only on the macro-level. The equations of both models are solved by using the finite difference method. In the equations in this work it is a full connection between the displacements and the temperature. The equations of the tolerance and the asymptotic models can be applied in the analysis of some specific cases, where distribution of the ingredients is functional but non-periodic.

14364 | DETERMINATION OF THERMAL CONDITIONS OF THE PROCESS OF CENTRIFUGAL INDUCTION WELDING OF COMPOSITE POWDER MATERIALS FOR THICK-LAYER AND MULTI-LAYER COATINGS (Thermal problems on Composite structures)

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The engineering method for calculating the thermal regimes of centrifugal induction surfacing (CIS) of composite powder materials for thick-layer and multi-layer coatings is developed.
The analysis of the basic features of CIS technology of composite powder materials for thick-layer and multi-layer coatings showed that the most important stage in the operating procedures that determines the physico-mechanical and service properties of the resulting two-layer products is the isothermal soaking at the temperature of the composite powder material melting. The basic technical task at this stage is maintaining a predetermined average temperature of the composite powder layer (melting temperature) for a certain period of time (melting time).
As a result of analysis of the CIS thick-layer and multi-layer composite coatings technological process under isothermal soaking within the developed thermophysical model is strictly mathematically determined that the thickness of the composite powder layer has no influence on the thermal regime of isothermal soaking the CIS. Thermal regimes of isothermal soaking of multilayer coatings CIW does not depend on the number of layers, their thicknesses, the thermal conductivity of the used composite materials, and for their calculation we can use the calculated ratios for CIW of thin-layer coatings.

14618 | Interlaminar shear strength of fibre metal laminates after thermal fatigue (Thermal problems on Composite structures)

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Fibre Metal Laminates (FMLs) consisting of metal sheets and fibre-reinforced composite layers were initially developed from motivation of aerospace industry. FML laminates are characterized by low density, high fatigue strength, high static properties, high resistance to impacts and good corrosion resistance. Currently the efforts are made in order to find new solutions which will contain carbon fibre reinforced polymer layers with metal layers e.g. aluminium (Carall laminates).
The study presents the analysis of the influence of thermal fatigue on interlaminar shear strength of fibre metal laminates. Fibre metal laminates based on aluminum and carbon fibres were tested. Two different aluminum surface preparation were used. One was the classic anti-corrosion surface protection, the second was the surface preparation for maximization of adhesive properties. Moreover three different fibres arrangement were used. First of them was the carbon fibres in one direction, the second was the carbon fibres with additional, external thin glass layer in the same direction and the third was the carbon fibres with external, additional layer of thin glass layer with opposite direction. Different aluminum surface preparation in FML and combination of carbon and glass as a separating layer between carbon and aluminum they are one of the most commonly used anti-corrosion protection in fibre metal laminates.
The tests of thermal fatigue were performed in range -50°C to 80°C. The heating and cooling were performed with rate 5°C/min. Three thousand thermal cycles were used.
The studies demonstrated that the thermal fatigue is an important phenomena in case of fibre metal laminates because of different expansion coefficient between aluminum and carbon fibres. The thermal fatigue can caused decrease interlaminar shear strength in FML even about 15%. In addition, additional changes in humidity during changes in temperature conditions can adversely affect on degradation of the interface between metal and composite. It means that the surface preparation of aluminum and additional protection by using thin glass layers can additionally influence on the shearing strength.
Research was funded by the National Science Centre – Project No UMO-2014/15/B/ST8/03447.

13813 | Micro-fibril cellulose as a green filler for glass fiber reinforced unsaturated polyester composites: preparation and mechanical characteristics (Delamination, damage and fracture)

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The waste of bamboo stick production processing collected from Vietnamese craft village was used as a source of microfibril cellulose (MFC) for a filler of polymer composites. The bamboo waste was pre-treated with an alkaline solution to remove the silica, hemicellulose, and lignin portions prior to kraft pulping. The mixture of MFC in unsaturated polyester was obtained by directly introducing the bamboo pulp into unsaturated polyester resin followed by a

grinding process using a ball grinding machine. The master batch method was also used for composite preparation in which the high content solution of MFC in unsaturated polyester resin was firstly fabricated and diluted into the other solution with the desired content. Morphology and mechanical characteristics of unsaturated polyester resin based composites were investigated in detail. Effect of different preparation methods such as hand layup and vacuum bag on mechanical properties of glass fiber reinforced unsaturated polyester resin composites were determined. The results showed that the tensile, flexural properties and impact strength of glass fiber reinforced unsaturated polyester composites were enhanced with a presence of MFC filler.
Keywords: Bamboo pulp, unsaturated polyester, microfibril cellulose, mechanical property

13868 | Fracture behaviour of carbon fibre reinforced composites modified by multi-walled carbon nanotubes (Delamination, damage and fracture)

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Multi-walled carbon nanotubes (MWCNTs) were added to an epoxy in an effort to improve the fracture toughness of the bulk epoxies and also when used as the matrices of carbon fibre reinforced epoxy composites (CFRE). Mechanical properties, such as tensile modulus and strength of the epoxy, and flexural modulus and strength of the CFREs were also measured. The structure/property relationships were considered, with an emphasis on the toughness and the toughening mechanisms. The mode-I fracture energy of the epoxy slightly increased from 118.5 J/m2 to 136.5 J/m2 for adding 0.5 wt.% MWCNTs, then to 161.1 J/m2 for adding 1 wt.% MWCNTs. The toughness improvement is more pronounced in mode-II. The mode-II fracture toughness of the epoxy increased from 177.2 J/m2 to 283.6 J/m2 due to the addition of 0.5 wt.% MWCNTs, and further to 411.8 J/m2 due to the addition of 1 wt.% MWCNTs. The toughening mechanisms of MWCNTs were observed to be crack bridging (nanotube pull-out), nanotube breaking and crack deflection in both mode-I and mode-II. However, more nanotube breaking mechanism accompanied with higher dense of crack deflection were detected on the mode-II fracture surface. This resulted in better toughening performance of MWCNTs in mode-II. Similarly, the mode-I fracture energy of CFREs slightly increased from 428 J/m2 to 462 J/m2 for adding 0.5 wt.% MWCNTs, and further to 537 J/m2 for adding 1 wt.% MWCNTs, while the average mode-II fracture energy dramatically increased from 2026 J/m2 to 3406 J/m2 due to the addition of 0.5 wt.% MWCNTs, and further to 5491 J/m2 due to the addition of 1 wt.% MWCNTs. The superior toughening performance of MWCNTs in CFREs in mode-II is attributed to two reasons: (1) the MWCNTs enhanced the fracture toughness more effectively under shear loading by introducing more nanotube breaking and crack deflection mechanisms; (2) the large fracture process zone ac- companied with extensive hackle markings and micro-cracks ahead of the mode- II crack tip of CFREs resulted in significant number of MWCNTs contributing to toughening mechanisms, and hence, to increase in the fracture energy.

13884 | Composite material behaviour of fatigue wind turbine blade (Delamination, damage and fracture)

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This work is initially devoted to study the cracking behaviour of a small composite wind turbine blade. In order to choose material, the blade is manufactured by different materials (glass/epoxy, carbon/epoxy, Aluminium, and PVC). Considering loads and boundary condition, we study in static analysis the stress, strain and displacement, in dynamic analysis the modes shape and naturals frequencies, in fracture analysis the stress intensity factor, crack initiation and crack growth in order give the results by finite element method, then follow the evolution of the displacement, strain, stress SIF and first six naturals frequencies a function as crack propagation. As results we provide the best and idol materials versus the fatigue life of blade.

14353 | Damage propagation at the interface of a sandwich beam (Delamination, damage and fracture)

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Damage propagation at the interface of a sandwich beam

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In this research work, damage propagation at the interface of a cracked sandwich beam is considered. The behavior of Sandwich Beams (SB) depends upon a law based on relationship between tangential or normal efforts with inelastic propagation. As the crack propagates; the energy release rate corresponding to the applied shear stress in mode II is determined. Linear and nonlinear models are presented and numerical results using Matlab software are obtained for the case of a sandwich beam at the interface (adhesive part) and agreed with those obtained by other researchers. It is also discussed throughout this study the strength and fracture mechanics parameters based failure criteria.

Keywords: Sandwich beam, Shear stress, Stress intensity factor, Energy release rate.

14357 | Bridging the macro to the mesoscale: developing tensorial damage models for anisotropic materials (Delamination, damage and fracture)

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Modelling and analysis of fracture propagation and progressive damage evolution are integral for damage-tolerant design in structural, geotechnical, mechanical, mining and civil engineering. Anisotropy is an important factor affecting the strength and stability of many anisotropic materials including composites, coal, shales, and concrete. Continuum damage mechanics is one of the most popular methods to model fracture and damage in brittle solids. However two challenges arise in applying continuum damage mechanics to anisotropic materials. Firstly the selection of variables to describe the internal damage, and secondly the difficulty in modelling materials with significant initial anisotropy such as composites or sedimentary rocks. A severe limitation imposed by many continuum damage mechanics models is the assumption of initial isotropy in many anisotropic damage models. Many theories have been proposed and various types of damage variables ranging from scalar to vector to tensor quantities have been used to model anisotropic damage.

In this paper we consider anisotropic damage and the most general form for damage by using a fourth order tensor for the damage variables. We demonstrate how non-destructive ultrasonic measurements of the stiffness reduction of a solid undergoing damage can be related to these internal tensorial damage variables. We apply this analysis to experiments of initially isotropic or anisotropic solids becoming anisotropic (with a change of symmetry class or magnitude of anisotropy) under loading. We have developed methods to identify the directionality and magnitude of the introduced damage using experimental ultrasonic measurements of damaged elastic moduli. This analysis provides a robust way to validate and further develop phenomenological models of general anisotropic damage evolution based on continuum damage mechanics. This represents a significant advance in the development of anisotropic damage models based on continuum damage mechanics which until now have not been able to be experimentally validated and tested.

14363 | Mode-I fracture toughness of carbon fiber/epoxy composites interleaved by aramid nonwoven veils **(Delamination, damage and fracture)**

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In this study, carbon fiber/epoxy (CF/EP) composites were interleaved with aramid nonwoven veils with an areal weight density of 8.5 gsm to improve their Mode-I fracture toughness. The reference and aramid interleaved CF/EP composite laminates were manufactured by vacuum-infusion technique in a [0]4 configuration. Mode-I (DCB) fracture toughness, Charpy impact and short beam shear tests were carried out on the reference and aramid interleaved composite specimens in accordance with ASTM standards. Glass transition temperature (Tg) of the specimens was determined via Dynamic Mechanical Analysis (DMA). The results showed that the propagation Mode-I fracture toughness values of CF/EP composites can be significantly improved (by about 72%) using aramid nonwoven fabrics. The incorporation of aramid nonwovens increased interlaminar shear and Charpy impact strength by 10 and 16.5%, respectively. The Tg of the specimens were not affected due to aramid nonwoven veils.

14384 | Investigating Intralaminar Crack Growth in Biaxially Stressed Composites for Extreme Aerospace Applications **(Delamination, damage and fracture)**

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For the past several decades, tape-laminate composites have been investigated for use in space launch vehicle cryotanks to reduce the overall weight and launch cost. Recent development programs funded by NASA have concluded that tape-laminate composites are not ready for this application due to the deficient understanding of ply-level damage caused by cryobiaxial loading [1]. Cryobiaxial loading is defined as one resulting from internal biaxial pressurization of the cryotank, coupled with thermal straining caused by the cryogenic fuel. In certain situations, extreme cryobiaxial loading can lead to formation of through-thickness networks of transverse cracks, which may cause uncontrolled permeation of the cryogenic fuel into the surrounding environment, and possibly failure of the entire structure [1].

In this combined numerical/experimental effort, an in-plane cruciform test method is used to simulate cryobiaxial loading and investigate the initiation and evolution of intralaminar cracks in composite laminates subjected to these loading conditions. The cruciform specimen offers several key features that make it suitable for ply-level investigation of damage evolution in cryobiaxially-loaded composites. These include: 1) an ability to apply different biaxial load ratios (e.g. 1:1, 2:1, etc.), 2) a geometry that allows for in situ and ex situ observation of 3D damage evolution using high-resolution X-ray CT, 3) an ability to test a broad range of stacking sequences, and 4) an ability to cool the gage region to LN2 temperatures through conduction or cryogen submersion. To this end, a newly developed cruciform geometry is evaluated based on its ability to evolve damage that is representative of damage observed in composite cryotanks. The proposed design incorporates aluminium doublers, compound corner radii, and a semi-hemispherical gage region. These unique features are meant to minimize damage accumulation caused by the inherent stress concentrations at the 90-degree transitions between adjacent loading arms and ensure centralized damage accumulation.

Evolution of damage is first simulated using BSAM, a finite-element-based, progressive-damage code developed by the Air Force Research Laboratory. BSAM allows for the simulation of intralaminar cracking by combining: (1) 3D crack initiation failure criterion, (2) mesh-independent crack insertion, and (3) crack propagation using a mixed-mode I-II cohesive zone method. In addition, BSAM predicts delamination initiation and growth using a mixed-mode I-II cohesive zone model. The BSAM framework is used as a design and optimization tool for the cruciform specimen geometry. In addition, BSAM load-displacement and crack predictions are used as impetus for the physical experiments.

In this study, biaxial testing is performed at room temperature using a custom-built table-top load frame. Strains in the gage region are monitored using a 3D digital image correlation (DIC) system. Loading of each specimen is interrupted at predefined load levels, determined by BSAM, to perform ex situ X-ray computed tomography (CT). The X-ray CT images are used to construct a 3-dimensional representation of the specimen in its damaged state at each successive load interval. The CT data and BSAM models are then used to establish initial hypotheses of crack initiation and growth in biaxially stressed composites.

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14405 | NUMERICAL AND EXPERIMENTAL ANALYSIS OF CRACK PROPAGATION IN A COMPOSITES WITH A DISORDERED STRUCTURE **(Delamination, damage and fracture)**

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The paper presents the results of laboratory tests and numerical analyzes concerning the removal of a piece of material by means of an anchor. The analyzes concern a composite with a brittle matrix with randomly distributed inclusions. This type of analyzed medium can be used to model some geo-materials such as concrete and rocks. Laboratory tests were carried out on lumps of sandstone and porphyry. The results obtained will allow to estimate the size of the extracted rock fragment and the strength necessary for this removal. Numerical analyzes were made using the commercial software Simulia-Abaqus and the original author's CrackPath3 code. The calculations were made for the axially symmetric numerical model using the Finite Element Method. Elements with an extended shape function (XFEM) and a cohesive zone method for determination of breakaway forces were used.

14440 | An experimental investigation of damage evolution of composite materials under low cyclic compression load in off-axis directions **(Delamination, damage and fracture)**

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A larger comprehension on manufacturing procedures have allowed the use of fiber reinforced composite materials in more challenging applications, involving thicker structures and complex 3D stress states.
In practice, unidirectional composite materials are designed to support loads in the fiber direction, where the structural response of the element is directly influenced by the mechanical behavior of the reinforcement.
Nevertheless, when considering complex loading states, the off-axis directions are also involved in the overall performance of the structure, whose behavior is mainly dominated by the mechanical characteristics of the matrix and the fiber/matrix interface.
Experiments on unidirectional weave fiber reinforced composites show a nonlinear stress – strain relation in the 90° off-axis and through-thickness directions for compressive loads, similarly to what has been reported for in-plane and out-of-plane shear stress states. This nonlinearity can be related to progressive damage, which could negatively affect the strength of the element.
To optimally design thick structures is necessary a deep understanding of the mechanical behavior of the material especially if damage mechanisms start to develop and evolve.
In this investigation, the compressive response of unidirectional composite materials is studied. Here, load/unload compression tests in the 90° off-axis and through-thickness directions were performed. The damage evolution in both directions was studied, where the degradation of the compressive elastic moduli and permanent strain were correlated. In this study, an orthotropic glass/epoxy uni-weave noncrimp fabric composite was considered.
Non transverse isotropic behavior, different degradation levels and different rates of damage evolution between both directions was found. However, compression-dominated failure by shear mechanisms was observed in both cases.

14462 | Experimental investigation of the influence of geometric parameters on the Modified Split Cantilever Beam (MSCB) test in mode III. **(Delamination, damage and fracture)**

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This study focuses on the interlaminar fracture of composite materials in mode III using the Modified Split Cantilever Beam (MSCB) test. MSCB test is applied to investigate the dependency of the mode III energy release rate on geometric parameters (specimen width, and thickness), initial crack length, and crack front material layup. A non-perforated release film is introduced to create delamination at the mid-plane of the specimens. All the specimens are made from unidirectional (UD) glass fibers. The length of the specimens is 154mm. Load versus displacement curves are given by the UTM (Universal Test Machine) and are used in the calculation of the mode III critical energy release rate (GIIIc). A total of 55 experiments are performed. Recommendation for a width of 12mm is given from the first set of experiments (12). It seems that a 12mm width leads to a crack initiation without any failure of the specimen. Results from the following experiments (43) show a dependency of the critical energy release rate GIIIc on the crack length, and boundary condition of the experiment. Almost same GIIIc is obtained for different crack front orientations.

14488 | Development of efficient approaches to simulate Compression After Impact strength of composite laminates **(Delamination, damage and fracture)**

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Composite materials and their applications are increasing exponentially in all engineering sectors including aerospace industry. With their usage as a primary and secondary component, their complete evaluation is of utmost importance at all stages of their life. For researchers and structural engineers, highly important aspect is low-velocity impacts on such structures, which leads to barely visible damage [BVID] areas. Such BVIDs leads to local delamination at or near the impact areas, which later play a critical role in terms of composites failures and its initiation until the complete component fails. The delamination resulted in impact, becomes even more critical for compression events. Scientific community especially has designated term CAI [compression after impact] for such and is being used to evaluate the residual strength of composite components in the aerospace sector.
Experimental evaluation of impact events followed by CAI residual strength is always been very expensive, while recent advancement in computational resources enabled researcher community to mimic such events computationally with more precision and accuracy.
In this research, a simplified finite element approach has been developed to simulate CAI in standard specimens and structural details. The effects of delamination size and location towards the residual strength of composites after CAI events have been evaluated computationally. Advanced finite element tool ABAQUS explicit with continuum shell methodology has been utilized to allow delamination at different locations of the composite laminate. ASTM D7137 and Airbus standard AITM 1-0010 were followed towards specimen geometry and implementation of CAI event. In addition, this modelling approach was extrapolated to typical aeronautical details. Multiple laminates were considered for CAI models with built-in delaminations mapped from the damage created in low-velocity impact events. Among different laminates configurations, hard, soft and quasi-isotropic configurations were validated, but

in all cases, the load-aligned layers were at least 10% of the total number of plies.
Circular, oval, rectangular, combination of circular and oval along with other shaped was also simulated to find their effect on composite strength reduction. The circular and oval-shaped delamination were found to be the closest representative of experimental C-SCAN results of such events. The python script was developed to generate a delaminated region of choice for ABAQUS. In this work, the surface-based cohesive criterion is being utilized for surface interaction for delaminated and non-delaminated regions.
The delamination near the surface was found to be very critical, as it contributes a lot towards damage initiation and its propagation in terms of local buckling of sub-laminate. Such delamination becomes even more critical when outer plies are oriented in load directions. Among different shapes simulated, the rectangular and circular delamination contributes much towards strength reduction in comparison to other shapes.

Keywords: Compression after impact, delamination, composites structures, Low-Velocity Impact

14498 | A Phase Field Approach of Damage Modeling in Composites using Natural Neighbor Galerkin Method (Delamination, damage and fracture)

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In this work, we present a phase field approach for modeling damage in composites using natural neighbor Galerkin method. Numerical simulations based on standard continuum damage models are often found to suffer mesh dependency. Coarse spatial discretization cannot capture the smallest band where the growth of damage tends to localize. As a consequence, increasingly finer discretization grids lead to faster crack initiation and growth. In the limit of infinite spatial resolution, the predicted damage band has a zero thickness and therefore the crack growth becomes instantaneous. The response is then perfectly brittle, that is no work is needed to complete the fracture process. This problem can be overcome by using regularization scheme such as gradient theory. The recently developed phase field approach to fracture ([2], [3]) also serves as a means to provide nonlocal results. The non-locality is introduced by considering a diffuse interface concept. Phase-field method is efficient in predicting different damage mechanisms for a composite system [1]. To this end, we propose in the present work a meshless natural neighbor Galerkin method outlined in [4] and [5] to overcome the shortcomings of the conventional FEM approaches resulting from the high gradients and singularities associated with debonding and microcracking, for modeling damage in composites using the phase field approach. The performance of the proposed formulation will be demonstrated by means of some representative numerical examples.

Keywords: Phase field method, Damage, Composites, Natural Element Method

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14499 | A study on the influence of interlaminar properties on the out of plane mechanical behavior of a composite material (Delamination, damage and fracture)

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The comprehension of complete mechanical states on composite materials is essential in order to get superior design requirements of structures. Composite materials have been designed for in-plane performance, however complementary out-of-plane knowledge is essential in present requirements. In order to accomplish an optimal composite design, representative mechanical tests as well as accurate constitutive laws are mandatory. Presently, proposals related with out-of-plane testing reach an important development however still it is far from accuracy needed. Technology advances as well as existing numerical methods are currently powerful tools, thus virtual testing based on micro-mechanical analysis is an important characterization method to consider. Virtual testing, on the composite transversal direction, exposes the important role that matrix and interlaminar zone plays in progressive damage and failure of the material.
This work pretend to combine experimental and numerical methods, specifically mechanical testing (in-plane and out-of-plane) and cohesive numerical modeling. Composites characterization will be carry on by three point bending test and compression tests supported by optical microscopy. The idea is to determinate experimentally parameters in order to validate the cohesive model.

14511 | Modelling fracture propagation in cortical bone tissue considered as a composite material using the phantom-node approach (Delamination, damage and fracture)

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Cortical bone can be considered as a heterogeneous composite at microscopic scale, composed of osteons acting as reinforcement fibres embedded in interstitial matrix. Cement line constitutes the interface between osteons and matrix, being the weakest link along which microcracks tend to propagate.

The cement line has been analysed in the literature since it is the constituent at the microscale showing the highest risk of failure in cortical bone tissue. This interface between osteons and the interstitial matrix it is a low mineralized tissue often being the origin of cracks and probable propagation path. Moreover, another reason of weakness is that collagen fibres do not cross cement lines. The microcracks tend to follow the cement lines rather than crossing osteons as it is observed in experiments. Several authors analysed the behaviour of cement lines in cortical bone tissue and claim that strain increases at these interfaces.

However, current simulations of crack growth using XFEM as implemented in commercial codes do not capture this behaviour: they predict crack paths that do not follow the cement lines surrounding osteons. The reason is that the numerical implementation of XFEM does not take into account the heterogeneity of the material, leading to simulations that differ from experimental results. In this work, a crack orientation criterion for heterogeneous materials based on interface damage prediction in composites is proposed and a phantom node approach has been implemented to model crack propagation. In phantom node method, crack is treated explicitly and crack opening and shearing are calculated based on displacements of both original and phantom nodes overlaid to some of the original nodes. The method has been validated by means of linear elastic fracture mechanics problems obtaining accurate results. Through this analysis, the phantom node approach has proven to be an accurate technique when fine meshes are used. Once the method has been validated, the procedure is applied to different problems.

Several examples with idealized osteons have been modelled using the phantom nodes method and the proposed crack orientation criterion and also a cortical bone microsample reported by other authors in the literature. As expected, crack paths mainly grow and propagate through the weakest interface (cement line) and do not tend to cross osteons. Thus, the crack growth predictions agree with the observed experimental crack paths. The presented results show the importance of considering the heterogeneity, in contrast to other current commercial implementations. Furthermore, the procedure can be applied to model crack growth in other heterogeneous structures.

14515 | Comparative Experimental Approach for the Mode I Interlaminar Fracture Toughness of Unidirectional and Cross-Ply Carbon/Epoxy Composite Laminates **(Delamination, damage and fracture)**

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The delamination is a special failure mode occurring in the composite laminates due to the defects in the manufacturing process, external impact and environmental factors, etc. The delamination is most critical failure mode that significantly reduces the stiffness and strength of composite laminated structures. The delamination properties can be characterized by the interlaminar fracture toughness or critical strain energy release rate. Especially, the Mode I interlaminar fracture toughness can be obtained from Double-Cantilever Beam (DCB) test. The ASTM 5528 for DCB test is suitable for the unidirectional composite laminates. However, in many structural applications, the multidirectional composite laminates are used rather than unidirectional composite laminates. In case of Mode I delamination in multidirectional composite laminates, not only the crack propagation due to delamination occurs with matrix cracking but also the crack path transference between lamina leads to fiber bridging effect. Due to these complex failure behavior, it is necessary to investigate whether the Mode I interlaminar fracture toughness of multidirectional composite laminates evaluated by the ASTM DCB test method is suitable or not.
This paper describes the experimental and analytical method for calculating Mode I interlaminar fracture toughness for unidirectional and cross-ply composite laminate through an experimental approach based on the DCB test method. An experimental approach for Mode I interlaminar fracture toughness of composite laminate are carried out based on the strain energy release rate of fracture mechanics. In a linear elastic system, the compliance are defined as the relationship between load and displacement at loading point. Also, the strain energy release rate can be expressed as the load and the variation of compliance according to crack length. Since the variation of compliance according to the crack length can be expressed independent of the delamination propagation form, it can be applied to the testing which delamination propagates in a complex form due to matrix cracking and crack path transference between lamina. The values of Mode I interlaminar fracture toughness were calculated based on ASTM DCB test method such as modified beam theory(MBT), compliance calibration(CC) and modified compliance calibration (MCC). Also, both the method for direct use of the variation of compliance calculated from the measured load and displacement data according to the crack length and the compliance obtained from the modified load-displacement relationship using measured strains of the beam were utilized and compared with the conventional DCB test results.
The DCB test was basically carried out according to the procedure as defined in ASTM 5528. The unidirectional and cross-ply carbon/epoxy composite specimens were prepared and several strain gauges were attached behind the crack tip front of specimens at regular intervals to investigate the relationship among the crack length, displacement of loading point and strains due to bending. Loads and displacement data were recorded by universal test machine and strains are also measured simultaneously with the crack growth observation by using a high resolution camera.
The results show that the occurrence of crack path transference between lamina and fiber bridging are observed during delamination propagation for the cross-ply laminates and also the cross-ply laminates have an obvious influence on the Mode I interlaminar fracture toughness of composite laminates.

14533 | Intralaminar damage model for composite materials: a novel approach for mixed mode fracture toughness determination. **(Delamination, damage and fracture)**

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Composite materials are commonly used in different industries due to their high stiffness-to-weight and strength-to-weight ratios compared with traditional materials. In the transport industry, the spread of composite materials has reached nowadays more than 50% of aircraft structures weight obtaining important economic and environmental benefits. On the other hand, the complexity of laminates behavior represents a challenge when trying to predict the response of composite structures.

The extremely orthotropic behavior of composite materials results in a different failure mechanism when they are subjected to different impact loads. In the case of low velocity impacts on carbon fiber reinforced polymers (CFRPs) the main failure mechanisms can be divided in two groups: interlaminar (delamination) and intralaminar damages (matrix cracking and fiber breakage). Concerning to intralaminar damages, an special effort has been done to define different failure criteria to predict the damage initiation in each failure mechanism. In addition, to predict the material degradation when the damage onset is reached, the Continuum Damage Mechanics (CDM) approach have been introduced in the recent years. This formulation associates the material degradation with the energy dissipated during the damage propagation. Experimentally, the maximum energy able to be dissipated until the total

degradation is defined as a material property (fracture toughness) for each failure mechanisms. However, for some criteria, that combine different components of the stress tensor, the fracture toughness has to be defined using an equivalent value, since it is not possible to obtain this property for the amount of load cases that can trigger the material degradation. For that cases, an equivalent stress-strain evolution is defined to calculate the material degradation. The numerical implementation of CDM models for CFRPs composite materials associates the fracture toughness with the characteristic length of the elements to ensure a correct damage evolution. On the other hand, the failure mechanisms are usually defined using a two-dimensional approach for each lamina inside the laminate as intralaminar or in-plane failure mechanisms.

In this work, the continuum damage approach is used to formulate a three-dimensional model for CFRPs subjected to combined loads. The model includes the intralaminar failure mechanisms along the longitudinal, transversal and through-thickness direction. A maximum stress criterion is used to predict the fiber failure while the out of plane failure criterion is modeled using a combined quadratic stress expression. The damage propagation is evaluated as an intralaminar mix mode to predict the energy dissipation in each load case without predefining an equivalent stress-strain evolution.

Finally, to validate the model, a low velocity impact tests on 5HS woven carbon-epoxy laminates have been performed. Experimentally, laminates have been subjected to low velocity impact using an INSTRON-CEAST Fractovis 9350 drop weight tower according to ASTM standards (D7136). To reproduce the experiment tests, the drop-weight impact has been modelled using a commercial explicit finite element software with a user VUMAT subroutine implemented to reproduce the intralaminar damages. In addition, the interlaminar damages were modeled using cohesive interactions.

Keywords: Low velocity impact test, FEM modelling, 5HS woven CFRP laminates, 3D model, Continuum Damage model.

14553 | Modeling of the Progressive Damage and Failure in Textile Composites (Delamination, damage and fracture)

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Textile composites (TCs) offer high strength at a low weight, and also promise a higher fracture toughness compared to traditional laminated composites. This makes TCs an ideal choice for applications where significant post-failure strength is required, as well as in applications where the total failure energy is to be maximized. Typical examples of such applications include crashworthy lightweight automotive structures, jet engine turbine blades and engine casings. In all cases, graceful rather than catastrophic failure is highly desirable. With the current analytical and computational tools available, it is possible to predict the elastic behavior and mostly damage onset very well. However, predicting progressive failure from damage onset to full failure remains challenging.

The present study focuses on predicting the progressive damage of textile composites through a bottom-up approach that centers around two representative unit cells (RUC) of different scales. In the first RUC, fibers and matrix are modeled explicitly and in the second RUC, matrix and undulating homogenized tows are modeled explicitly. The fiber level RUC is used to derive the constitutive behavior of the fiber tows of the larger scale RUC. The material constitutive behavior of fibers and matrix is modeled using standard continuum mechanics models including plastic behavior in the matrix. Failure is explicitly taken into account through a smeared crack formulation. The unit cell is subjected to a variety of loading conditions and macroscopic the stress-strain response is recorded.

This data is next used to derive a suitable continuum mechanics model to represent the response of the fiber tows in the larger scale unit cell. This needs to be anisotropic in its elastic, plastic and damage response. Failure and cracking within the fiber level unit cell also leads to an apparent macroscopic strain softening behavior. This behavior introduces a characteristic length scale into the continuum mechanics representation of the fiber tows. Therefore, a higher order continuum model such as gradient based nonlocal continuum is necessary to guarantee a well posed problem. Alternatively, a characteristic length scale has to be introduced numerically and consistently such as in a smeared crack approach.

Several tow level RUCs are combined and service loads are applied to the finite element model. The predictions are compared against experimental data of TCs. It is shown that the present model is capable of deriving the response of the structure from the knowledge of the fiber and matrix properties and geometry alone. It can be expected that the present numerical model help reduce the amount of experiments needed to characterize the material properties and thus minimize the development cost of new composite systems.

14567 | STUDY ON UNDESIRABLE EFFECTS INDUCED BY DRILLING OPERATIONS IN COMPOSITE LAMINATES (Delamination, damage and fracture)

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Composites' drilling is an important machining process, often used when joining parts is required. However, this operation may cause different undesirable effects, such as delamination due to stacking configuration with its inherent different strength/stiffness layers or thermal shock due to low thermal conductivity of composites, which limits heat dissipation.
This work intends to characterize the influence of drilling parameters, such as the tools characteristics, spindle speed and feed rate as well as the influence of laminate thickness ratio and the use of short or fabric glass-fibre in the laminate. To this purpose an extensive set of experimental tests are performed which are digitally recorded via thermographic cameras for subsequent image processing. The laminated plates with the drilled holes are also scanned for further image evaluation. The information acquisition of the affected areas was carried out both through scans and thermographic digital videos and images. The results obtained are presented in tabular and graphical form, and aim characterizing the induced damaged area and the thermally affected area. A set of illustrative cases is presented to support the conclusions.

14586 | Macroscale Modeling of Low Velocity Impact of basalt-epoxy laminates (Delamination, damage and fracture)

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Basalt is a mineral fiber obtained from rocks and doesn't require additives during its processing. Composites made from it are therefore more environment friendly during disposal as compared to some other fibers used in aerospace industry. Like other aerospace composites, unidirectional laminates of basalt-

epoxy are more susceptible to damage in form of matrix damage and delamination.
Macro scale numerical simulations using elasto-plastic constitutive law combined with damage mechanics are used to predict force-time behaviur and extent of damage in Fiber Reinforced Plastic (FRP) composite during low velocity impact [1]. The elasto-plastic behaviour is due to significant inelastic deformation in the matrix accompanied with damage in the matrix and fiber.
For more accurate predictions of force and damage propagation, simulations require elastic and strength properties, fracture energies (inter-laminar and intra-laminar) and elasto-plastic properties of the lamina at different orientations. The interlaminar and intralaminar fracture energies of basalt-epoxy composites are calculated Double cantilever beam and End Notch flexure tests and compact tension and compact compression tests. Off-axis tests were used to predict the non-linear plastic behaviour of laminates which improves the prediction of indentation after impact.
Low velocity impact experiments were performed on basalt-epoxy composite plate using a drop weight tower. The impact force as function of the contact time, t, was recorded and the deformations of the top surface of plate in real time were obtained using Digital Image Correlation. The force-time curves, extent of damage and deformation of the plate obtained from the simulations were found to agree well with the experiments.

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14588 | Telephone cord blister morphology (Delamination, damage and fracture)

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Telephone cord blisters (TCBs) in film/substrate material systems are considered to be one of the most interesting instability problems in mechanics. They nucleate and propagate forward with wavy boundaries between the film and the substrate like worms. The current study considers the nucleation and growth of TCBs in thin films subject to biaxial compressive residual stresses. It views the problem from a completely new angle: It hypothesises that the nucleation and early growth of TCBs are driven by pockets of energy concentration (PECs), with subsequent primary and secondary buckling driving the growth when energy is seamlessly transmitted to the TCB tip (or nose) to provide the necessary crack-driving force. By following this hypothesis, completely-analytical formulae are derived for the first time for the two local morphology parameters of TCBs (width and height), and for the two global morphology parameters of TCBs (wavelength and transverse amplitude). Mechanical conditions are also given for the first time for the formation of TCBs. The predictions of the present theory agree very well with experimental results.

14589 | Properties of films determined by blister morphology (Delamination, damage and fracture)

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Thin film/substrate material systems are widely used in industries including aerospace, automotive, marine and electronics. As one example, in the aerospace industry, thermal barrier coatings (TBCs) are often applied to metallic components on gas turbine engines to protect them from high and prolonged heat loads. The properties of thin films are, in general, completely different to the properties of bulk material. As such, it is imperative to be able to accurately determine thin film properties to allow more efficient use of these systems and further improvements. Two major mechanical properties of thin film/substrate material systems are the mode I and mode II adhesion toughnesses and this is the focus of this work. One way to determine adhesion toughness is by using blister tests. In some blister tests, the size of the blister is driven by a pressure load, or a point load, and the adhesion toughness is determined by measured the blister size. In other scenarios, it is residual stress in the film that drives the formation of straight blisters, circular blisters, elliptical blisters, telephone cord blisters, or branched blisters. This work proposes a new way to determine the adhesion toughness of various thin film/substrate material systems under residual stress with high accuracy by considering measurements of blister morphology. Furthermore, if the adhesion toughness is already known via another method, the residual stress or the Young's modulus can be determined instead.

14827 | A bi-phasic modelling approach for interlaminar and intralaminar damage in the matrix of composite laminates (Delamination, damage and fracture)

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The research work, herein presented, shows an approach to model both delamination and transverse cracking in the matrix of composite materials. The damage processes are modelled by a single constitutive law with two separate damage variables, one for the delamination phenomenon and the other one for the transverse matrix cracking. The method is based on the decomposition of material stiffness properties into idealized fiber and matrix phases [1], then, the bi-phasic model is used with a 2D/3D hybrid modelling technique. The modelling technique was presented and validated in previous works to develop efficient numerical models, which can predict complex delamination phenomena [2]. In the proposed approach, the combination of hybrid modelling technique and bi-phasic decomposition are used to model composite laminates at the meso-scale level by adopting a stack of alternated bi-dimensional and tri-dimensional elements. The bi-dimensional elements represent the idealized fiber phase and they are embedded in the tri-dimensional mesh, representing the idealized matrix phase. Thanks to the peculiarity of the approach, the elements of the matrix phase can be used to model both intralaminar and interlaminar damage with a single constitutive law. In the paper, the decomposition procedure is first explained, then the introduction of a cohesive zone model into matrix elements and the structure of the related constitutive law are presented. It will be shown how the damage variables, which represent the damage evolution, affect the stiffness properties of the matrix phase and how the two variables interact with themselves in order to model the different damage processes interaction in real laminates. The application to several test cases show how the approach can accurately model delamination tests as well as transverse matrix cracking phenomena by using the matrix constitutive law. In particular, numerical experimental correlations are presented considering mode I and mode II delamination tests and the development of transverse matrix cracking in cross-ply specimens, characterized by a statistical distribution of matrix properties. It is also shown that the approach constitutes an appealing standpoint to model matrix cracking at the level of individual cracks, with a coarse through-the-thickness mesh refinement, avoiding the confinement problems originated in meso-scale models when a crack has to be modelled between adjacent undamaged layers [3]. The peculiar aspects of the technique are exploited to model the development of delamination from the evolution of individual matrix cracks, as documented by experiments reported in literature [4]. The evolution of crack

density in the presence of delamination appears to be correctly captured by the model, so that the potential of the approach is proved to include some of the most complex aspects of composite material response by using relatively coarse models.
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13828 | TLS-based Health Monitoring of Composite Structures with Robust EM Model (Structural Health Monitoring)

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Composite structures nowadays play an important rule and need to be significantly understood for their mechanical and physical properties. One of the most important issues is the deformation analysis within load experiments. Therefore, measurements can assist the theoretical analysis in several manners. The focus will lie on the so called terrestrial laser scanning (TLS), a 3d surface measurement technique which allows to measure up to 1 mio. points per second with up to sub-mm accuracy. It can sample a composite structure within seconds. From this point, the theoretical analysis from the raw measurement data to the final 3d deformations is presented. This includes some preprocessing steps for denoising, segmentation of relevant areas and optimal surface fitting strategies.

14516 | A Study on the Defect Detectability Using Electrical Resistance Method in Composite to Composite Single-lap Joint. (Structural Health Monitoring)

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Mechanical joint and adhesive bonding are two typical joining methods for composite materials. The bolt fastening method is reliable but increases the weight of the structure and cuts the composite fiber, which may cause stress concentration and strength degredation. The adhesive bonding method has higher bonding strength than the mechanical fastening, but the bonding strength can be deteriorated depending on various parameters involved in environmental conditions and manufacturing process. In addition, bonding defects due to foreign substances on the bonding surface or immature surface treatment is called Kissing Bond, which can greatly reduce the bonding strength. The electric resistance method is a very promising technique for detecting Kissing Bond defects by measuring electrical characteristics by dispersing CNTs in an adhesive.
In this study, the composite to composite single-lap joint specimens with CNTs were fabricated and the defect detection capability and the static strength of composite joints were evaluated by electrical resistance method were evaluated. The AC and DC impedances of composite adhesive joints with artificial defects were measured by using an LCR meter and a high resistance meter, and their strengths were evaluated.

14543 | Development of THz wave imaging processing to detect delamination of the composite structures (Structural Health Monitoring)

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We introduce a nondestructive inspection technique of composite materials using terahertz wave, which has been attracting much attention these days. A terahertz time-domain spectroscopy system based on photoconductivity antenna was hired to detect the internal defects of composites, and a hidden delamination, a type of the composite defects, was simulated inside of the composite specimen. In order to avoid possible errors from the total reflection angle, which is defined with reflection angles between the emitter and receiver, 6:4 THz beam splitter was adopted in the system. Due to the limitations of defect visualization results using commercial software, an imaging processing technique was newly developed by authors' group. The imaging processing method includes time-domain and frequency-domain analysis, and defect sizing technique based on Canny edge detection algorithm. A 2D THz wave image was obtained at a certain time, and 3D defect visualization was done with 2D image data gathered through time elapse. Finally, we confirmed that the hidden delamination of the composite structure has been successfully visualized in the B- and C-scans.

14571 | DESIGN AND MAINTENANCE PRACTICE BASED ON SHM SYSTEM (Structural Health Monitoring)

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The use of composite materials in civil aeronautical structures is becoming increasingly widespread, but some issues still persist: their high sensitivity to damages and defects, and uncertainty of using bonded parts. Such constraints can lead both to the design of oversized structures and to very complex and conservative maintenance approaches.
In the framework of CIRA project, SMAF, funded by Italian Program for Aerospace Research, a new design and maintenance approach has been developing by using the information given by SHM systems. New design paradigms has been conceived, trying to overcome the current limits of the design of composite structures, that is conservatively based on the assumption in the structure of BVID (barely visible impact damage) damages, whose sizes are based on the limits of the current visual inspection. The possibility to trust on a reliable SHM system, able to detect low energy impact damages with size and indentation smaller than that one currently assumed for design and certification, can improve the static strength (compression after impact) of the structure: i.e. adoption of a higher design allowable with a consequent reduction in weight. Besides, the use of bonded parts if monitored by sensors/actuators, can overcome the current uncertainty of long-term adhesive performance.
This work resumes the innovative design approach and results achieved, until today, in SMAF project, with reference to CFRP stiffened panels,

representative of the upper skin of a typical regional aircraft wing box. SMAF is focused on the benefits evaluation (weight and costs reduction, maintenance improvements) resulting from the use of an off-line SHM system, based on PZT sensors/actuators and FBO. Both are dedicated to the detection, localisation, and measurement of the damaged areas induced by low energy impact damages: PZT for damages in the skin panel and FBO for debonding between the skin and stringers. Experimental and numerical results are available on flat composite panels.
The PZT system is based on an elliptical triangulation method: a non-destructive method that employs PZT sensors/actuators and ultrasonic waves (Lamb waves). Any discontinuity in the structure, if crossed by a wave, generates an additional wave representing the perturbation. A comparison between the signals measured on the undamaged structure (baseline) and that one that occurs in presence of damage (damaged signals) is performed. No changes in the Lamb waves before and after the impact implies that the perturbation is negligible (no damage is occurred). Conversely, a modification in the Lamb waves implies the presence of damage. The position and dimension of the damage is obtained by the calculation of the Time of Flight (ToF) of the direct signals and of the perturbation wave, and knowing the actuator-sensor position.
The FBO system is based on gradient “features” indicators extracted from a distributed strain spectrum provided by a Rayleigh backscattering fiber optic monitoring system. The damaged configuration gives rise to local irregularity in the difference signal between the non-damaged and damaged state, as a direct consequence of the generated discontinuity. Nevertheless, the signal-to-noise ratio sometimes hide too small deviations; a threshold value choice is needed. Empiric observations have shown that the use of derived features extracted from the original strain spectrum, may improve the signal to noise ratio of the signal, highlighting its “dispersed” nature respect to whatever structure is considered. The method starts with the elaboration of the strain full spectrum, acquired during the experimental session or just after. Then a set of statistical gradient features are extracted. Large variations of the features magnitude become indicators of the presence of a structural discontinuity. Finally, a cumulative damage index is defined as combination of the selected features contemporarily overcoming the prescribed thresholds.

14615 | Finite Element Models for the Guglie bridge in Venice based on non-destructive testing: sensitivity to design shape (Structural Health Monitoring)

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Venice is a unique city all over the world for several aspects, among which the most important resides in its “aquatic” environment. Although Venice continues to witness admirably its historical architecture, the quality and performance of existing buildings and bridges and the ability to keep them in operation is becoming an increasing issue. Accordingly, there is a growing interest in methodologies capable to evaluate efficiently the degradation state of existing structures. The city was originally born as a set of 121 islands, connected only by boat. The bridges have been built in a second stage of urban expansion, with their design adapted to the existing complex network of streets (named in Venice “Calle”). Nowadays, there are about 430 bridges, realized with several design shapes, arch shapes and materials.
The “Guglie” bridge is made of masonry and Istrian stone, a compact lithographic limestone of the Tithonian age, from Istrian peninsula. The same stone has been used for the parapets of the bridge and the “Guglie”, from which come the name and can be geometrically described as a sort of pyramids with square base (pinnacles) posed at the edges of the bridge. The bridge is not orthogonal from one bank to the opposite. In this work, the structural sensitivity to bridge orientation respect to the banks is analyzed. For this aim, a reference bridge model, designed with an orientation orthogonal to the opposite banks, is studied. Hence, the structural behavior of the “Guglie” bridge is compared with the reference model. Theoretical and numerical investigations are carried out starting from a non-destructive experimental procedure (tromographic analysis) based on seismic noise measurements.
The mechanical characterization of bridge has been performed starting from an identification procedure based on non-destructive experimental analyses. Tromographic analysis is a passive and non-destructive structural monitoring technique, fast and cheap. The measurement sites are located in correspondence of the abutment, the middle and the crown. The natural frequencies and modal shapes of the structure have been evaluated measuring and analyzing the orthogonal velocimetric components of environmental noise.
Modal Analysis and Static Analysis for the two 3D models have been carried on. The mechanical model of the existing bridge has been calibrated by means of modal analysis in order to reproduce the experimental tromographic results and, in this way, the mechanical characteristics of the material have been identified.
Two FE models have been considered and compared: 3D full FEM models have been built for both bridge shapes. They have been done by 8000 4-nodes bricks elements and the two models have the same elements.
The effective materials constituent bridge are considered: masonry, fill and Istrian stone. The mechanical characteristics of adopted material are:
Mansory: 1800 Kg/m3 specific weight (γ), 0.2 Poisson ratio (v), 3000 Mpa Elastic module (E)
Fill: 1000 Kg/m3 specific weight (γ), 0.2 Poisson ratio (v), 800 Mpa Elastic module (E)
Istrian Stone: 2300 Kg/m3 specific weight (γ), 0.2 Poisson ratio (v), 10000 Mpa Elastic module (E)
In the comparison of the results of the modal analysis for the two different design some important aspects have been identified. For both models the frequencies results for main mode have negligible differences. Interesting differences may be found in the modal mass participant.
In the model referred to realized bridge, during the modal analysis, the mass participant is a combination of the three spatial direction of bridge, consequently is more articulated and complex the comprehension of the bridge behavior, while in the reference bridge, orthogonal to the bank the mass participant is referred separately to three spatial direction of bridge.

14921 | Identification of stress field change in multi-strands cable anchorage via FRP-PZT interface (Structural Health Monitoring)

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Structural health monitoring of the cable-anchorage system is very important to secure the integrity of the cable-stayed bridge. The cable-anchorage system carries most of self-weight, so that any damage in the system may significantly reduce the load carrying capacity of the bridge. The demand on structural health monitoring (SHM) has been increased in aerospace and civil infrastructures over the past two decades. Among a variety of SHM studies on cable-anchorage system, many researches have been focused on monitoring of cable force by using electro-mechanical (EM) impedance response of tendon anchorage. The impedance-based method has been found sensitive to any structural change in local area like anchorage zone. By utilizing EM impedance of anchorage zone, the loss of cable force or anchorage damage would be detected.
In this study, a prototype of FRP-PZT interface is designed to identify the change of stress fields in multi-strands cable anchorage. First, a hoop type of FRP-PZT interface is proposed to detect the stress field change in the multi-strand cable anchorage systems based on local dynamic characteristics of the interface. Next, a FE model of a 7-strand cable anchorage is established to evaluate the feasibility of the proposed PZT-CFRP interface. Local dynamic responses of the FRP-PZT interface are analyzed for various stress fields simulated by loosening prestress-forces of some strands in the cable

anchorage. The change of stress fields and the location of damaged cables are identified via comparing the sensitivity of the local dynamic signatures of the array sensors.

13824 | Pseudo-ductile effects on ±45° CFRP under three-point bending (Experimental Methods)

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This work investigates analytically and experimentally the flexural pseudo-ductile response of symmetric ±45º angle-ply laminates consisting of unidirectional and continuous CFRP plies. Most of the existing literature about pseudo-ductility deals with uniaxial testing. To our knowledge, this is the first attempt to investigate the pseudo-ductile effects under three-point bending taking into account the higher degree of complexity introduced by the variation of the strain through the cross-section thickness. The analytical study takes into account the different behaviour of the material under tension and compression. Then, during the linear stage, the homogenised section technique allows to predict the neutral fibre deviation from the mid-height plane as well as the damage initiation mode and its position. The experimental description of the non-linear stage is developed thanks to the full normal strain field acquired by means of a DIC system and strain-rosettes that help to complete the data. Besides, the understanding of the damage initiation process and its evolution is studied by means of micrographic observations applying SEM technology. Finally, an optimisation procedure is proposed for determining the stacking sequences that minimise the bending-twisting coupling but favour the pseudo-ductile response with design purposes.

14162 | The effects of Diesel at different temperatures on fiber reinforced Polyoxymethylene composites. (Experimental Methods)

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Due to environmental concerns Biofuels have started to partially replace non-renewable fuels. Biodiesel is an important fuel used as alternative to extend the usefulness of petroleum, and the longevity and cleanliness of diesel engines. Engineering polymers have great importance in the industry thanks to the years of improvement in their properties, which allowed equipment manufacturers to replace metals by polymers. Often, polymers are in direct contact to fuels and understand its compatibility is primordial. Polyoxymethylene (POM) is thermoplastic used to manufacture automotive fuel pump gears and rotors due to its low coefficient of friction and thermal and dimensional stability. In this study POM and glass fiber reinforced POM were assessed with Diesel at different temperatures, -10ºC, 23ºC and 60ºC for different periods of time. After degradation, tensile tests were performed to evaluate the material mechanical properties and analyze the effect of Diesel degradation.

14383 | EFFECT OF ANGLE-PLY ON THE VISCOELASTIC BEHAVIOUR OF GFRP LAMINATES SUBJECTED TO HOSTILE ENVIRONMENTS (Experimental Methods)

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Polymer composite materials (PMCs) are used in many structural components, and this tendency is to continue as consequence of their high specific strength and stiffness, competitive cost and dynamic properties. However, when such components are subjected to loads for long periods of time, they can be seriously affected due to the viscoelastic behaviour of the polymer matrix. This effect is, according with the bibliography, more remarkable when they are subjected to off-axis loading.
On the other hand, the interest in glass-reinforced plastics (GRP) components for highly corrosive environments, as an alternative to the traditional metals, is becoming common. In this context, the open literature reports that the mechanical properties are strongly dependent of the exposure time, solutions' concentration and temperature. In terms of alkaline and acid solutions, independently of the solution, for example, both flexural strength and modulus are affected by the exposure time as consequence of the matrix degradation and interface matrix/fibre.
Therefore, this work intends to study the effect of angle-ply on the stress relaxation behaviour of GFRP laminates subjected to hostile environments. For this purpose, hydrochloric acid (HCl) and sodium hydroxide (NaOH) solutions were used. The effect observed was conveniently quantified and the Kohlrausch-Williams-Watts (KWW) function was used as model to fit the stress relaxation data.

14421 | Experimental and Numerical Study of inter-yarn friction coefficient behavior on the ballistic impact response of High-Performance Fabrics (Experimental Methods)

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High-performance fabrics, manufactured in Aramid, have increased their demand in recent years due to their high strength in applications where high levels of energy absorption are required, as is the case of ballistic protections. The impact strength of a fabric depends on the abilility of the yarns which are in contact with the projectile to absorb the local energy and diffuse it to adjacent yarns without producing severe damage or failure. Additionally to this yarn deformation and failure, yarn pull-out also contributes significantly to the dissipation of impact energy.

In this work, several experimental tests and numerical simulations have been performed to study the effect of inter-yarn friction on the response of different woven aramid fabrics under high velocity impact. Yarn pull-out is produced by yarn uncrimping and successive yarn translation. Hence, if friction

is significant, a large amount of impact energy can be dissipated before the penetration of the projectile occurs. Therefore, an accurate estimation of both static and kinetic friction coefficients is crucial. For that porpous, and for the correct numerical prediction of the mechanical behavior of aramid fabrics under impulsive loads, an exaustive study of the yarn has been conducted; including experimental tensile yarns test to predict the mechanical properties, and pull-out tests to calculate the inter-yarn friction between yarns.

ABAQUS Finite Element code has been used to perform realistic models that includes all the characteristics of the test. The validation of each model is carried out with its corresponding experimental results. A semi-analytical model from the literature has been used to determine the inter-yarn friction coefficients of the different woven fabrics. This model requieres some parameters from the load-displacement curve obtained from the pull-out tests. The friction coefficients obtained are used both in the pull-out and ballistic impact simulations. The pull-out numerical model is used to determine the friction coefficients of the different fabrics, being the obtained values very consistent with the range reported in the literature.

Therefore, a complete methodolgy to analyze te inter-yarn friction on the response of balistic impact test is presented in this work.

The authors acknowledge the Ministry of Economy and Competitiveness of Spain and FEDER program under the Project RTC-2015-3887-8 and the Project DPI2017-88166-R for the financial support.

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Sanhita Das, S.Jagan, Amit Shaw, Anjali Pal. Determination of inter-yarn and its effect on ballistic response of para-aramid woven fabri under low velocity impact.

14487 | In situ observation of damage and its evolution inside engineering materials via synchrotron laminography
(Experimental Methods)

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Computed laminography has been established at synchrotron imaging set-ups to complement computed tomography for three-dimensional (3D) imaging of laterally extended (i.e. plate-like) specimens [1]. Due to different contrast modes (such as absorption, different phase-contrast modes, fluorescence, diffraction) available and spatial resolutions ranging from about 30 down to approx. 0.5 μm, there is a wide application potential in the materials sciences. Selected examples demonstrate the interest of the method especially for in situ measurements of large planar specimens where sample extraction needs to be avoided and/or engineering-relevant boundary conditions have to be fulfilled. In particular, progress about 3D damage characterisation in carbon-fibre composite panels [2,3], about the in situ study of strain-damage interactions under mechanical loading in aluminium alloy sheets [4] and about damage micromechanisms ahead of a severe notch in semicrystalline polymers [5] is reported.

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14532 | Experimental study on fibre kinking and compressive strength in unidirectional (UD) composite laminates
(Experimental Methods)

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A new design for the experimental determination of fibre kinking strength in unidirectional (UD) FRP laminates at quasi-static loading rates is proposed in an attempt to overcome issues that have plagued previous studies on this type of failure. The proposed UD specimen, mounted on an alignment fixture and clamping system, is designed to avoid premature failure due to bending, matrix cracking, fraying, and stress concentrations that arise from the imposed boundary conditions. As a result, more reliable and repeatable measurements can be obtained than what has been previously reported in the literature.

However, under high-rate dynamic loading conditions, inertia from the clamps and fixtures can affect wave propagation and introduce uncertainty in the results. Therefore, an alternative design, more suitable for high-rate testing systems such as the split-Hopkinson bar, is also proposed. Using ±45° cross-ply specimens aligned with the loading direction, fibre kinking failure in the longitudinal plies can be reached without the need for complex fixtures and the unidirectional strength and stiffness properties are then extracted from the measured axial data using classical laminate theory.

This second approach has been verified against the first set of UD specimen tests, showing good agreement between the obtained fibre kinking strength values and proving the cross-ply design as a viable replacement for UD specimens in high-rate experiments. Finally, a series of specimens from both

above designs with varying degrees of misalignment relative to the loading direction (3, 6, 10, and 15°) were prepared and tested in order to investigate the effects of off axis stresses on kinking strength and evaluate existing failure criteria.

14570 | Influence of the MFC actuator on dynamics of a rotor with constant angular velocity (Experimental Methods)

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An experimental and numerical analyses of the dynamic behaviour of an active rotor with three composite blades are presented in the paper. The study focuses on determining an effect of an active element on dynamics of the rotor with constant rotational speed.
The rotating structure composed of an electric drive, a hub with a drive shaft and three grips with active blades is installed at Lublin University of Technology. The blades with rectangular cross-section are made of glass-epoxy unidirectional prepreg with the six layers laminate configuration of [±45/90]s. Macro fibre composite (MFC) elements used to reduce vibrations (excitation of the system) and strain gauges applied as a sensors are embedded to opposite surfaces of the beam. A Digital Signal Processor (DSP) system is applied to control the rotary speed in the experimental analysis. The MFC actuator is activated by a harmonic voltage signal, which caused excitation of the blade. However, the blade response is measured by the strain gauges. The resonance curves for three-bladed rotor with different rotational speeds and voltage signals applied to the MFC element are obtained.
Next, the finite element model of the active rotor is developed using the Abaqus software package. Due to the complex structure of rotor, some assumptions are included in the numerical model. The FE model consists of a hub and three laminated beams with actuators. The complex structure of the active element is not taken into account but an equivalent homogeneous material tested in static and dynamic studies is proposed. The transducer and the hub are modeled by solid elements, while the blades are modeled as continuum shell finite elements with reduced integration. The sequence of the laminate layers is modeled by the layup-ply technique. The interaction “TIE” is used to join the appropriate components of the system. Moreover, all translational degrees of freedom for the hub are locked. In the numerical analysis two types of the excitation are considered: (a) where the harmonic voltage signal is supplied to MFC actuator or (b) periodic external force is loaded on the free end of beam. Both cases are examined taking into account the constant rotational speed, which is modeled as the centrifugal force acting on the blades. During simulations, the system response of the selected point at the free end of the blade is recorded. The selected resonance curves are determined and compared with experimental results. A good correlation between the numerical results and the laboratory findings is achieved. The validated model of the active rotor will be used for control and vibrations reduction in future tests. The paper is supported by the statutory resources allowed to the Department of Applied Mechanics, Lublin University of Technology as “The Grant for Young Researchers” No. 30/MN/2017.

13881 | INFLUENCES OF DOUBLE TAPERING ON THE FLAP AND LAG NATURAL FREQUENCIES OF ROTATING TAPERED COMPOSITE BLADE (Variable Stiffness Composite Laminates)

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Doubly-tapered composite beam is used in rotating structures such as helicopter rotor blades and wind turbine blades for its outstanding engineering properties that include high strength/stiffness to weight ratios, capability to be stiff at one location and flexible at another location and favorable fatigue characteristics. Due to its distinct characteristics from stationary beam and wide range of applications, the rotating beam requires a comprehensive study to understand its dynamic response. In the present paper, the free vibration response of rotating doubly-tapered cantilever laminated composite beam is investigated considering a specific practical taper configuration. The Rayleigh-Ritz method in conjunction with the classical lamination theory is used to obtain the system mass and stiffness matrices for the out-of-plane (flap) and in-plane (lag) flexural vibrations. Numerical and symbolic computations have been performed using the software MATLAB. The developed formulation and analysis have been validated using Finite Element Analysis (FEA) results obtained using well-known FEA software ANSYS. The combined and relative influences of width and thickness tapering on the natural frequencies of the rotating laminated composite beam are studied. In addition, the influence of stacking sequence of the composite laminate on the natural frequencies is also investigated. Design aspects are systematically brought out based on the parametric study.

14458 | REINFORCEMENT OF COMPOSITE MULTILAYERED STRUCTURES – OPTIMAL DESIGN OF LAMINATES WITH VARIABLE STIFFNESS (Variable Stiffness Composite Laminates)

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The simplest method to counter the weakening effects of foreseen damage zones of structures is to design local or global reinforcing layers or a system of meridional and circumferential stiffeners. The nature of composite materials as well as the technological processes used in the production of composite structures (e.g. vacuum bag or autoclave methods) allow us to manipulate with the number of plies and their dimensions in order to produce locally reinforced structures. For steel structures Calladine presented the effects of a steel reinforcement of spherical shells with the use of layers made of the identical material as dome itself – the analysis of the maximal carrying capacity of structures (plastic hinges). Another approach is to apply as reinforcing layers fibre reinforced plastics (FRP) which offer a significant amount of material savings (over that for isotropic materials) and additionally a great simplicity in tailoring and bonding them to steel shells. Those effects have been investigated by Muc. In the paper various effects have been discussed dealing with the influence of the reinforcement length, thickness and mechanical properties of composite materials. The hybrid structures made of steel/FRP has been also considered. The numerical results have been confirmed in a series of experiments. The similar method have been proposed in the analysis of the stress concentration zones arising at the junction of the nozzles to the cylindrical body of composite pressure vessels – see Muc. The aim of the study was to optimize the composite reinforcement along the junction of the pressure vessel elements in order to equalize the energy strain distributions.
Now, the discussed previously methods are extended to more general formulation of optimization problems dealing with plated and shell structures.
Let us introduce two load parameters characterizing two types of failure modes of composite structures (denoted by the symbol λ):
-buckling load factor – and
-first-ply-failure load factor .
Buckling load factor is understood as the multiplier of the load corresponding to the loss of stability by the structure. It is evaluated numerically using the Rayleigh-Ritz method or the FE method. In the both cases the Love-Kircchoff plate/shell theory is employed as well as a geometrically linear approach is

used in the description of the prebuckling state.
First-Ply-Failure load factor is derived with the use of the FPF criterion in the form of the maximal allowable strains and it is necessary to calculate it for each individual ply in the laminate.
The total volume of the structure is described in the classical manner and it is denoted as V. Since the analysis deals with laminates (not hybrids) the total volume is equivalent to the total weight of the structure.
With the use of the above definitions two optimizations problems can be formulated:
Maxλ and V=const
MinV and $\lambda<\lambda al$
where λal is an allowable value of the load factor and s is the vector describing the characteristic geometrical parameters of the local reinforcement.
The reinforcement dimensions can be prescribed as discrete values what is convenient for FE discretization of the problem or as real (continuous) values. In the latter case the reinforcement can be treated as smeared out over the structure and the method of their dimensions evaluation is identical as for the shape optimization problems. Therefore, the methods of optimization (understood in the sense of the reinforcement description as well as the optimization algorithm) is identical to that discussed by Muc, Mróz. It is assumed that the reinforcement is located symmetrically with respect to the plate/shell mid-surface.
The numerical examples dealing with the rectangular plates and cylindrical shell structures illustrate the effectiveness of the proposed method. The evaluation of the all considered objective functions is conducted with the use of the FE program NISA and symbolic package.

14565 | Optimal Design of Variable Stiffness Composite Plates (Variable Stiffness Composite Laminates)

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The use of fibre reinforced composites has become consolidated through the years, in many different areas of engineering and science. The use of long fibres has been used extensively either considering them in a unidirectional architecture or as a fabric where a few of entanglement configurations may be provided.
However in recent years, associated to relevant technological manufacturing advances an important concept arose, related to the possibility of conferring a curvilinear path to these fibres. This manufacturing possibility allowed to a more flexible and customized design when compared to the previously mentioned composites and inevitably the optimal design of these curvilinear path fibres became imposed by potential applications requirements.
The present work considers the optimal design of variable stiffness composite plates, considering different cases studies, and a metaheuristic optimization technique approach. The plates modelling and analyses are performed through the Rayleigh-Ritz method implemented through the use of orthogonal polynomials. The conclusions are supported by a set of illustrative results.

14381 | Draping simulation of carbon/epoxy fabric prepregs and prediction of mechanical behavior of the cured structure (Morphing of composites)

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Recently, Strict international environmental regulations are created for reducing carbon emissions of fossil fuels, so various studies like weight-reduction and eco-friendly fuels are in progress. Carbon fiber reinforced composites which has high specific stiffness and strength have emerged as a substitute for metal materials. But unidirectional fibrous composites are not suitable for complex shapes structures. In case of woven fabric composites, they show high formability due to in-plane shear deformation. In this study, the behavior of woven fabric composites was materialized by finite element analysis using non-orthogonal constitutive equations. For this purpose, woven fabric prepreg tensile test and picture-frame shear test were simultaneously performed. The accuracy of the finite element analysis was evaluated by comparing the analysis result with the corresponding draping experiments. The local mechanical moduli were estimated by the non-orthogonal model by prediction local fiber orientation after completing the draping process. Based on the deformation information of the draped structure, the cured mechanical properties were calculated and inserted to each element of deformed structure. The fracture mode of the cured structure was predicted and compared through compression test and finite element analysis.

Acknowledgement
This research was supported by the Nano-Material Technology Development Program through the National Research Foundation of Korea funded by the Ministry of Science, ICT and Future Planning (NRF2016M3A7B4910532).

14433 | Trade-off between functional and structural performances in composite skins for morphing applications (Morphing of composites)

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The presentation discusses the issues and the possible solutions related to the development of skins for morphing aeronautical structures, based on composite laminates with different geometries and materials. The basic requirements of morphing skins are reviewed, considering studies presented in literature [1,2] and the differences between morphing skins designed for bending and stretching functional performances are outlined.
An appealing solution for the skins which are required to undergo large extensional deformation is represented by the adoption of composite corrugated laminates, which have been considered by several authors [3-5]. Aerodynamically efficient skins made of corrugated laminates can be produced, by integrating smooth elastomeric covers that can be supported by means of honeycomb inserts. The resulting element can be used to design aeronautical panels, which can also be actuated, and also provide significant stiffness contributions in non-morphing directions. Design solutions and manufacturing techniques are presented, including the use of siliconic and neoprene elastomeric covers. The trade-off between functional and structural performances for such solutions is evidenced by introducing performance indices, which make possible a comparison of panels stiffness and strength with the those of conventional flat panels of identical weight. The risks of failure due to delamination of the corrugated laminate are outlined and a method to predict the ultimate strength of corrugated composite sheets is presented.
For the applications where only bending morphing is required, and significant aerodynamic loads have to be carried, the limits of corrugated sheets are

discussed, considering the specific design case of a morphing leading edge [1]. The different morphing performances and structural requirements suggest alternative and more conventional solutions, based on conventional curved laminates. However, it is shown how hybrid lamination sequences, combining carbon fibre reinforced and glass fibre reinforced plies can lead to a better trade-off between structural stiffness, which is required to maintain a smooth and regular shape under pressure, and the achievement of high curvatures within the elastic range.

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13854 | Transverse mechanical stress and optical birefringence induced into single-mode optical fibre embedded in a smart polymer material (Smart Composites)

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There are presented simulation results regarding an important optomechanical characteristic of single mode (SM) optical fibre used as light propagation guide for fabrication of fibre sensors commonly by inscribing gratings when embedded into the polymer matrix of a smart composite material: the internal transverse mechanical stress induced by the surrounding polymer matrix. Related to the SM fibre internal transverse mechanical stress is the optical birefringence, an important SM fibre light propagation characteristic.
The fibre sensors have the role to provide the feedback of smart composite materials used for various applications in research, medical, industrial, aerospace and security domains. Smart composite materials using embedded grating fibre sensors provide feedback at a large number of ambient stimuli such as applied force or pressure, temperature, mechanical load but including also, humidity, change of aggregation state, micro-changes. There were investigated the two main types of grating fibre sensors: the short period one (known as Fibre Bragg Grating - FBG) and the long period one (known as Long Period Grating - LPG). The FBGs are operated as sensors using the reflection band induced by the Bragg diffraction grating into the fibre transmission or reflection spectrum. They are operated as sensors exploiting the coupling process between the incident and the grating diffracted/reflected modes guided through the SM fibre core. The whole process is produced into the core and is not directly affected by the microscale possible changes of the SM fibre ambient. FBG are used mainly as sensors for applied force/pressure and temperature. The LPG are operated as sensors (LPGFS) using the absorption bands induced by the grating scattering in the optical fibre transmission spectrum. The LPGFS are operated as sensors exploiting the coupling process between the propagating through the fibre core mode and the modes propagating through the fibre cladding. The whole process is produced into the optical fibre placed in direct contact with the ambient and can be directly affected by the microscale possible changes of ambient measured by refractive index variations. LPGFS are used as sensors for applied force/pressure and temperature on one side and for detection of ambient refractive index variations induced by chemical modifications, presence of impurities such as water molecules or of other compounds.
The analysis of the SM optical fibre internal transverse mechanical stress and the induced optical birefringence were performed in both cases of SM optical fibre with or without inscribed FBG or LPG. A reason for applying this procedure consists in observing that any change of polarization state of the light propagating through optic fibre is a measure of interaction between the smart composite material and the ambient. Another reason for applying this procedure arose by considering a calibration procedure of the smart composite material status without any applied change of its ambient at macroscale (mechanical loads, temperature) or at microscale (chemical modification, including humidity in the composite). The analysis was performed for the cases of an external force applied normal to the optical fibre surface in one point, in two diametrically opposite points, distributed on an angular sector, distributed on two diametrically opposite angular sectors and distributed on the entire optical fibre circumference.
The results of the performed simulations are compared to experimental results reported in literature observing a good agreement.

13855 | Analysis of mechanical vibrations applied on a LPGFS smart composite polymer material (Smart Composites)

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Results obtained in simulation of the mechanical vibrations applied on a smart composite material embedding long period grating fibre sensors (LPGFS) in its polymer matrix as its feedback loop are presented. The effects of mechanical vibrations are simulated as observed using the embedded LPGFS feedback signal generator/provider. The investigated issue is of high interest especially in the aerospace applications of smart composite materials based on the use of LPGFS.
The investigated smart composite materials are manufactured of LPGFS embedded into its polymer matrix. They have the role to provide the feedback of the smart composite materials used for various research, medical, industrial, aerospace and security applications to the inputs stimuli applied by the ambient medium in which the smart composite material is mounted. A LPGFS consists of a single mode (SM) optical fibre basically used as light propagation guide which is processed for improved sensitivity optical fibre sensors, commonly by inscribing gratings into it. A smart composite material is fabricated by embedding the LPGFS into its polymer matrix. LPGFS consists of a uniform or a modulated magnitude variation fibre core refraction index along it over a length of 5 - 75 mm with a period of 1 - 100 m. In this way, a Bragg diffraction grating is fabricated by inscribing it into the optical fibre. The LPGFS are operated as sensors using the absorption bands induced by the grating scattering in the optical fibre transmission spectrum. The long period gratings are operated as sensors exploiting the coupling process between the mode propagating through the fibre core and the modes propagating through the fibre cladding. The whole process is produced into the fibre placed in direct contact with the ambient and can be directly affected by the microscale possible changes of ambient measured by refractive index variations. LPGFS are used as sensors for applied force/pressure and temperature on one side and for detection of ambient refractive index variations induced by chemical modifications, presence of impurities such as water molecules or of other compounds on the other side. Basically, the LPGFS are operated as sensors by observing spectral shifts of the peaks and half amplitude broadenings of the absorption bands induced in the optic fibre transmission spectrum at resonance wavelengths by the coupling of light propagation modes. Among the force/pressure stimuli applied on a smart composite material mechanical part and which affect the LPGFS there are included the vibrations induced in it or the pressure waves propagating along the smart composite material mechanical part surface and knock it on normal direction.

The most appropriate way to describe the effect of vibrations or pressure wave on LPGFS is by observing the micro-bending of the optical fibre. The smart composite material simulation model developed for describing the effect of the vibrations induced in it or of the pressure waves is defined as an imbricated one: into the exterior model describing the interaction of the LPGFS with the polymer matrix in which it is embedded there is imbricated a model defining the micro-bending of LPGFS.
The results of the performed simulations are compared with experimental results reported in literature observing a good agreement.

14327 | Semi-analytical solutions for thermo-electro-elastic analysis of piezoelectric laminates (Smart Composites)

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Smart composite materials comprising of elastic core and piezoelectric sensor-actuators are self-controlling, self-governing materials, which are used in high-end applications like aeronautical and aerospace industry. The stress off-sets in smart laminates working in thermal environment due to the different thermal coefficients of neighboring laminae is one of the major concerns and the material response has to be analyzed accurately to avoid de-lamination at the interfaces. Many researchers have presented exact and approximate; analytical and numerical solutions for thermo-electro-mechanical loading of smart materials. The elasticity solutions may be sought only for simple geometric, support and loading conditions. Equivalent single layer theory solutions are suitable only for thin and moderately thick laminates. Layer-wise theory approach is computationally expensive for a large number of layers in a laminate.
The motive behind present work is to develop a simple, accurate and inexpensive mathematical model for static analysis of smart materials. In this paper, thermo-electro-elastic analysis of an all-round simply supported (SSSS) piezoelectric laminate is presented with a novel Semi-analytical model. The coupled electric-elastic fields equations in thermal environment, 3-dimensional (3D) equilibrium equations, 3D strain-displacement relations and charge equilibrium equations are the governing equations. Thus, the formulation part is based upon elasticity approach and the method is free from any a-priory assumptions in thickness direction. After some manipulation on these equations, a set of partial differential equations (PDEs) in chosen eight primary variables is obtained. Using Kantorowich approach of reducing dimensionality of the problem, the PDEs are converted into ordinary differential equations (ODEs) in primary variables. The laminate is thus modeled as a two-point boundary value problem (BVP) in the domain $-h/2 \le z \le h/2$, with half of the variables known at $z = \pm h/2$. Secondary variables are expressed in terms of primary variables using field equations. Solution to ODEs is obtained using numerical integration in thickness direction. Availability of modern ODE solvers helps catch the through-thickness variation of the entities accurately. Changes in material properties are easily incorporated by changing the property matrix. Any arbitrarily distributed load may be analyzed using this approach. The new model is validated by comparing numerical results obtained by present theory with exact solutions available in literature and are found to be in good agreement with the same.

14402 | The theoretical analysis of a broadband magnetic energy nanoharvester array by considering surface effect (Smart Composites)

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Nanoharvester, which can convert various forms of energy into electric energy in nanoscale, is now a high-profile issue. To better improve the performances and further fulfill the potential applications, it is essential to analyze the physical and mechanical properties of nanoharvester as well as evaluating the size effect qualitatively and quantitatively. In the current work, a nonlinear magnetoelectric (ME) coupling model of the magnetic energy nanoharvester array with the consideration of the surface and nonlocal effects is developed and used to investigate the extensional vibration of a magnetic energy nanoharvester, which is composed of a magneto-electro-elastic (MEE) laminated cylindrical nanoshell array when the circuit is connected either in series or in parallel. The analytical results indicate that the performance of nanoharvester exhibits obvious size-dependent phenomenon, including the resonant frequency, output electrical power density, efficiency and so forth, which is only attributed to the surface effect. Based on this, a critical thickness, related to material parameters of surface layer, is proposed, below which the size-dependent effect is obvious and the surface effect must be considered. On the other hand, the output electrical power and operating frequency band of the nanoharvester can be better tuned by applying a matched magnetic field and pre-stress, which provides us opportunity to improve its work performance. The current work is essential and crucial for the physical phenomenon explanations and experimental design of the MEE nanodevices, especially in the extremely complex magnetic and pre-stress field environments.

14411 | Magnetic-Elastic-Electric Coupling and Hysteresis Behavior Study of Terfenol-D based Multiferroic Magnetoelectric Composites (Smart Composites)

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As a new type of multifunctional materials, Terfenol-D-based multiferroic magnetoelectric composites have stimulated a sharply increasing number of academic and engineering research activities in recent decades, due to their giant magnetoelectric effects, which have been widely used in the modern new high-tech fields, such as sensing technology, information technology, microelectromechanical system, and so on. In this paper, the nonlinear magnetic-elastic-electric coupling behavior and hysteresis behavior inherent to multiferroic magnetoelectric composites are investigated in details. Based on the nonlinear dynamic constitutive model with hysteresis of Terfenol-D, the linear constitutive model of PZT-5X, and the stress/strain transfer relationships between magnetostrictive and piezoelectric materials, a novel nonlinear hysteresis model with magnetic-elastic-electric coupling effects is established for Terfenol-D/PZT-5X/Terfenol-D trilayer, which is worked under L-T mode. The validity and reliability of the obtained nonlinear hysteresis model are verified by comparing its predicted results with experimental data. Then the nonlinear magnetic-elastic-electric coupling behavior and hysteresis behavior inherent to the magnetoelectric laminated composites are numerically simulated by using the nonlinear hysteresis model. The numerical simulation results indicate that the nonlinear hysteresis behaviors of magnetoelectric composites are mainly dominated by the nonlinear hysteresis characteristics of Terfenol-D in the composites. Meanwhile, the numerical simulation results demonstrate that the nonlinear hysteresis model established in this paper can more accurately and conveniently describe the nonlinear magnetic-elastic-electric coupling behavior and hysteresis behavior than the linear theoretical model for Terfenol-D based magnetoelectric laminated composites. Therefore, the research work of this paper can be used in the property characterization and optimization design of Terfenol-D-based magnetoelectric laminated composites, and eventually provide theoretical basis for the design and research of the novel magnetoelectric multifunctional devices, which exhibit high precision and high performance characteristics.

14457 | BUCKLING ANALYSIS OF COMPOSITE MULTILAYERED STRUCTURES PARTIALLY COVERED BY PIEZOELECTRIC LAYERS (Smart Composites)

With the rapid development of piezoelectric materials and their versatile applications in engineering systems, studies of piezoelectric systems have drawn much attention in recent years. Developments in adaptive composite structures incorporating integrated piezoelectric elements open the possibility to adaptively modify the structural behavior offering potential benefits in a wide range of engineering applications such as vibration suppression, shape control, precision positioning and buckling control, among others. Smart materials are usually attached or embedded into structural systems to enable these structures to sense disturbances, process the information and evoke reaction at the actuators, possibly to negate the effect of the original disturbances. Thus, smart materials respond to environmental stimuli and for that reason they are called responsive materials (response to an applied mechanical stress – direct piezoelectric effect or to an external voltage – converse piezoelectric effect). The general requirements expected in these materials that integrate the functions sensing, actuation, logic and control include full integration of all functions in the system and intelligent operational system.
The PZT (S/As) have to be of suitable size and placement to ensure maximum effectiveness and efficiency. The problem of finding the optimal size and location of S/As is very challenging. The issues of S/A location and geometry, and their optimal selections with respect to certain performance criteria, have drawn much attention due to their importance in structural sensing and control. Tauchert presented a review of theoretical developments in the piezoelasticity relevant to adaptive composite structures, addressing also the structural control via piezoelectric actuation. Reddy proposed a higher-order shear deformation theory, in which a parabolic distribution of transverse shear strains through the shell thickness was followed. The related formulation has been frequently applied in the static, buckling and vibration analysis for composites and piezoelectric structures
The buckling (eigenvalue) problem of biaxially compressed laminated plates and shallow cylindrical panels having two symmetric piezoelectrical (PZT) patches on the top and the bottom of laminates is considered. The analysis is carried out with the use of the classical laminate theory and of the first order shear deformation theory. The variable thickness of structures (the local positions of PZT patches) is described by piecewise constant step functions in one direction or in both directions due. Three different methods of the solution of the linear eigenvalue problem are proposed: the exact analytical solution, the approximate solution based on the definition of the Rayleigh quotient and the numerical 3D FE analysis. For the approximate theory of shallow panels two variational formulations of the eigenvalue problem are derived in the form of the Hu-Washizu functional (the Airy functions and transverse normal displacements) and in the form of the Legendre functional (displacements). The influence of geometric parameters of composite panels and PZT patches , piezoelectric effect, external electric voltage and laminate configurations (angle-ply, cross-ply laminates) on buckling characteristics are discussed in detail. The analysis demonstrates evidently that the use of the local piezopatches should be considered as the buckling problem for structures with the non-uniform thickness distribution. The appropriate use of the local PZT patches should be always combined with the appropriate choice of the best (optimal) laminate configuration. The formulation system developed is suitable to other shell theories and to account for the analysis of thermal effects or the imperfection sensitivity. The methodology and results presented herein can provide valuable tool for researchers who are developing numerical techniques and software for buckling&vibration analysis

14467 | Influence of core on smartness of viscoelastic-magnetorheological sandwiches (Smart Composites)

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Viscoelastic-magnetorheological sandwich structures are a class of smart structures which dynamic behaviour can be modified in response to magnetic fields. In particular, the magneto-dynamic behaviour of viscoelastic-magnetorheological sandwiches is the result of the coupling of physical effects generated due to interactions between electromagnetic field and mechanical vibration. Depending on the composition of the sandwich and the configuration of the magnetic field the contribution of these effects is different and so the magneto-dynamic behaviour of the sandwich.

This work is focused on the magnetorheological effect and the magnetoelastic force generated in the core of these sandwiches. A magneto-dynamic model of viscoelastic-magnetorheological sandwiches including both effects is developed and validated with experimental results. The magnetorheological effect is described by a dipole-dipole interaction model. The magnetoeslatic force model developed for ferromagnetic beams vibrating in transverse magnetic fields is considered to describe the force generated in the viscoelastic-magnetorheological core of the sandwich. Sandwiches composed of different viscoelastic-magnetorheological cores are analysed and the relation between the composition of the sandwich and its magneto-dynamic behaviour is established.

14468 | Linear viscoelastic region of magnetorheological elastomers in dynamic compression mode (Smart Composites)

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Magnetorheological elastomers (MRE) are a type of smart materials, due to the variability of their dynamic properties under the influence of an external magnetic field. This effect is larger at low strain levels, in the linear viscoelastic (LVE) region, where their viscoelastic properties are independent of the strain level. In this work, the LVE region of isotropic MREs is defined in dynamic compression tests.

In order to define the LVE region of the MREs at high frequencies, a new magneto-dynamic compression test device has been designed and manufactured. The MREs studied in this work consist of a natural rubber matrix where carbonyl iron powder (CIP) particles are embedded. Three different volumetric particle contents are analysed (0%, 15% and 30%), in a frequency range from 50 to 200 Hz and in a magnetic field density range from 0 to 85 mT. The LVE region of the MREs is defined by performing strain-sweep tests, and the influence of synthesis variables (particle content) and characterization variables (frequency and magnetic field intensity) when defining this region are analysed.

14564 | Structural vibration damping of a woven composite fan blade using passive piezoelectric shunts (Smart Composites)

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This study concerns the vibration damping in the low frequency range of a woven composite fan blade of a turbojet engine. The interest is to increase lifespan and avoid flutter phenomena by reducing the vibration amplitude. The solution considered in this work consists in using piezoelectric elements integrated into the composite structure and connected to a passive electric circuit usually called shunt. A part of the work will focus on the development of a predictive finite element model of the structure coupled to the piezoelectric material to quantify the performance of the damping device. Comparisons between simulations and experiments will be also presented. It will be shown in particular that purely passive resonant shunts can significantly reduce the level of vibration of the first bending modes of a complex industrial structure. The importance of placement and geometry of the piezoelectric elements in order to maximize the electrotechnical coupling, and thus the efficiency of the system, will be also highlighted.

14692 | Theory of magnetoelectric response in cylindrical composites with nano-scale thickness (Smart Composites)

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Cylindrical magnetoelectric (ME) composites are believed to be advantageous to enhance ME coefficient by improving interfacial mechanical coupling and mechanical boundary condition. However, studies on nonlinear ME coupling in cylindrical composites with nano-scale thickness which have unique superiorities are rather limited. Considering surface piezoelectric and piezomagnetic effect, and nonlinear material characteristics, this work proposes a nonlinear theoretical model for cylindrical ME nanocomposites by using nonlinear constitutive and elastodynamic equations. The calculated results show that the ME coupling in the cylindrical composites with nano-scale thickness is significantly size-dependent and can be enhanced by surface stress. A resonant enhancement peak of ME coefficient is obtained in the electromechanical resonance region, and the resonant frequency is predicted to change with altering the thickness of the composites, volume fraction, and boundary condition, which suggests that one can obtain strong ME effect and proper resonant frequency by optimizing geometry structure or controlling mechanical conditions. when subjected to combined stress and magnetic loadings, cylindrical ME nanocomposites exhibit obvious magneto-mechanical coupling characteristics due to the complex multi-filed coupling properties of constituent materials. This study provides an approach to accurately analyze and evaluate the nonlinear ME coupling of nanostructures-based devices operating in complex environments.

14905 | BUCKLING ANALYSIS OF COMPOSITE MULTILAYERED STRUCTURES PARTIALLY COVERED BY PIEZOELECTRIC LAYERS (Smart Composites)

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With the rapid development of piezoelectric materials and their versatile applications in engineering systems, studies of piezoelectric systems have drawn much attention in recent years. Developments in adaptive composite structures incorporating integrated piezoelectric elements open the possibility to adaptively modify the structural behavior offering potential benefits in a wide range of engineering applications such as vibration suppression, shape control, precision positioning and buckling control, among others. Smart materials are usually attached or embedded into structural systems to enable these structures to sense disturbances, process the information and evoke reaction at the actuators, possibly to negate the effect of the original disturbances. Thus, smart materials respond to environmental stimuli and for that reason they are called responsive materials (response to an applied mechanical stress – direct piezoelectric effect or to an external voltage – converse piezoelectric effect). The general requirements expected in these materials that integrate the functions sensing, actuation, logic and control include full integration of all functions in the system and intelligent operational system. The PZT (S/As) have to be of suitable size and placement to ensure maximum effectiveness and efficiency. The problem of finding the optimal size and location of S/As is very challenging. The issues of S/A location and geometry, and their optimal selections with respect to certain performance criteria, have drawn much attention due to their importance in structural sensing and control. Tauchert presented a review of theoretical developments in the piezoelasticity relevant to adaptive composite structures, addressing also the structural control via piezoelectric actuation. Reddy proposed a higher-order shear deformation theory, in which a parabolic distribution of transverse shear strains through the shell thickness was followed. The related formulation has been frequently applied in the static, buckling and vibration analysis for composites and piezoelectric structures.
The buckling (eigenvalue) problem of biaxially compressed laminated plates and shallow cylindrical panels having two symmetric piezoelectrical (PZT) patches on the top and the bottom of laminates is considered. The analysis is carried out with the use of the classical laminate theory and of the first order shear deformation theory. The variable thickness of structures (the local positions of PZT patches) is described by piecewise constant step functions in one direction or in both directions due. Three different methods of the solution of the linear eigenvalue problem are proposed: the exact analytical solution, the approximate solution based on the definition of the Rayleigh quotient and the numerical 3D FE analysis. For the approximate theory of shallow panels two variational formulations of the eigenvalue problem are derived in the form of the Hu-Washizu functional (the Airy functions and transverse normal displacements) and in the form of the Legendre functional (displacements). The influence of geometric parameters of composite panels and PZT patches , piezoelectric effect, external electric voltage and laminate configurations (angle-ply, cross-ply laminates) on buckling characteristics are discussed in detail. The analysis demonstrates evidently that the use of the local piezopatches should be considered as the buckling problem for structures with the non-uniform thickness distribution. The appropriate use of the local PZT patches should be always combined with the appropriate choice of the best (optimal) laminate configuration. The formulation system developed is suitable to other shell theories and to account for the analysis of thermal effects or the imperfection sensitivity. The methodology and results presented herein can provide valuable tool for researchers who are developing numerical techniques and software for buckling&vibration analysis.

13896 | Influence of silane modified minerals on properties and performance of thermoplastic-based composites (Applications of Composites)

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This experimental study investigates the influence of silane modified silicate-based minerals on different properties of high-density polyethylene (HDPE). Two different types of organo-functional silanes, namely vinyl-trimethoxy and amino-ethyl amino-propyl trimethoxy silanes are used for the surface

treatment of mineral fillers. The different amounts of treated mineral fillers with neat HDPE are mixed by using a twin-screw extruder. The effect of mineral fillers on different properties of HDPE is assessed by means of the mechanical (tensile), rheological (rheometer), thermal (thermogravimetric TGA), chemical (Fourier infrared spectroscopy FTIR), and microstructural (scanning electron microscopy SEM) analyses and compared with the neat polymer. The achieved results implicated that addition of silane modified minerals to neat HDPE improved the mechanical properties and thermal stability of the final product. The rheological results also indicated the dependency of complex viscosity on mineral filler content more specifically when vinyl treatment was used. The SEM observations also revealed that the agglomeration of mineral fillers in the polymeric matrix was reduced when amine silane was used.

14518 | Electro-mechanical studies of filamentary MgB2 composite wires at low temperatures (Applications of Composites)

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The effect of bending and tensile stress on the critical current of MgB2 wires manufactured by powder-in-tube (PIT) and by internal magnesium diffusion into boron (IMD) has been studied experimentally at 4.2 K. Filamentary MgB2 wires of different compositions, sheath materials and filament density were subjected to mechanical load allowed estimating the stress and strain tolerances. It was shown that the mechanical strength of outer sheath plays a dominant role, but the filaments quality (additions, density and twisting) has also some effect on the electro-mechanical behavior of MgB2 wires. Wires with not doped MgB2 filaments show much higher increase of critical current at reversible strains in comparison to C-doped ones and positive effect of W-particles doping on the strain tolerance has been also observed. Filament density is affected by the applied deforming mode, which results in improved tolerance for more dense filaments. Filament twisting changes the residual strain inside the composite wire and consequently affect the strain tolerances as well. The effect of bending strain degradations shows the differences for wires made by PIT and IMD due to not the same mechanical support by outer sheath annealed at temperature range of 640-920oC and different filament's quality. It was found that MgB2 cables allow the highest bending strains without critical current degradation in comparison to monolithic wires or tapes, but, flat cables are more sensitive to tension strain due to combined stressing (by tension and bending) of individual strands.

14546 | Optimization procedure for the design of a multimaterial joint CFRP-Steel in a coach structure to improve the energy absorption in a rollover scenario (Applications of Composites)

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The selection of a material for bus structures is a complicated optimization problem between mechanical properties required in the operation of vehicle and manufacturing as well as their production costs. Hollow structural steel tubing has been shown to be capable energy absorbers because of their progressive buckling under compressive loading and their structural lightness. Energy absorption is a crucial factor for analysing crashworthiness because of the importance of protecting the occupants during crashes.

Various research works have been carried out in order to study the introduction of different types of materials such as aluminium alloys and composite for bus and coach body manufacturing in order to optimize fuel consumption by reducing vehicle weight without compromising strength or safety. While fibre reinforced composites, mostly used in aerospace and marine applications, have showed potential for automobile parts in the past several decades, the application has yet to be realized on a mass production scale.

Bus manufacturers have also turned their attention to multimaterial design strategies. Structures built in that manner consist not only on regular steel parts, but contain also a mix of components made from various lightweight materials like aluminium alloys or composites, which allows a significant reduction in vehicle curb weight. However, due to the differences in mechanical characteristics, the material substitution is not a straightforward task. For these reasons, new concept designs, materials and assembly methods have to be developed and applied by bus and coach manufacturers. Adhesive joints present important advantages against other techniques for joining dissimilar materials, because it is a simple and flexible technology, which leads to a continuous joint without stress concentration and does not require great inversions.

As a solution against the problems previously mentioned, in this work a new concept of joint made with CFRP (Carbon Fibre Reinforced Polymer) is introduced in the steel bus structure in the most stressed joint. This joint is connected to the steel structure by means of an elastic adhesive bond. In this regard, it is necessary to perform an optimal design of the joint so that it sustains a given load in the best way, using the least possible amount of material. Prior to carrying out the optimization, a sensitivity analysis is often performed in order to determine how changes in the parameters of the optimization problem influence over the model output. In this work, a sensitivity analysis has been conducted in order to know better the influence of the new CFRP node mechanical characteristics in the behaviour of the coach structure. Specifically, two variables have been analysed as design variables because of their importance in the global node stiffness: adhesive Young's Modulus and composite thickness. Influence of these inlet variables in the node behaviour has been analysed in terms of the variation of the stress distribution in the area surrounding the node.

After the sensitivity analysis, a design optimization procedure has been carried out to find the proper values of the two considered variables (adhesive Young's Modulus and composite thickness) in order to minimize the amount of CFRP used while maximizing the amount of energy absorption in the deformation of the node. To do so, a stress test has been conducted in order to analyse the node response to a severe load state, similar to those that take place in bus rollover accidents. The optimization has been conducted by means of a FEM model of the node which was previously validated with tests of a node prototype in a bench testing.

14698 | The model to calculate the fracturing extent of reactive composites after perforating a thin plate (Applications of Composites)

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Penetration-induced deflagration reaction, as a typical terminal efficiency, stemmed from chemical reaction contributed by the fracturing reactive composites. In this paper, a metal/polymer reactive composite named PTFE/Al/W is researched. The degree of this reaction is closely related to the fracturing extent of reactive composite after perforating a thin plate. According to energy conservation theory, it can be assumed that the total external work in the process of penetration, transforms into the elastic energy, kinetic energy and crack propagation energy of the reactive composite. With this assumption, a model is established and the fracturing extent of reactive composite after perforating can be calculated. Further analysis shows that the maximum fracturing extent is tightly correlated with the bulk modulus and the Poisson's ratio of the reactive composite, and increases with an increase in both. For the same impact velocity, an increasing target thickness always means that the delaying rarefaction wave effect. Hence more reactive composites are initiated to deflagrate in the penetration, enhancing the influence of chemical energy released during penetration. Furthermore, a comparison of the reaction degree for impact-induced deflagration obtained from various conditions with the result calculated using this model presented here is consistent.

14896 | Development of silicon nanowire-graphene composite for energy storage applications (Applications of Composites)

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Abstract:
Energy storage devices are popularly used nowadays in mobile electronics and electric vehicles. As current batteries have a relative small capacity for energy storage, the mobile electronics and electric vehicles can only be powered by current commercial batteries for a limited time. In the past decades, significant research efforts have been put into development of alternative materials and technologies for use on energy storage devices to improve their energy capacity, cycling life and power output. Among various materials being researched, silicon has been identified as a promising material for use as anode in lithium ion batteries. However, the volume expansion and low conductivity of silicon cause intrinsic issues in its use as anode in lithium ion batteries. Here we report our recent work on development of a silicon nanowire-graphene composite which can be used as anode in lithium ion batteries. The synthesized silicon nanowire-graphene composites have been experimentally tested on rechargeable lithium ion battery cells. When compared with pure silicon nanowire and bulk silicon as anode in lithium ion battery cells, the silicon nanowire-graphene composite can largely improve the specific capacity, cycling life and columbic efficiency of the lithium ion battery cells.

Keywords: silicon nanowire, graphene, composite, application, energy storage.

14910 | STUDY OF MECHANICAL PROPERTIES OF COMPOSITE WITH SILICONE MATRIX TO MIMETIZATE BIOLOGICAL TISSUE (Applications of Composites)

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It is of scientific interest to know the mechanical properties of biological materials so they can be reproduced in synthetic materials, since the study in living tissues is often arduous. With the help of the principles of mechanical engineering it is possible to understand the normal functions of organisms, to foresee changes and to propose artificial methods of interventions. Silicone is one of the synthetic materials most used to mimic the properties of biological tissues. The present study has as objective to evaluate the similarity between silicone matrix composites and fibrous biological fabrics from the characterization of the mechanical properties of these composites. As specific objectives are the manufacture and testing of silicone matrix test specimens with cotton fibers in different orientations, as well as the application of the correlation technique of digital images to obtain displacement field and, later, the mechanical properties of these composites and development of a mathematical model that corroborates the experimental results found. Untill now, composites with fibers oriented at 0º, 45º and 90º have been tested and, as expected, the graphs obtained are typical of hyperelastic materials, so the relation between tension and deformation is non-linear and from low stress there is great stretch. In addition, a relationship was found between the orientation of the fibers and the mechanical properties of the material, since when the tension is applied in the same direction of the fibers, there is an increase in the mechanical strength and a decrease in the elasticity of the material. In order to obtain a better characterization of the material, composites with different proportions between their constituents will be manufactured and tested and a correlation will be shown between the mechanical properties of the manufactured synthetic materials and the properties of fibrous tissues.

14904 | Challenges of Aircraft Structures Impacts (1. Plenary lectures)

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This Plenary lecture will show the most important impact scenarios that the aircraft structure should withstand in the certification process of an aircraft.

These scenarios could be classified in two big families:

- When an impactor hits the aircraft structure (bird strike, ice impact, runway debris, vulnerability, etc.)
- When the entire aircraft is impacting (Crashworthiness, ditching, wheels up landing, etc.)

The numerical simulation and test challenges that these scenarios impose in the engineering community will be described highlighting the contribution of the role of mechanics of composites on them.

14906 | Multiscale modeling of composites: towards virtual testing (1. Plenary lectures)

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A bottom-up multiscale modeling approach is presented in this work in order to simulate the mechanical behavior of structural composites.The overall multiscale simulation scheme takes advantage of the fact that composite structures are made up of laminates which in turn are obtained by stacking individual plies with different fiber orientation. This leads to three different entities (ply, laminate and component) whose mechanical behavior is

characterized by three different length scales, namely fiber diameter, ply and laminate thickness, respectively. Fiber diameters are of the order of 5-10 µm, while ply thicknesses are in the range 100-300 µm and standard laminates are several mm in thickness and above. This clear separation of length scales is very useful to carry out multiscale modeling by computing the properties of one entity (e.g. individual plies) at the relevant length scale, homogenizing the results into a constitutive model, and passing this information to the simulations at the next length scale to determine the mechanical behavior of the larger entity (e.g. laminate). Thus, multiscale modeling is carried out through the transfer of information between different length scales rather than by coupling different simulation techniques. In this talk, we will focus on recent developments in the field of micromechanics of unidirectional fiber reinforced composites with special emphasis on realistic models fed with parameters that can be measured independently. For instance, the models make use of important parameters such as the strength of the matrix and the fiber/matrix interface which can be measured independently by means of nanoindentation tests. This detailed information is incorporated in the micromechanical models which were able to represent the current deformation and failure mechanisms.

14907 | Impact damage prediction in thin composite laminates : Semi continuous strategy and validation (1. Plenary lectures)

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Composite materials are widely used in many applications, especially where high strength and stiffness to weight ratio isconcerned. These material characteristics are interesting for a widerange of industries, particularly in the transport industry such asaircrafts, helicopters, boats or cars. However, when submitted to low energy impacts, composite laminates exhibit a relatively brittle behavior with extensive matrix cracking, delamination or fibers breakages. These damages are classically divided in intralaminar damages (the damages developing inside the ply like matrix cracking, fiber/matrix debonding or fibers breakages) and interlaminar damages, i.e. the damages developing at the interface between two consecutive plies, namely delamination. The consideration of the interaction which exists between this two damage types inside and between plies is the key point for the development of predictive numerical models. Indeed, in order to avoid numerous expensive experimental tests, a large number of models have been proposed to represent experimental data according the approach of “Virtual Testing”. The composite group of Institut Clement Ader has developed some very efficient modeling strategies based on semi continuous or semi-discrete approach. These strategies consist in differentiating the behavior of the fiber and the resin. The bundles of fibers are modeled with rod elements and a specific damageable shell element is used to stabilize the rod elements.Delamination is modeled using cohesive elements.
The semi-continuous approach, initially developed for woven composites, has been adapted for the modelling of damage mechanisms in unidirectional composites under low velocity impacts. It makes now possible the study of hybrid unidirectional/woven laminates that could be used to improve the performances of composite structures under impact loading.The presented approach is accurate enough to predict the sizeand shape of the damage. For each stacking sequence configuration studied, the local breakage of fibers and failure of the resin is well represented.

14908 | Mathematical modeling of non-ageing linear viscoelastic composites with general periodicity (1. Plenary lectures)

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Nowadays, the advantages of composite materials lie in the possibility of individually controlling each component (or phase) and its distribution (or microstructure) to optimize the performance (weight, mechanical resistance, resistance to heat, corrosion, etc.) of the structures thus formed. Often at least one of the constituents of the composite material has viscoelastic properties. Some authors have used different methods to calculate the effective properties of viscoelastic composite materials, for example, Maxwell homogenization, Generalized Self-Consistent (GSC) schemes and Mori-Tanaka homogenization, among others.
In the present work, two-scales Asymptotic Homogenization Method (AHM) is applied to viscoelastic composites. The theoretical aspects of the method and the fact that the solution of the heterogeneous problem converges weakly to the solution of the homogeneous problem, when the small parameter that describes the microstructure tends to zero, are rigorously developed in different books and research articles. The AHM is applied on problems with rapidly oscillating parameters where the structures are strongly heterogeneous. The fundamental problem lies in the solution of the so-called local problems on the periodic cell. The AHM is a direct method because it allows, through the solution of local problems, to obtain the effective properties. In many works, the potential of this method for elastic, thermo-elastic and piezoelectric materials have been exhibited but it has not been used sufficiently in the case of viscoelastic materials.
Classically, the investigation of effective properties of non-ageing viscoelastic composites are mainly based on the correspondence principle and Laplace transform. The methodology consists to change the convolution constitutive law that describes the non-ageing viscoelastic behavior into a fictitious elastic one in the Laplace domain. Then, the inversion of the Laplace transform is performed to derive the effective behavior in the time domain. Due to the unstable of such inversion, the numerical procedure is complicated. On the other hand, many homogenization problems of complex heterogeneous structures are characterized by more general periodic functions. This idea is related to homogenization problems of shell, cylindrical and wavy periodic structures of technological interest.
The present work, deals with the estimation of the effective properties for non-ageing linear viscoelastic composites with such generalized periodicity. As a validation of the present model, the results are compared with numerical algorithms developed using FEM, experimental data and other theoretical approaches proposed in the literature. The usefulness of the results have impact in engineering and biomechanical applications.

14911 | Integration and use of composite material and process modelling for business decision. (1. Plenary lectures)

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It has become increasingly evident that the descriptions of many com- plex material and manufacturing process are only possible by taking into account multiple influences at different physical scales and complex business processes. To be reliable, this process must be built upon a physical and engineering framework and based upon methods that are systemic, effective and efficient in modelling complex, hierarchical materials and process. For

composite material design and selection, understanding and quantifying the links between material structure at the nano/mesoscale/microscale and their macroscopic effects is, therefore, essential and requires the integration of several models that have overlapping scales (polymer chemistry, matrix-fibre interface, fibre properties and topologies, etc.). This implies the need for development and integration and of models to describe the behaviour of the class of materials at different scales as well as material-processing-property relationships [5]. In parallel, high performance requires not only comprehen- sive material properties modelling but also understanding of risks, costs, and business opportunities for a range of decisions, from material selection to designing functional structural components and systems. Last but not least, design and selection of material must also accommodate societal require- ments for health and sustainability. This talk shares and contributes to a ground-breaking vision developed and being implemented in the EC H2020 Composelector project which consists in the integration of materials modelling methodologies and materials informa- tics and knowledge-based systems material with business process for decision making. The proposed concept proposes moving towards a new paradigm of material and process selection and design by developing and implementing an integrated multi-disciplinary, multi-model and multi-field approach together with its software tool implementation for an accurate, reliable, efficient and cost effective prediction, design, fabrication, LCE, cost analysis and decision making. This new paradigm of integrated material design is indeed endowed with a great potential by providing further insights that will promote further innovations on a broad scale.

14922 | The structural engineering skills of orb-web spiders (1. Plenary lectures)

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An orb-weaving spider's likelihood of survival is influenced by its ability to retain prey with minimum damage to its web, and to use the web as a waveguide for the transmission of vibrations coming from prey, predators or courting mates. This set of requirements has forced spider silk to evolve towards extreme strength and ductility to a degree that is rarely observed among other materials, either natural or manmade. However, the superior performance of the orb web as an aerial prey trap and vibration sensor is not due merely to the exceptional mechanical properties of the silk, but also to outstanding structural topology. These two factors are closely related, with the arrangement of the threads making the most efficient use of the different silks strands spun by the spider [1].
The importance of the position of silk threads in the impact performance of the web can be uncovered using the principles of structural mechanics. In particular, the crucial contribution of seemingly irrelevant threads that are outside of the characteristic radial-spiral topology of the orb-web will be highlighted [2]. Likewise, an analysis on how the geometry and mechanical features modify the dynamic response of the web will be presented [3]. Thus, in the strong evolutionary contrast between topological changes in webs that enhance prey interception and sensoring, and those that reduce energetic costs, the spider finds major opportunities for improvement through subtle –and seemingly irrelevant– structural details. Uncovering the strategies that contribute to this requirement in a structure of superior performance, such as the web, not only helps us reach an understanding of how it evolved, but also provides design principles that might apply to other structural systems.
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