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The use of composite materials has grown exponentially in the last decades and has affected many engineering fields due to their enhanced mechanical properties and improved features with respect to conventional materials. For instance, they are employed in civil engineering (seismic isolators, long-span bridges, vaults), mechanical engineering (turbines, machine components), aerospace and naval engineering (fuselages, boat hulls and sails), automotive engineering (car bodies, tires), and biomechanical engineering (prostheses).

Nevertheless, the greater use of composites requires a rapid progress in gaining the needed knowledge to design and manufacture composite structures. Thus, researchers and designers devote their own efforts to develop new analysis techniques, design methodologies, manufacturing procedures, micromechanics approaches, theoretical models, and numerical methods. For these purpose, it is extremely easy to find many recent journal papers, books, and technical notes, focused on the mechanics of composites. In particular, several studies are presented to take advantage of their superior features by varying some typical structural parameters (such as geometry, fiber orientations, volume fraction, structural stiffness, weight, lamination scheme).

Therefore, this Conference aims to collect contributions from every part of the globe that can increase the knowledge of composite materials and their applications, by engaging researches and professional engineers and designers from different sectors. The same aims and scopes have been reached by the previous editions of Mechanics of Composites International Conferences (MECHCOMP), which occurred in 2014 at Stony Brook University (USA) and in 2016 at University of Porto (Portugal).

Euro 20,00

SOCIETÀ EDITRICE ESCULAPIO
www.editrice-esculapio.it

ISBN 978-88-9385-029-2
ISSN 2421-2822

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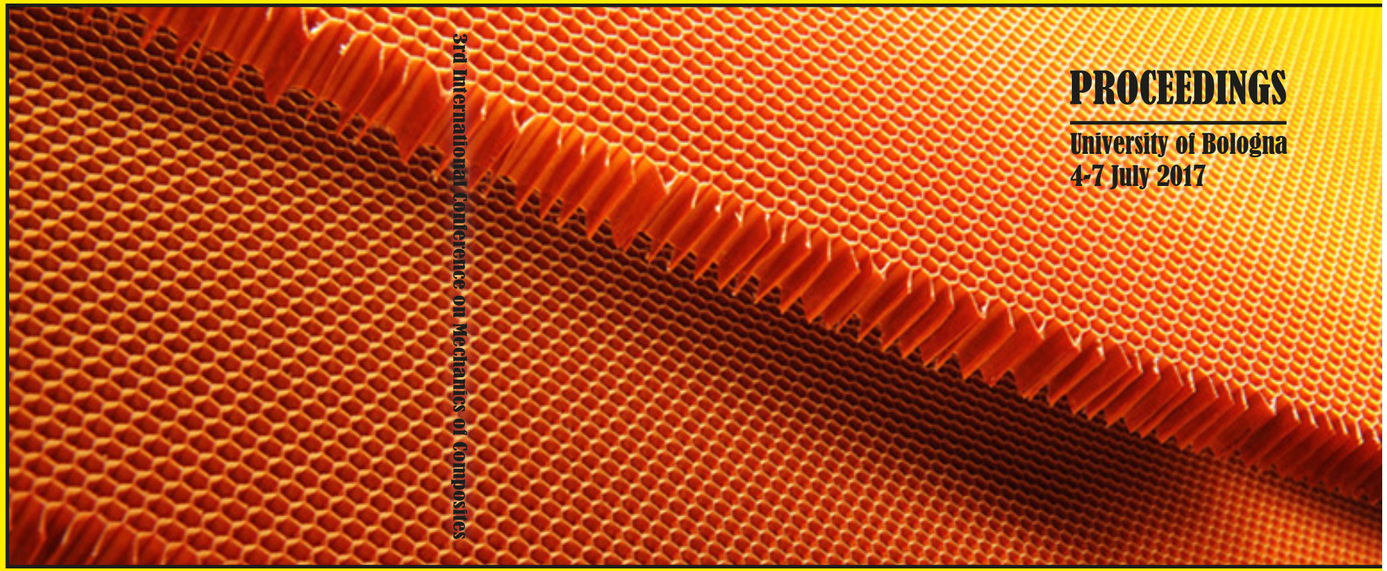

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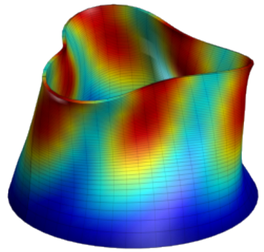

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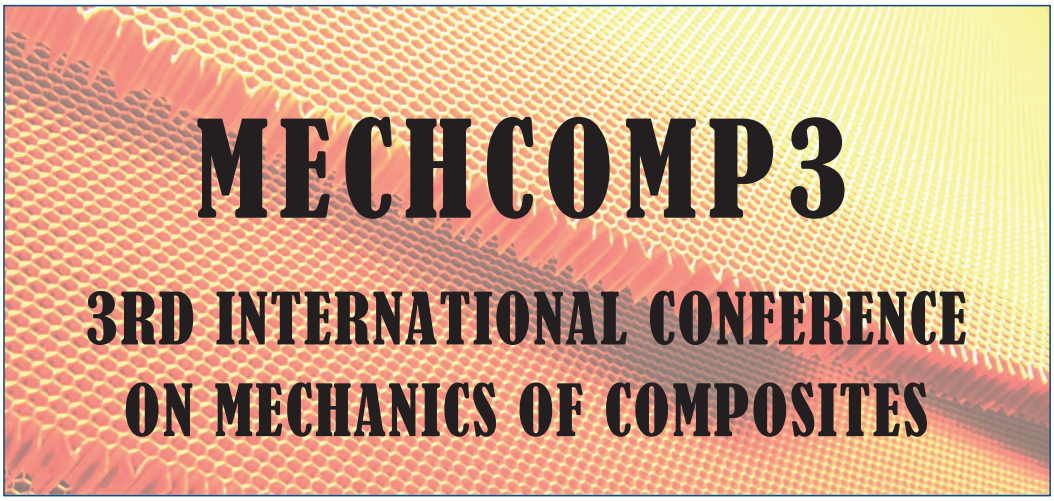

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STRUCTURAL AND COMPUTATIONAL MECHANICS BOOK SERIES

ISSN 2421-2822
ISBN 9788893850292
DOI 10.15651/978-88-938-5029-2

First edition: June 2017

Publishing Manager: Alessandro Parenti
Editorial Staff: Giancarla Panigali, Laura Tondelli

SOCIETÀ EDITRICE ESCULAPIO

40131 Bologna - Via U. Terracini 30 - Tel. 051-63.40.113 - Fax 051-63.41.136
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PREFACE

The use of composite materials has grown exponentially in the last decades and has affected many engineering fields due to their enhanced mechanical properties and improved features with respect to conventional materials. For instance, they are employed in civil engineering (seismic isolators, long-span bridges, vaults), mechanical engineering (turbines, machine components), aerospace and naval engineering (fuselages, boat hulls and sails), automotive engineering (car bodies, tires), and biomechanical engineering (prostheses).

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Therefore, this Conference aims to collect contributions from every part of the globe that can increase the knowledge of composite materials and their applications, by engaging researches and professional engineers and designers from different sectors. The same aims and scopes have been reached by the previous editions of Mechanics of Composites International Conferences (MECHCOMP), which occurred in 2014 at Stony Brook University (USA) and in 2016 at University of Porto (Portugal).

The third edition of the Conference at University of Bologna (Italy) attracted more than 450 delegates from around the world of composites. The plenary lectures were given by Fernando Fraternali (University of Salerno, Italy), Marco Gigliotti (Université de Poitiers and Ecole Nationale Supérieure de Mécanique et Aérotechnique, Poitiers, France), Salvatore Russo (IUAV University of Venice, Italy), Gaetano Giunta (Luxembourg Institute of Science and Technology (LIST), Luxembourg), Alberto Milazzo (University of Palermo, Italy), Christophe Bouvet (Institut Supérieur de l'Aéronautique et de l'Espace (ISAE-supaéro) and Institut Clément Ader (ICA), France).

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Yiqiang Xiang, Department of Civil Engineering, Zhejiang University, China

PLENARY LECTURES

1001 | On the mechanics and engineering of composite lattices

Fernando Fraternali (f.fraternali@unisa.it, University of Salerno, Italy)

The present talk is aimed at deepening the fundamental understanding of lattice mechanics, and its application to the design of unconventional materials and structures with properties mainly derived from their geometric design. There is an increasing interest in mechanical metamaterials, and a growing demand for exploring the potential of such systems in real life engineering applications. The talk's goal to expand the current scope of material design is based on: a) tuning the mechanical response of composite lattices through local and global prestress; b) employing nonlinear lattices as effective impact mitigation devices and acoustic lenses, without relying – or only partially relying – on energy dissipation; d) designing ultralight renewable energy supplies and seismic devices for smart buildings. The main focus is on designing new tunable lattices, and applying lattice-based metamaterials to the fabrication of novel composite materials and structures. A modeling research line presents the effects of internal and external prestress on nonlinear lattice mechanics, with the aim of designing arbitrary lattice behaviors. Material-scale applications of multiscale lattices deal with novel dynamic metamaterials and seismic isolation devices. A structure-scale application exploits lattices with morphing abilities to design adaptable envelopes for energy efficient buildings. Nano-, micro- and macro-scale lattice materials are studied through a closed-loop approach including the computational design and the additive manufacturing of physical models via innovative, multimaterial deposition techniques. An experimental characterization implements and verifies the theoretical predictions.

1002 | Multi-physics and multi-scale characterization of ageing phenomena in organic matrix composites for aircraft applications

Marco Gigliotti (marco.gigliotti@ensma.fr, Université de Poitiers and Ecole Nationale Supérieure de Mécanique et Aérotechnique, France)

The present talk collects the main results of a series of research activities – carried out by the authors at the PPRIME Institute, Poitiers, in collaboration with colleagues and PhD students over several years – concerning durability and ageing of organic matrix composites (OMC) for aircraft applications. The list of discussed topics includes: humid ageing, thermo-oxidation, environmental and "multi-physical" fatigue of OMC. For all these topics, the complex phenomenology related to the interaction of the material with its surrounding environment is emphasized. The unified strategy for the assessment of all these issues involves the employment of multi-physics experimental/numerical coupled methods, applied at several different observation scales. All the cited topics have a relevance in the context of the aeronautical industry, since aircraft manufacturers foresee the employment of OMC in structural parts undergoing quite severe environmental solicitations.

1003 | Analytical approach for understanding the mechanical behaviour of pultruded FRP material under severe conditions

Salvatore Russo (russo@iuav.it, University of Venice, Italy)

The use of pultruded FRP (fiber reinforced polymer) material is by now extended in many fields of the engineering's applications, from civil-construction side to aereo-spatial and for specific technology or employment in mechanics. Particularly, in the field of constructions and structural engineering that material is utilized for new buildings and for restoration and/or structural rehabilitation of existing constructions. In this frame of application, one topic that still need implementation and research is related to the damage detection and identification and to the evaluation of residual mechanical performance under severe conditions as well as fire, high and very high temperatures or effect due to hard environments context. By the way, the key note tries to propose and face this theme with particular reference to two aspects, also as consequence of first results of recent researches. The first aspect is related to the structural answer of pultruded FRP element subjected to mechanical damage as induced cracks, while the second one is related to the performance of FRP pultruded material subjected both to peak and cycles of temperature. The outputs demonstrate from a general point of view the high reliability of the material and in detail, even if in presence of high temperature, the positive performance, and residual strength values, in compression. The analytical approaches proposed are based on energy absorption measure and then calibrated in function of the experimental data. Nevertheless, at the same time, the need to continue the investigation and to acquire more information is evident in function of the possibility to define prediction's curves in presence of extreme events.

1004 | Hierarchical modelling of composite three-dimensional beam structures
Gaetano Giunta (gaetano.giunta@list.lu, Luxembourg Institute of Science and Technology, Luxembourg)

This talk addresses a way to derive in a concise manner a wide family of one-dimensional theories for the analysis of three-dimensional beam structures. This approach, known as Carrera's Unified Formulation, consists in the identification of a representative "generic" term in the main unknown field approximation (displacements, typically) that, then, leads to a generic term (or "nucleus") of the resulting boundary value problem (strong form solution) or stiffness and mass matrices (finite element solution). In such a manner, the model approximation can be enriched to hierarchically obtain higher-order models or retrieve classical theories as special cases. Some representative examples are presented to discuss the advantages (and limitations) of the proposed approach when considering composite (e.g., laminated, functionally graded or piezo-electric) three-dimensional beams.

1005 | A unified formulation for multilayered smart plate advanced models
Alberto Milazzo (alberto.milazzo@unipa.it, University of Palermo, Italy)

Magneto-electro-elastic (MEE) composite materials are attracting increasing consideration as they couple mechanical, electrical and magnetic fields and this makes them particularly suitable for smart applications. They are often employed as multilayered configurations that appear to be more effective than bulk MEE composites. Thus, reliable and efficient modelling tools are required for an effective design. The present talk deals with a unified formulation to derive advanced models for multilayered MEE plates. The approach is based on the condensation of the electro-magnetic state into the plate kinematics. This leads to models involving kinematical variables only, which takes the multifield coupling effects into account by effective stiffness, inertia and loading characteristics. Assuming variable kinematics, both layer-wise and equivalent-single-layer advanced plate models are systematically deduced via the Principle of Virtual Displacement and the Reissner Mixed Variational Theorem. Results are presented to show the accuracy and potentiality of the approach.

1006 | Evaluation of fracture toughness in composite structures using infrared thermography
Christophe Bouvet (christophe.bouvet@isae.fr, ISAE-supaéro (Institut Supérieur de l'Aéronautique et de l'Espace) and ICA (Institut Clément Ader), France)

Fracture toughness is one of the most important properties of composite material for a lot of design applications involving damage and crack growth. Unfortunately, its value can be difficult to evaluate with standard methods such as the "compliance" method, for example in the case of cracks inducing small variations in specimen stiffness. In these special cases, the infrared thermography measure can permit to overcome the limitations of conventional methods. The first studied case, compressive fiber failure in unidirectional composite laminate has been chosen due to its difficulty to evaluate fracture toughness. Infrared thermography has been employed to follow compressive failure mode developing during an indentation test and a compression after impact test, and to evaluate the fracture toughness of compressive fiber failure. The obtained results show a good correspondence with the value found in a previous work on FE analysis of impact damage and are consistent with literature. Then an end notched flexure (ENF) test has been used to study the effect of growth stability on mode II interlaminar fracture toughness (FT) of a carbon/PEEK composite. The instability of the ENF test has been used to induce both stable and unstable crack growth with a static loading. Then two processes have been used to evaluate the FT; the standard process and the infrared thermography process. The both processes show similar conclusions and their complementarity allow to conclude GIIc varies between a low value for crack growth start or unstable propagation, and a high value for stable crack growth.

PARALLEL LECTURES

ADVANCED NUMERICAL TECHNIQUES

270 | Modeling of the progressive damage and failure in textile composites

Wooseok Ji (wsji@unist.ac.kr, Department of Mechanical Engineering, Ulsan National Institute of Science and Technology, South Korea)
Sion Kim (Department of Mechanical Engineering, Ulsan National Institute of Science and Technology, South Korea)
Heeyoung Choi (Ulsan National Institute of Science and Technology, South Korea)

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.

241 | Discrete Element Method to simulate the mechanical behavior of heterogeneous materials

Leclerc Willy (willy.leclerc@u-picardie.fr, Laboratoire des Technologies Innovantes, France)
Haddad Hamza (Laboratoire des Technologies Innovantes, France)
Guessasma Mohamed (Laboratoire des Technologies Innovantes, France)
Fortin Jérôme (Laboratoire des Technologies Innovantes, France)

The contribution is dedicated to the mechanical simulation of heterogeneous media using a cohesive discrete element method. This latter uses an equivalent continuous model based on granular packings typically composed of disks in 2D and spheres in 3D. In the present work, granular packings are generated using the efficient Lubachevsky-Stillinger algorithm and the cohesion between particles is modeled using beam elements described by Euler-Bernoulli theory. In such an approach, the local parameters related to the geometry and the mechanical behavior of the beam element does not fit the macroscopic elastic coefficients. As a result, a calibration process is set up to relate local and macroscopic parameters. Please notice that only two local parameters, namely the microscopic Young's modulus and the dimensionless thickness of the beam suffice to characterize the elastic behavior of an isotropic medium. Similarly to a finite element method, the issue of discretization is of crucial importance since this directly affects the accuracy of results. That is why, we perform preliminary tests to estimate the suitable number of particles using the discrete element code MULTICOR3D++ developed in our laboratory. In the context of a homogeneous medium, it turns out that a minimum number of particles of 700,000 particles has to

be considered to avoid discretization effects. In a first step, several tests are carried out on 2D and 3D models composed of a single inclusion or a more complex microstructure composed of several spherical or circular inclusions. Comparisons are done with several numerical approaches such as the finite element and the fast-Fourier based methods. These highlight the ability of the proposed DE approach to yield a suitable elastic response in the context of heterogeneous media. In a second step, interfacial debonding and a failure criterion based on the hydrostatic stress are considered. The idea is to better appreciate the suitability of the discrete element method to model cracks initiation and propagation in heterogeneous media. Again, results exhibit the consistency of this approach in comparison with the finite element one. These findings are encouraging and enable us to expect thermomechanical simulations as well as non-linear models in a next future.

178 | Modeling of fracture and damage of textile composites

Gianluca Cusatis (g-cusatis@northwestern.edu, Northwestern University, USA)
Marco Salviato (University of Washington, USA)
Weixin Li (Northwestern University, USA)

This presentation discussed a general constitutive model to simulate the orthotropic stiffness, pre-peak nonlinearity, failure envelopes, and the post-peak softening and fracture of textile composites. Following the microplane model framework, the constitutive laws are formulated in terms of stress and strain vectors acting on planes of several orientations within the material meso-structure. The model exploits the spectral decomposition of the orthotropic stiffness tensor to define orthogonal strain modes at the microplane level. These are associated to the various constituents at the mesoscale and to the material response to different types of deformation. Strain-dependent constitutive equations are used to relate the microplane eigenstresses and eigenstrains while a variational principle is applied to relate the microplane stresses at the mesoscale to the continuum tensor at the macroscale. The application of the model to a twill 2 x 2 shows that it can realistically predict its uniaxial as well as multi-axial behavior. Furthermore, the model shows excellent agreement with experiments on the axial crushing of composite tubes, this capability making it a valuable design tool for crashworthiness applications. The formulation is computationally efficient, easy to calibrate and adaptable to other kinds of composite architectures such as 2D, 3D braids or 3D woven textiles.

305 | Numerical continuation – A robust approach for nonlinear stability analysis of composite shell structures

Rainer Groh (rainer.groh@bristol.ac.uk, University of Bristol, UK)
Bradley Cox (University of Bristol, UK)
Alberto Pirrera (University of Bristol, UK)

Designing lightweight aerospace structures typically entails optimisation for a particular design driver and/or embedding multi-functionality for improved efficiency. In the case of the former, it is well known that optimising structural performance in one domain can lead to the coalescence of failure modes, or make the structure prone to collapse once the failure load is reached. The sudden deformations that occur as a result of these instabilities are typically governed by non-linear equations and require careful analysis via computer-aided engineering tools, such as the finite element method. Multi-functionality can also be incorporated into structures by exploiting the capabilities offered by advanced composite materials. For example, composite laminates can be designed to "morph" or change shape in response to different loading environments, simply by locking-in residual stresses during the high-temperature curing process. The shape-changing mechanism of morphing structures is typically governed by inherent instabilities as the structures snap to different equilibrium configurations or bifurcate onto orthogonal equilibrium paths. Previous research has shown that current commercial finite element packages are often incapable of robustly predicting the instabilities in detail, and a priori experimental knowledge of the structural behaviour is typically required. Therefore, the predictive capabilities of these tools are limited. In this regard, it is our aim to place the instability analysis of optimised and multi-functional morphing structures on a more solid theoretical footing. In pure and applied mathematics, a rich literature on the so-called numerical continuation techniques exist that are used to explore the solution space of non-linear ordinary or partial differential equations in terms of a set of arbitrary parameters that govern the intrinsic properties or external factors acting on the physical system under investigation. When coupled with the concepts developed in bifurcation theory, a numerical continuation algorithm is capable of tracing any non-linear solution path, traverse and identify different instability points, and switch onto other solution branches if so required. Hence, such an algorithm embedded within the finite element method significantly enhances the engineer's capability of designing optimised and morphing structures. A second advantage of this numerical solution methodology is that the state of the structure is parametrised via any number of parameters, e.g. load, stiffness, geometry, boundary

conditions, etc. This means that once a single load-displacement equilibrium path for a nominal set of stiffness, geometry and boundary conditions has been determined, any point of interest on the fundamental equilibrium path can be traced with respect to any one of the additional parameters, for example, the Young's modulus of the material. The significance of this capability is twofold. First, a locus of instability points can be traced in the deformation-load-additional parameter space without having to solve the full equilibrium path for each value of the additional parameter. Second, the sensitivity of the structure to small imperfections in any one of the parameters is easily investigated in one unified algorithm. Such a capability is especially useful due to the inherent imperfection sensitivity of nonlinear structures. Our aim is therefore to present some of the advantageous capabilities of numerical continuation for composite shell structures by means of exemplary case studies.

135 | A highly efficient prediction of multi-delamination in sandwich composites using an extended cohesive damage model

J. Chen (jiye.chen@port.ac.uk, University of Portsmouth, UK)
X. Li (University of Portsmouth, UK)

The extended cohesive damage model (ECDM) has been recently developed by authors for highly efficient prediction of multi-delamination in sandwich composites. The ECDM is developed within the framework of the extended finite element method (XFEM), unlike the standard XFEM the enriched degree of freedoms (DoFs) are eliminated from the final equilibrium equations. However, the effects from enrichments and cohesive forces are accounted into a fully condensed FEM formulation. The ECDM takes the advantage of XFEM in simulating arbitrary crack propagation within elements, and keep the advantage of traditional cohesive zone model (CZM) in reflecting material evolution from elastic, plastic, damage accumulation and fracture. As the ECDM eliminates the enriched DoFs, the ECDM based modelling is much efficient in simulating multicrack propagation comparing to the standard XFEM. Meanwhile, the ECDM avoids the limitation of CZM, applied along element boundaries only, for simulating reality of complex multicrack propagation. As an example, the multi-delamination mechanism of a sandwich composite panel is investigated by the ECDM, which proves the ECDM is a highly efficient approach in predicting multi-delamination behaviour of sandwich composites.

77 | Continuum mechanics of beam-like structures using one-dimensional finite elements based on Serendipity Lagrange cross-sectional discretisations

Sergio Minera (sergio.minera@bristol.ac.uk, ACCIS, University of Bristol, United Kingdom)
Mayank Patni (ACCIS, University of Bristol, United Kingdom)
Paul M. Weaver (ACCIS, University of Bristol, United Kingdom)
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A novel approach for the analysis of beam-like structures is presented. The approach is based on the Unified Formulation by Carrera and co-workers, and is therefore able to recover complex, three-dimensional stress fields in a computationally efficient manner. As a novelty, hierarchical Lagrange polynomials are used to define cross-sectional displacement fields. This new element class, called Serendipity Lagrange, is benchmarked against traditional finite elements and other implementations of the Unified Formulation by means of static stress analyses with various loads and boundary conditions. Retaining the advantages over traditional finite element formulations, Serendipity Lagrange elements solve some of the shortcomings of the most commonly used Unified Formulation beam models. Like Lagrange elements, Serendipity Lagrange expansions can be used to model complex cross-sectional geometries. In addition, similarly to elements based on Taylor expansions, Serendipity Lagrange elements are hierarchical, meaning that cross-sectional meshes do not need to be refined in order to increase their degree of accuracy. The performance of the model, in terms of computational cost and precision, is assessed in comparison to reference solutions. The analyses performed emphasises the features, behaviour and advantages of Serendipity Lagrange expansions over the state-of-the-art.

32 | Three dimensional analysis of polycrystalline microstructures by a differential quadrature hierarchical finite element method

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Polycrystalline microstructures can be treated as composite materials with constituent grains and grain boundaries. The ability to understand the collective changes to metals microstructure as the metal deforms is imperative for improving metal properties. This work presnts a differential quadrature hierarchical finite element method

(DQHFEM) for three dimensional analysis of polycrystalline microstructures. The geometric model of a representative volume element (RVE) for the metallographic structure is automatically generated as irregular hexahedral p-elements. The DQHFEM modelled one grain / grain boundary as one element, which is impossible for common finite element method (FEM), especially for grain boundaries, due to geometric singularity. The effectiveness and high accuracy of the DQHFEM for two-scale analysis of the problem is validated through calculating the Young's modulus of the RVE by taking the material constants of all components as the same isotropic material. Then DQHFEM analysis of polycrystalline microstructures is caaried out. The material constants of grains and grain boundaries are either taken as isotropic or orthotropic with randomly distributed material directions. The Young's modulus of the RVE is obtained and the stress maps of the RVE are plotted to show the distributions of the stress components. The three dimensional (3D) DQHFEM presented in this work combines with plasticity theory should have great potential in crystal plasticity analysis.

48 | Study of forced dynamic problem of viscoelastic sandwich structure by reduction and asymptotic numerical method

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To reduce vibrations and noise, viscoelastic materials are often used in many domains (e.g. the aerospace industry, the automobile industry…). To maximize this passive damping, these materials are usually sandwiched between two identical elastic layers. Thus, the damping is introduced by an important shear deformation in the viscoelastic central layer. The governing equation, for a plate or shell excited by a force is nonlinear. That is why all resolution methods need triangulation of Jacobean matrix which is of complex type. In addition, if the displacement vector is written with separating the real and imaginary parts, the governing equation in finite element will have two time the number of degrees of freedom of equivalent real problem. Then resolution could lead to high computational cost in the case of large scale structures. In this paper, an efficient asymptotic basis is proposed to reduce the forced dynamic problem of viscoelastic sandwich plates and shell. The numerical resolution is based on the asymptotic numerical method (ANM) and finite element method. The validity of the present methods is illustrated by sandwich plates and shells with Young's modulus variable with respect to the frequency. The comparison of the results obtained in the reduced order model with those given in the full order model shows both a good agreement and a significant reduction in computational cost.

ANALYSIS OF COMPOSITE BEAMS, PLATES AND SHELLS

281 | Overlying strata control technology of backfilling mining with superhigh-water content material and its application

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Superhigh-water content material (SCM) has been widely applied in the fields of goaf backfill. In this paper, the strength properties of superhigh-water content material concretion (SCMC) and the relationship between SCMC and overlying strata were studied combined with open-type and pocket-type backfill technologies, and the mechanical model of "SCMC-main roof" for backfilling mining has been established. The factors of overlying strata stability with backfilling mining of SCM were confirmed. The study results indicate that: 1) The strengths of SCMC specimens in different cementation states and under different compression conditions increase with curing time and that of pure SCMC decreases with water volume percentage; the SCMC formed by a mixture of SCM and gangues shows a higher strength than that of pure SCM. 2) The critical factors in controlling the subsidence of overlying strata with backfilling mining of SCM were increasing the strength of concretion and filling rate. Combined with geological conditions and mining techniques in mines of Handan Mining Group,

several techniques and processes on guaranteeing filling rate were proposed and applied, including mixing gangues into SCMC, the optimization of separator-layout, burying pipes into goaf and drilling into separation area to replenish grouting filling. The measured results show that the strata behaviors of coalface is relaxed and surface subsidence is also controlled effectively.

Keywords: superhigh-water content material; engineering mechanical properties; cementation state; overlying strata control; filling process.

259 | Investigation the effect of thickness on failure propagation in a composite flexural beam

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The main objective of this paper is to investigate the effect of thickness on failure initiation position and propagation pattern in a composite beam when it is subjected to clamping load of bolt joints and flexural bending. Composite materials are considered as the desirable choice in the aerospace industry where high strength and stiffness is required besides low weight. Therefore, their application has been growing at a fast rate. As an example, unidirectional thick Glass/Epoxy laminates are being utilized in the helicopter industry to manufacture the yoke of the helicopter. The yoke is the part that connects the main rotor blades to the hub using bolt joints. Since the failure of the yoke will cause the stall of the aircraft, it is of great importance to predict the failure behavior of the yoke during the design process. This study compares the failure initiation and propagation between plates made of 4 to 80 unidirectional layers of glass/epoxy when they are subjected to both bolt clamping loads and flexural bending. A 3D finite element model was developed and verified via experimental tests. The results of the stress analysis are combined with a progressive damage simulation in order to predict the initiation and propagation of the crack in laminates with different thicknesses. The results showed considerable differences between thin and thick composites failure behavior.

447 | Stochastic vibration of the sandwich beam due to stream of moving forces

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The paper presents the stochastic analysis of the sandwich beam's vibration under a random train of moving forces. The arrival of forces at the bridge is assumed to constitute a Poisson process of events. This train of forces idealizes the flow of vehicles having random weights and travelling at the same speed. Explicit expressions for the cumulants (semi-invariants) and spectral analysis of the sandwich beam response are provided in the case of the Poisson process. Additionally, the uncertain parameters of the structures subjected to a stochastic excitation are considered. Formulation of this problem introduces fuzzy random variables for parameters of the structure and fuzzy stochastic processes for the load process using the probability theory and the imprecision by use of fuzzy sets. In this paper, we present two different situations and solutions: one for the arbitrary locations of the forces on the beam and another when one of the forces is located in the point in which the response of the beam has the maximum value. The first model can be used to estimate the reliability of the beam with respect to fatigue and the second model can be useful in the reliability problem of the beam with respect to the maximum response. In order to obtain general solutions for the stochastic response of the beam's response the normal mode dynamic influence function has been introduced. Also, the solution for the problem dynamic coefficients for above stochastic sandwich beam vibrations will be proposed. As an example, the cumulants and spectral density functions of the response of a bridge modelled as a simple supported sandwich beam are determined for some practical situations and discussed. Presented solutions and graphs allow to analyze the influence of the sandwich beam on the spectral density function of the response.

441 | Dynamic FEM analysis of composite shell structures subject to through-the-thickness confinement

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An effective strategy for seismic retrofit of existing structures [1], such as reinforced concrete or masonry shear walls, vaults and shells, is represented by Through-the-Thickness Jacketing (TTJ) that amounts to employing steel, FRP, glass or aramidic ties crossing the thickness of the original structure. In particular, this reinforcing

technique allows for increase of ductility and strength [2] granted by the confining action produced by the jacketing elements [3]. Recently, the authors have proposed an Equivalent Single Layer (ESL) First-order Shear Deformation (FSDT) shell theory [4] capable of capturing the TTJ interaction by a 2D continuum layered formulation. FEM analyses have shown the capability of this enhanced TTJ-ESL formulation to effectively reproduce the structural response of shell elements in the elastic-plastic regime while accounting for the effect of the confining interaction on both membrane and plate behaviors. In particular, by considering a Drucker Prager constitutive response for the material of the shell core, a significant strength increment is captured, driven by the triaxial stress state originated by the transverse ties. The present contribution extends the employment of the TTJ shell theory presented in [4], and of the related numerical Finite Element (FE) tools, to time–history dynamic analyses. Numerical results are presented by investigating the features of the structural response predicted by the TTJ formulation in presence of cyclic actions. The reported analyses are also aimed at assessing the computational robustness of the related FE strategy, based on a MITC element, in dynamic analyses. The structural motion excited in a shear wall by a ground motion derived by seismic records is simulated. A sensitivity analysis is performed in order to investigate the influence of the confinement rate on the energy dissipated during the post-yield excursions of core material and transverse ties.

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283 | A multiple scales based asymptotic theory for free vibration analysis of laminated hemispherical shells

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Hemispherical shells find a wide range of applications in areas such as civil structures, pressure vessels and aerospace structures. The design and analysis of such structures are challenging due to the complexity of the governing equations. The vibration characteristics of such hemispherical shells need to be thoroughly understood for an effective design. This paper presents a multiple scale asymptotic theory based method for the free vibration response analysis of annular isotropic and laminated hemispherical shells. Though there is a large body of literature on doubly curved shells and shells with rectangular planform only few works are reported on the vibration characteristics of complete hemispherical shells. Closed form solutions have been reported for axisymmetric free vibration of isotropic completely spherical shells. Numerical techniques have been widely used for free vibration analysis of laminated spherical shells. In this paper, an asymptotic theory based approach is used to estimate the natural frequencies and mode shapes of simply supported annular hemispherical shells. In this formulation, the exact 3-D elasticity equations are first recast through an appropriate choice of dimensionless variables and multiple scales in terms of a shell thickness parameter. The reformulated equations are expressed in a form that relates the through-thickness derivative of the variables to the other quantities on the corresponding surface layer. Substitution of asymptotic expansions for the displacements and stresses in powers of the small parameter yields recursive sets of differential equations for various orders. The asymptotic equations can be integrated through the thickness and together with associated lateral boundary conditions yield a modified set of equations in terms of the surface displacements which can then be solved. A shear diaphragm type boundary condition is assumed at the bottom surface of the shell. The elimination of secular terms in the higher order equations yields corrections to the higher order estimates of the natural frequencies. The convergence of the solution is very fast. The first few orders of the recursive equations are sufficient to obtain a convergence of the solution to the exact 3D solution. For arbitrary edge boundary conditions, the asymptotic method can be combined with other numerical methods such as the generalized differential quadrature to analyze the structure.

436 | A non-linear large deflection analysis for FGM beams under the different boundary conditions and different loads based on generalized Ludwick law

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Functionally Graded Materials (FGM) have been commonly used in engineering studies because of their adaptability to different situations by changing the material composition in a preferred direction with respect to requirements. In a simple FGM, two different material ingredients change in a discontinuous way or gradually from one to the other. The purpose of our study is to deal with analyzing a beam made of non-linear FGM. In this way, a non-linear functionally graded beam subjected to concentrated and combined loads was examined. We specifically focused on generalized Ludwick's type material behavior in order to overcome the shortcoming of Ludwick's type materials by utilizing three - parametric law and here, for FGM beams are taken into consideration whose Poisson's ratio is constant and, Young's modulus varies with Power law through the thickness. Based on the finite element modeling, numerous analyses were performed by utilizing ANSYS Workbench. The FGM beam was modelled by discontinuously changing material ingredients. The effects of Young's modulus varying with Power law and material non-linearity parameter on the deflection were analyzed. The results of these analysis show that the different gradient indexes and material constant of generalized Ludwick's law have great influences on the bending strength of the beam. Therefore, a FGM beam can be produced stronger than a homogenous beam by choosing proper gradients and constants. Furthermore, the bending stress distribution shows significant differences between FGM and homogenous beam. The obtained results were compared with the analytical results of previous studies considered different materials, load and compositions in order to characterize the robustness of the model and the advantages issued by the properties.

348 | Localization of buckling patterns in composite cylindrical shell structures via semi-analytical and finite element based reduced order modelling

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Thin-walled composite shells are used as main structural components in various branches of engineering. Buckling is the key design criterion for these thin-walled structures. Cylindrical shells and panels typically exhibit unstable post-buckling behavior and their behavior is correspondingly very sensitive to small geometric or load imperfections. In this work, the localization of buckling patterns, typical of shell type structures, is investigated using semi-analytical and Finite Element based reduced order modelling. In many experimental and numerical investigations, a typical localization phenomenon, the buckling process starting with a single buckle type deformation, followed by a spreading of the buckling pattern over the shell, was observed, e.g. [1]. In earlier work [2], a multi-mode finite element implementation of Koiter's initial post-buckling theory, which gives the possibility to analyze modal interactions under arbitrary geometric imperfection patterns, was presented. By using a large number of selected modes, one has the possibility to describe localized deformation patterns. Information on the localization of the buckling pattern and the connection of this localization with the "linearized" buckling and post-buckling modes can be obtained using the Finite Element based reduced order model. In the present work, additional insight into this localization phenomenon is obtained by the use of a semi-analytical approach based on the partial differential equations governing shell buckling. Donnell-type equations formulated in terms of the radial displacement W and an Airy stress function F are used, and classical laminate theory is employed. Corresponding two-point boundary value problems for sets of fourth order differential equations are derived in order to describe characteristics of the localization behavior in the axial direction and in the circumferential direction, respectively. The results of (full model) Finite Element analysis are compared with the results of multi-mode reduced order analysis for typical composite cylindrical shells and panels. The semi-analytical analysis illustrates relevant mechanisms in the localization of the buckling pattern initiating the buckling process.

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296 | Non-prismatic multi-layered planar beams: critical issues and effective modelling approaches

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The usage of composite structures with complex geometry (e.g., curved structures, tapered beams and plates, Functionally Graded Material (FGM) beams and plates) is a continuously increasing trend in several engineering fields since complex geometries allow for structural optimizations, which may lead to a better utilization of the material and, consequently, to significant cost savings. Furthermore, the trend takes advantage of the new production technologies, like additive layer manufacture techniques and 3D printing that allow to manufacture complex objects without significant increase of the production costs. Obviously, 1D (beam) or 2D (plate) models are the most natural choices for modelling such structures, but, unfortunately, models developed for prismatic bodies with constant mechanical properties along the axis/mid-plane are generally inadequate and do not capture practically-relevant stresses with sufficiently accuracy. As an example, analytical results available since the beginning of past century [1] highlight that the shear stress distribution within a planar, linearly tapered beam is substantially different from prismatic beams. Furthermore, the analytical results indicate that the shear stress and, consequently, also the shear deformation depend on axial internal force and bending moment, leading to more complex constitutive relations. Starting from the remarks discussed in the previous paragraphs and following a derivation path recently proposed in [2, 3], this contribution aims at (i) highlighting the non-trivial effects that a continuous variation of both the geometry and mechanical properties induces on stresses, displacement and stiffness distributions within a non-prismatic planar beam body and (ii) illustrating the ability of the First order Shear Deformation Theory (FSDT) proposed in [3] to tackle the main effects of cross-section variation. In greater detail, the beam model results naturally expressed by six linear Ordinary Differential Equations (ODEs) considering both Timoshenko-like displacements and internal forces as unknowns. Furthermore, the beam model takes the variation of the cross-section centroid position into account and, thus, avoids the usage of local coordinate systems (according to the strategy proposed in [4]). Subsequently, the beam model provides an effective strategy for the evaluation of the constitutive relation coefficients. Numerical examples demonstrate that the proposed beam model is able to catch the following main effects induced by cross-section variation with good accuracy: (i) variations of the cross-section centroid position, (ii) non trivial stress distribution (the shear stress is usually non-vanishing, independently from the external loads), (iii) complex beam constitutive relations, and (iv) non-trivial stiffness and displacements.

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319 | Assessments of manufacturing imperfection effects on pultruded GFRP material thorugh modal analysis

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Structural stability is a major consideration in the design of lightweight structures. The stability is affected both by sizing, geometrical and mechanical imperfections. In this paper the imperfection effects on the performances of open or closed thin-walled GFRP (Glass Fiber Reinforce Polymer) members are investigated using experimental data and model-driven approach through the modal analysis. The relationship between analytical model and experimentally acquired modal data is used to investigate the manufacturing-process-specific imperfection signature of materials and the mechanical characteristics variation for pultruded profile with different cross sections. The structural performance derived by the pultrusion technique, that defines the behaviour anisotropy

along the fibers and isotropy transversally, exalts the initial imperfections affecting the structural response of GFRP members. Taking into account of this aspect the stability has been verified on column subjected to axial load in order to investigate the first and second order effects when triggered by the imperfections. This imperfection signature is then used as input into finite-element analyses. Unavoidable imperfections of workmanship, emphasized by orthotropic mechanical structure of pultruded material, which prohibit the application of critical load concept. I showed how the centrally loaded strut theory can be extended to take into account of plastic distorsion. I indicated what kind of result is to be expected when inaccuracies in the specimen or in the experimental apparatus introduces displacements which increase continuosly with the load. Initial deflections due to inaccuracies either of manufacture or of loading are intensified by the action of the applied forces. The imperfection signature represents a "first-approximation" mean imperfection shape that is suitable for developing preliminary-design data. Comparisons of test data and analytical results obtained by using several different imperfection shapes are presented for selected profiles. Reasons for discrepancies are discussed, and potential design implications of this line of research are addressed.

232 | Semi-layerwise analyis of delaminated composite and sandwich plates

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The semi-layerwise modelling technique is developed for the analysis of orthotropic composite and sandwich plates containing a delamination. Because of the fact that cracks and delaminations induce significant perturbations of the mechanical fields, the equivalent single layer theories cannot be applied in the traditional way to model accurately such problems. Thus, the proposed modelling approach applies four equivalent single layers to capture the problem. The system of exact kinematic conditions is utilized to formulate the continuity between the neighboring layers. The sets of conditions include the continuity of the in-plane displacements, shear strains and their first and second derivatives between the perturbation planes. Also, the so-called shear strain control condition is introduced in this work. Using the principle of virtual work and by introducing the vector of primary parameters the invariant form of the equilibrium equations is formulated for the first-, second- and third-order plate theories. The invariant form of equilibrium equations incorporates the so-called displacement multiplicator matrices depending on the layer thicknesses. The governing PDE systems are derived for both the delaminated and undelaminated regions and solved by the state-space approach and Lévy plate formulation in an exact way. Throughout the analysis, the generalized continuity conditions are formulated including the theorem of autocontinuity (AC theorem) and the introduction of the equivalent stress resultants. The boundary conditions are also formulated for each theory. To demonstrate the effectiveness of the proposed modelling technique, simply supported composite and sandwich plates with through-the-width delamination are analyzed. For the composite plates two examples including four positions of the delamination in the thickness direction were investigated. In the sandwich plates a soft core material is assumed and three scenarios were considered including delamination in the core material, the facesheet-core delamination and finally when the crack takes place only in the top facesheet. The 3D J-integral was determined based on all three theories and was decomposed into mode-II and mode-III components. It is important to note that for plates the J-integral components have a certain distribution, i.e. they cannot be assumed to be uniformly distributed like e.g. in beams. The obtained results are compared to 3D finite element results for the mode-II, mode-III energy release rates and the mode ratios. It was concluded that for the composite plates there are serious limitations (locking) regarding the first-order plate theory. On the contrary, the second- and third-order plate theories perform very well: these captures accurately the mechanical fields and provide an excellent prediction for the J-integral components compared to the results obtained by the finite element model and the virtual crack closure technique. The evaluation of results of the sandwich plates showed again the deficiency of the first-order plate theory. Again, the second- and third-order plate theories are significantly better. An important observation is that although the standard and higher-order shear forces do not appear in the J-integral, it is very important capture the transverse shear stresses as accurately as possible by the analytical model. Based on the model sizes the second-order plate theory was chosen as the optimal and computationally reasonable solution of the presented problems. Moreover, it is recommended to be the basis of some plate and shell finite elements, which can replace the computationally expensive 3D finite element types and models for the delamination analysis of thin and moderately thick laminated composite and sandwich structures.

326 | An experimental investigation on the compressive response of sandwich panel under edgewise compression

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A sandwich panel is a type of laminated composite that is produced by inserting a lightweight thick core in between two stiff thin skins. The utilization of composite sandwich panel is becoming a popular trend in the construction, marine and aerospace related engineering applications. The increasing demand can be linked to their high strength to weight ratio, extraordinary bending stiffness and ability to provide good thermal insulation. The current study has been executed to investigate the compressive properties of the composite sandwich panel under different strain rates, where the compressive force is applied parallel to the plane of its face. The load carrying capacity of the sandwich panel can be attributed with the edgewise compressive strength. The information of load carrying capacity plays a central role towards the sandwich panel design. As a guide, ASTM C364/C364M test procedures were adopted to conduct the study for the different strain rates. The sandwich panels considered for the study consist of polyurethane (PU) foam as a core material and different combinations of galvanized iron (GI) and aluminum (Al) as skin materials were utilized. The full paper and presentation will report and highlight the influence of strain rate observed for the sandwich panels with different skin materials.

181 | Strain rate effects on sandwich panel's core shear properties via beam flexure

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Composite sandwich panels are fabricated by adding a light weight thick core material surrounded by thin metallic faces. These structures mainly offer high specific strength-to-weight ratio in addition to good insulative properties, rendering them attractive for outdoor storage and structural applications. The objective of this research is to characterize the effects of high strain rates on the core shear properties of insulated composite panels through standard configuration 3-point bending tests. Multiple strain rates were investigated, ranging from static conditions of 1 mm/min to intermediate conditions of 50 mm/min. Beam flexure experiments on polyurethane (PU) foam panels, 200 mm long × 75 mm wide × 45 mm thick, utilized an ASTM C393 standard test procedure to a great extent. Preliminary experimental results revealed that the core shear yield strength and the core shear ultimate strength increased by as much as 90% and 120%, respectively, over the wide range of strain rate load applications. The full paper and presentation will also highlight the strain rate effects observed on panels made using different foam densities such as Polyisocyanurate (PIR).

220 | A three-node flat shell element based on refined zigzag theory

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Another alternative to 3-D finite element model is the use of plate elements based on a single-layer plate theory with zigzag functions, referred to as Refined Zigzag Theory (RZT). This study presents a new three-node flat shell element based on RZT. The element has 11 degrees of freedom (dof) at the corner nodes. Also, it is available as an ABAQUS user element. It accounts for both transverse stretching and transverse shear deformations in laminated composite structures. The representation of kinematic variables includes quadratic shape functions for the in-plane and transverse displacements, and linear shape functions for the average rotations and the zigzag amplitudes. The zigzag kinematics represented by piecewise-linear C0-continuous functions through the thickness enable sufficiently accurate and computationally efficient modeling of a wide range of homogeneous and heterogeneous laminates without the use of shear correction factors. The consequence of the kinematic assumptions leads to an element with three corner nodes and three mid-side nodes. The corner nodes have nine dof consisting of in-plane displacements, out-of-plane slopes, transverse displacement, and its symmetric and anti-symmetric modes, out-of-plane zigzag rotations. The mid-side nodes have only the transverse displacement as a dof. After introducing the mathematical drilling rotation and drilling zigzag dof at the corner nodes, the mid-side dof is removed by enforcing continuous shear strain constraints along the three element edges. The stress resultants obtained from the equilibrium equations are physically consistent with their definitions based on Hooke's relations. Therefore, the stress fields can be directly calculated from the strain fields. However, the accuracy of the transverse stress components are enhanced by integration through the thickness in conjunction with peridynamic differentiation. This element provides robust and accurate prediction of all stress components in highly heterogeneous laminates. Its accuracy is demonstrated by considering a simply supported sandwich panel

made of a soft core with graphite/epoxy face sheets under transverse sinusoidal load. The comparison of the results from this element and the analytical solution shows close agreement.

320 | Modeling thin pretwisted and delaminated composite strips: a variational asymptotic method based approach

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This study presents a comprehensive analysis of the effect of delamination on the static, dynamic and stability behavior of thin pretwisted composite strips. An asymptotically exact cross-sectional model coupled with geometrically nonlinear one-dimensional (1D) theory is developed for a thin composite strip in the presence of delamination. The model is generic in scope and can consider delamination at any position along the length and breadth of the strip. This analytical model is based on the dimensional reduction of laminated shell theory to nonlinear 1D theory using the variational asymptotic method. Delamination model follows the sublaminate approach. The cross-sectional nonlinearity explicitly accounts for the delamination size. The predictive capability and the accuracy of the model are demonstrated by considering a variety of numerical examples. First, quasi-static behavior of a composite strip with Winckler layup subjected to tip loading is considered to predict trapeze effect. Model predictions are compared with experimental results available in the literature. Dynamic analysis is then carried out for a variety of composite layups with varying delamination length and location to investigate its effect on the modal behavior of the strips. Model predictions are extended to predict the modal behavior in pretwisted composite strips and validated with complimentary expermients undertaken to obtain the free vibration characteristics of these structures using the scanning laser Doppler vibrometer. The results from the model and the experiments show good agreement. The model is extended to determine the free vibration characteristics of a rotating pretwisted composite strip in the presence of delamination. Finally, stability analysis is carried out for composite strips with delamination for various boundary conditions. In general, the analytical approach undertaken in the modeling of delamination in composite strips reduces the overall computational effort necessary to obtain static, dynamic and stability response of the strips. Further, it helps to identify key stiffness terms that directly affect the response thus aiding in the preliminary design process. Generalization of the methodology proposed in this work finds engineering application in helicopter rotor flexbeams and slender turbine, propeller and wind turbine blades.

331 | A new enriched plate macro element

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This article presents the formulation of a new enriched plate macro element. This formulation is based on the First Order Shear Deformation Theory (FSDT) with the incorporation of new parameters. These parameters are calculated by compatibility of FSDT displacement and various Higher Order Shear Deformation Theories (HSDT) displacements. In this way, an approximation C0 is obtained. Shear correction factor is not required because this HSD theories account for tangential stress-free boundary conditions on the plate boundary surfaces. The macro element is obtained using the principle of virtual work and Gram-Schmidt orthogonal polynomials as enrichment functions. Several examples corresponding to the static and dynamic analysis of symmetrically laminated composite plates are presented to show the capability of the developed formulation.

317 | Analysis of plates and sandwich structures subjected to non-classical boundary conditions

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While the vast majority of the literature deals with composite plates subjected to classical boundary conditions - simply-supported, free and clamped edges -, relatively few results are available for arbitrary sets of edge conditions. These latest include plates supported at discrete point locations, at the corners, and along specific thickness-wise positions. The present work discusses the analysis of laminated and sandwich panels in terms of bending, free-vibration and buckling response by considering non-classical boundary conditions, which are imposed using Lagrange multipliers and penalty techniques. The approach is developed within the context of the

Sublaminate Generalized Unified Formulation (S-GUF) [1,2], where the structure is modeled as an assembly of group of plies called sublaminates, each one characterized by an independent kinematic theory. The S-GUF formulation is applied in conjunction with the method of Ritz for deriving and solving the governing equations. Exemplary results are presented, where the capability offered by the proposed techniques are fully exploited.

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120 | Static response of functionally graded magneto-electro-elastic plates subjected to thermal, electric and magnetic loads

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In the present article, the static behavior of layerwise functionally graded magneto-electro-elastic (FG-MEE) plates subject to various load forms is analysed. Based on the first order shear deformation theory (FSDT), a three dimensional FE model is derived considering the magneto-elastic, electro-elastic and magneto-electric coupling effects. Also, the principle of total potential energy and coupled constitutive equation of magneto-electro-elastic material are used in the formulation. A particular attention has been paid to evaluate the effect of thermal, electric and magnetic loads on the direct (displacements, electric potential and magnetic potential) and derived quantities (stresses, electric displacements, magnetic flux density) of FG-MEE plates. Meanwhile, in thermal environment, the influence of additional coupling such as pyro-electric and pyro-magnetic effects are also taken into consideration. In addition, the influence of various parameters such as boundary conditions, aspect ratio and stacking sequence has been investigated. The results presented in this study can have a significant contribution in enhancing the performance and applicability of FG-MEE structures in various working environment.

121 | A fully coupled FE formulation for the free vibration and static analysis of functionally graded magneto-thermo-electro-elastic plates

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The current work presents the free vibration and static studies of magneto-thermo-electro-elastic (MTEE) plates by considering full coupling between elastic, magnetic, electric and thermal fields. A finite element (FE) formulation is derived using the principle of total potential energy and coupled constitutive equations of MTEE material. The kinematic relations are based on the first order shear deformation theory and FE model is developed with the help of eight noded isoparametric element. This study mainly focus on evaluating the influence of various coupling effect on the natural frequency of layerwise functionally graded (FG) MTEE plates. In addition, the effect of boundary conditions, stacking sequence and aspect ratio on the natural frequencies has been investigated. The static studies are carried out to compute the variation of displacements, electric potential, magnetic potential, stresses, electric displacement and magnetic flux density. The various field forces like thermal, electric and magnetic fields are considered for the analysis. Particular attention has also been paid to investigate the effect of product properties. The results from the investigation reveal that this study can have a significant contribution in enhancing the performance and applicability of FG-MTEE structures in the field of sensors and actuators.

302 | Closed-form solution for stress calculation of finite anisotropic plates with elliptical cutouts considering different material stiffness within the model

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Primary structures made of composites are widely extended in aeronautical industry, mostly due to lightweight requirements of this sector. It is usual to find structures of aircrafts weakened by the inclusion of cutouts due to a wide variety of requirements. For instance, there are cutouts in the structure that provide human access to internal

systems or structures (e.g. manhole, handhole, headhole…). These openings cause a stress concentration around them which may produce an important reduction of the structure strength. Therefore, stress distribution around the cutouts must be quantified for a safe design of the structure. As a particular case, wing composite panels weakened by the presence of cutouts are usually subjected to change of thicknesses (either chordwise or spanwise). Hence, if a region of the wing is intended to be simulated it is required to consider such variables in the model in order to provide an accurate solution. To this end, material stiffness might be modified in each region with different thickness, stacking sequence and/or material. In order to calculate the stress-state over the component, two approaches may be considered. On the one hand, finite element formulations provide a direct approach. Nonetheless, for the initial phases of the design, such formulations may require high computational capacity in order to perform parametric studies, with the added computational time required to carry out remeshing with each parameter change. On the other hand, analytical formulations (closed-form solutions) provide an alternative strategy in order to reduce the computational time, even if it is achieved by adding complexity and reducing versatility to the problem. In this article, a closed-form solution based on Lekhnitskii formalism for anisotropic plates under membrane loads will be presented. The tool includes an innovative approach in order to consider different regions (each one with a specific material stiffness matrix) within the model. The solution is reached through equilibrium of internal forces and continuity of displacements at each region interface using collocation points. Subsequently, the matrix of unknowns is solved by using the least squares method. In a previous work developed by the authors a similar procedure for the calculation of a reinforced elliptical cutout was presented. An enhancement of the tool is thus achieved by increasing the range of application of the method. Further developments may include the effect on the model of a beam stiffener and membrane-bending coupling.

381 | Analysis and design of laminated glass composite panel

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The study is focused on analysis and design of laminated glass composite panels (LGCP) with at least one flexible plastic/viscoelastic interlayer. The interlayer(s) play key role design of laminates. There are at least three principally different interlayers available: 1) strengthening layer for safety glass, holds glass together when shattered, 2) acoustic layer for sound attenuation, and vibrations damping, 3) multifunctional layer has both abovementioned functionalities. Furthermore, it has been observed that the aging of the laminates is determined mostly by the properties of the interlayer. In this reason one sub-goal of the study is to determine mechanical properties of the interlayer and to apply different materials models for more precise describing interlayer. The properties of the interlayer are different before and after manufacturing of the LGCP due to high temperature treatment effects. For that reason, the manufacturing process has been performed in such a manner that the interlayer can be separated after manufacturing in order to evaluate/measure its properties. Vibration analysis of the LGCP with different interlayers and configurations has been performed. FEM simulation model has been treated. Haar wavelet method based solution has been developed. In the case of tempered glass, there are significant residual stresses in glass after manufacturing. The experimental study for determination residual stresses has been performed. In future study, it has been foreseen to include these residual stresses in analysis models.

88 | Plane stress analysis of magnetoelectric composite and reinforced plates

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Composite materials made up of piezoelectric and piezomagnetic phases have attracted attention in recent years both because of their potential for engineering applications and because of the interesting properties they exhibit. These properties are called product properties and examples include magnetoelectricity, pyroelectricity and pyromagnetism [1-3]; product properties are unique because they are typically exhibited by the macroscopic composite as a result of the interaction and strain transfer between the different constituents but may be absent from the constitutive behavior of the constituents themselves. As such, in order for the product properties to be

manifested, there must be a good degree of bonding between them. Perhaps the most common product property in composites of piezoelectric and piezomagnetic phases is the magnetoelectric effect, see Nan et al [1]. Applying an electric field to such a composite induces a mechanical strain in the piezoelectric phase. This deformation is transferred to the piezomagnetic constituent thus generating a magnetic induction. Overall, an applied electric field generates a magnetic field and vice-versa. In this work, the equations of dynamic force and thermal balance as well as the time-varying form of Maxwell's equations are used to develop a comprehensive asymptotic homogenization model for the design and analysis of composite and reinforced magnetoelectric plates. The model generates twenty unit cell problems that can be used to determine the effective elastic, piezoelectric, piezomagnetic, electrical conductivity and other properties of the structure under consideration. This paper applies the model developed to three general magnetoelectric structures; wafer-reinforced plates, rib-reinforced plates and three-layered honeycomb plates. For the sake of generality, all structures considered are assumed to be made of generally orthotropic constituents. We seek an approximate solution to the boundary value problem at hand by solving the unit cell problems in each region of the unit cell of the structures separately and then superimposing the results. In doing so, we accept the error incurred at the regions of overlap of each constituent; however, the results obtained and the expressions for the effective coefficients in particular will be quite accurate since the aforementioned regions of intersection are highly localized and do not contribute significantly to the integral over the volume of the unit cell. Unlike previous models it is discovered in this work that the effective coefficients of such structures are not constants, but are, instead, functions of time. As a direct consequence, the dependent field variables (stress, strain, electric and magnetic field, heat flux, current density and all others) are also functions of time; this results in a homogenized structure which exhibits memory-like behavior. In fact, it is shown in this paper that other previously derived models can be viewed as particular special cases of the model developed here when electrical conductivity is ignored and all pertinent quantities are time-averaged by integrating them over the entire time spectrum. Collectively, the results presented here represent a significant refinement of previously established results.

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297 | The phased behavior analysis of deformation for arch and beam structures

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The goal of this research is to investigate the difference of load-displacement relation between arch and beam through static load experiment based on TLS techniques and surface analysis method. The innovation is that we try to reveal the phased behavior changing rules and the influence mechanism of pre-stress. The contribution of this paper is named as "phased behavior analysis" which is a new method to investigate the behavior of structure. Finally, the result shows that both structures in the loading progress would suffer three phases in deformation behavior which are steady phase, developing phase and fracture phase. Furthermore, considering the effect of pre-stress, steady phase would last longer and developing phase and fracture phase would be hysteretic.

Keywords: Pre-stress; Phased behavior; Surface deformation; Terrestrial Laser Scanning; Arch Structure

355 | Bending, vibration and buckling of of laminated composite and sandwich beams using a four-unknown shear and normal deformation theory

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This paper deals with bending, vibration and buckling of composite beams with arbitrary lay-ups by using a quasi-3D theory, which accounts for shear and normal deformation effects as well as coupling effects arising from the material anisotropy. The axial and transverse displacement variations are assumed to be cubic and quadratic functions of the depth, respectively. Using an assumed displacement field, the governing differential equations of motion are derived by applying Hamilton's principle. A two-noded C1 finite element with six degree-of-freedom at each node is developed to solve the free vibration problem. Numerical results are obtained for representative composite beams and the effects of fiber orientation on the deflections, stresses, natural frequencies, buckling loads and mode shapes are demonstrated. The results are discussed and the paper concludes with some important remarks.

173 | Damage growth in composite plates with openings – experimental and theoretical considerations

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The stress concentrations near the edge of the hole are the natural consequence which in most cases reduces the static strength of the structure. Moreover, the great number of the failure forms, especially in the case of the laminated structures complicates the design process and service life prediction. Up to now, a lot of research effort has been concentrated on experimental verification of the failure criterions and models and determination of the mechanical properties of the composite materials. From the other point of view the greatest challenge is to develop the monitoring system integrated with the composite part which would permanent verify the state of the structure. In this paper, the experimental tests and numerical investigations have been carried out to verify the failure form of the laminated composite plate with circular and elliptical holes. The non-destructive evaluation system based on infrared passive thermography has been applied to observe the failure of the composite plate during the uniaxial static and fatigue tension tests. The analysis of the thermograms demonstrates the temperature rise connected with the cracks propagation. The accumulated energy in the overloaded plate is rapidly released in the form of temperature gradient. It is worth to notice that first visible difference between temperatures at analyzed points corresponds to the local initiation of the defects at the edge of the hole. The transition of the damage to the global form cause the thermal energy dissipation and local temperature drop. Subsequently, the evolution of the global failure form causes the dynamic temperature increase at the damaged area. The visible change in the slope of a tension force curve (time: 500 [s]) illustrates the effect of the damage transition from the local to the global form.

91 | Critical state evaluation of three-layered annular plates with symmetry and asymmetry damaged composite structure

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The problem to evaluate of the critical state and supercritical behaviours of plate element is the complex task depended on many parameters. Among them there are properties of the plate cross-section. Composite, three-layered structure of examined annular plate, whose facings are laminate and the core is made of the soft, polyurethane foam could be subjected to different kinds of damages. Among many others there could be the local defects in the form of fibre or matrix cracks of single lamina, several layers or all together ones. The damages of plate facings change the structure rigidity and generate the disturbance of the symmetry of the plate preliminary structure. Considering different combinations of facing damages expressed by the failures of the laminate fibres or matrix the responses of analysed plate structure to acting of the static and dynamic loads were evaluated. The loads as the quickly linearly increasing forces radially compress the facings in their plane. Plate loses static and dynamic stability. As a criterion of the loss of the plate dynamic stability the criterion presented by Volmir in work [1] was adopted. According to this criterion, the loss of plate stability occurs at the moment of time, when

the speed of the plate point of maximum deflection reaches the first maximum value. Numerous analyses of the annular plates with laminate facings show the great differences both in values of critical static or dynamic loads and corresponding with them buckling modes. Rapidly growing loads acting on inner or outer plate edge strongly deform the plate close to the loaded perimeter. The global, quasi-eulerian buckling forms practically are not observed. The values of the critical, dynamic loads are much greater than static ones. For example, for plate with damaged facings in the form of matrix cracks of all facings laminas, loaded on inner edge the values of the critical loads are equal to: pcrdyn=103.43 MPa - dynamic critical load, pcr=27.54 MPa – static critical load [2]. Similar observations are confirmed by the numerical investigations of plates with undamaged and damaged facings [2,3]. The calculations were led for plate models built of finite elements using the ABAQUS system (KBN/SGI_ORIGIN_2000/PŁódzka/030/1999). The results were referred to the analyses of plates with undamaged layers, whose configuration of the composite layers fulfils the conditions of the quasi-isotropic composite. The code of the accepted glass/epoxy composite is following: [0/-45/45/90]. The calculations were carried out using both finite element method and analytically-numerical problem solution based on the orthogonalization and finite difference methods. The axisymmetrical and asymmetrical plate buckling modes were examined. The mechanics of the fibrous composite is based on the classical lamination theory. Accepted model of the composite degradation is based on the theory of correction parameter method presented in work [4]. The matrix or fibre cracks change the mechanical properties of laminate. Mathematically, it is described by the modification of the stiffness matrix. The evaluation of the values of the critical static loads of plates with structure failures shows some regularity of changes together with the form of facing damages. The exemplary values of the critical static loads pcr are following for loaded on inner edge plates with: undamaged facings – pcr=36.84 MPa, both facings damaged in the form of matrix crack of lamina, whose fibres are arranged with angle 0 - pcr=34.28 MPa, both facings damaged in the form of all matrices cracks - pcr=27.54 MPa, matrix crack damage of only single lamina with fibres arranged with angle 0 in one of plate facings- pcr=36.17 MPa, damaged all laminas of one of plate facings in the form of matrices cracks - pcr=31.86 MPa. The last two examples show the results for the plate with transversely asymmetric structure. In real structure the distribution of the lamina defects could be located randomly and differently in two plate facings. Such regularity of values of critical loads is not observed in dynamic analyses.

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50 | Thermal buckling analysis of thin-walled functionally graded box beams

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Paper presents buckling analysis of thin-walled functionally graded (FG) box beam type structures exposed to thermal loading. The non-linear stability analysis is performed in a load-deflection manner based on the framework of corotational formulation. Model is based on Euler-Bernoulli bending theory as well as the Vlasov torsional theory. Material properties are assumed to be graded through the wall thickness of beam. 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 the critical buckling temperature and post-buckling response

45 | A shear-flexible beam model for large displacement analysis of composite beam-type structures

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This work presents a beam model for large displacement analysis of composite beam-type structures composed of the straight and prismatic shear flexible composite thin-walled beam members. By applying the virtual work principle, the updated Lagrangian incremental formulation and the nonlinear displacement field of thin-walled cross-sections, the equilibrium equations of a straight beam element are firstly developed. Although displacements

are allowed to be large, strains are assumed to stay small. External loads are static and conservative. A linear interpolation for the axial displacement and a cubic interpolation the deflections and angle of twist are employed, respectively. Internal moments are represented as the stress resultants calculated by the engineering theories. Due to the nonlinear displacement field, the incremental geometric potential of the semitangential moment is obtained for both the torsion and bending moments. The generalized displacement control method is employed as an incremental-iterative solution scheme. At the end of each iteration, the updating of nodal orientations is performed using the transformation rule which applies for semitangental incremental rotations. Force recovering is performed according to the conventional approach. Linear shape functions are used for the axial displacement, while cubic shape functions are employed for the transverse displacements and angle of twist. Also, using a non-linear displacement field for the cross-section that includes the large rotation effects, the geometric stiffness matrix for the spatial thin-walled beam finite element is derived, in which internal semitangential moments are obtained. Semi-rigid connections are allowed to occur at finite element nodes by modifying the stiffness matrices and nodal vectors of a conventional large-displacement beam element having rigid connections at the end nodes. Flexible connections are allowed to occur at finite element nodes. In order to include flexible connection characteristics into the numerical procedure, the data for load-deformation relationships of the given connection must be mathematically represented. The accuracy of the numerical algorithm is examined through several test problems.

85 | Investigation on the structural response of plates and shells with variable mechanical properties: modeling of the damage

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The structural response of plates and shells in terms of static and dynamic behavior is highly affected by the variability of the mechanical properties within the reference domain. It should be noted that in the literature several approaches have been introduced to define variable mechanical properties. For instance, the class of graded materials and of laminated composites reinforced by curvilinear fibers can be taken as a reference. In the current work, an innovative way to describe the variability of the mechanical properties is presented. A proper mathematical formulation is developed to define linear, sine-wave, and exponential variations of the elastic constants of the composites. In particular, two-dimensional laws, such as the Gaussian and the elliptic functions, are taken into account to model the damage of plates and shells. In other words, the damage of a structure can be seen as a rapid and concentrated variation of the mechanical properties of the elastic medium. Several parametric investigations are performed to analyze the effect of the damage parameters (intensity and size) on the structural response. The solution is achieved numerically by means of the Generalized Differential Quadrature (GDQ) method. The structural model is developed in the framework of a Unified Formulation which allows to consider in an efficient manner several higher-order theories. Finally, it should be pointed out that the description of the doubly-curved geometries with variable radii of curvature is obtained by using the well-known differential geometry.

86 | Mechanics of structural components by using a numerical approach based on blending functions mapping and a strong formulation

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Generally, modelling composite materials in engineering design is a complicated subject because inclusions can have an arbitrary shape within a homogeneous matrix. In this matter, several numerical approaches have been introduced to overcome this particular issue. If a standard finite element (FE) model is used, the discretization in such cases must be very refined near the discontinuities due to low order approximating polynomials. This results in heavy numerical models that are complex to solve. Moreover, since the stress jumps among the elements within the mesh are not continuous the approximation of such field is not always accurate. For these reasons, the authors are proposing a new numerical approach based on the strong formulation which needs continuous displacements and stresses among the elements. The present feature gives the possibility of having a complete continuous field in the whole mesh and of presenting more accurate results if compared to classic FE approaches. This important result is achieved due to the strong formulation that solves the partial differential system of equations that govern

the physical problem. Moreover, the present paper presents a study wherein blending functions are utilized in the mapping technique to approximate the boundaries of the elements in the given mesh. Such blending functions are taken as NURBS (Not-Uniform Rational B-Splines) from CAD software. This novelty allows a more accurate geometrical approximation of the patches with consequent reduction on the total number of degrees of freedom since less elements are needed for accurately approximates the discontinuities present in the physical problem.

78 | Three-dimensional stress fields for beams with arbitrary cross sections using the Unified Formulation with Serendipity Lagrange polynomial expansions

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Analytical and one-dimensional finite element models are widely employed for the stress analysis of beam structures because of their simplicity and acceptable levels of accuracy. However, the accuracy of these models is limited by consideration of Saint-Venant's Principle, i.e. applicable remote from boundary constraints, discontinuities and points of load application. To predict accurate stress fields in these regions, computationally expensive three-dimensional finite element analyses are now routinely performed. To capture localised three-dimensional stress fields, displacement based high-order models are required. In this work, a Unified Formulation approach based on a Serendipity Lagrange expansion is used to capture localised stresses in beams of arbitrary cross section. This approach offers a computationally efficient means of capturing high-fidelity fields that extend beyond those recovered by classical theories. One-dimensional beam finite elements are subsequently defined. The additional fidelity is derived by expressing the cross-sectional displacement fields in terms of high-order Serendipity Lagrange polynomial expansions. The advantages of using Serendipity Lagrange expansions for beams of various cross sections over finite elements, Taylor and Lagrange type models are discussed in the present study. Results show an excellent agreement with three- dimensional finite element solutions obtained with ANSYS.

47 | Development DKMQ24 and DKMQ20 shell elements in composite structures

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Quadrilateral element called DKMQ (Discrete Kirchhoff-Mindlin Quadrilateral) 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 DKMQ element for composite plate structures has been proposed by Katili et al. in 2015. It gives the results converge to the reference solution. Moreover, DKMQ plate element has been developed in to DKMQ24 and DKMQ20 shell element by Katili et al. in 2015. 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 DKMQ24 and DKMQ20 shell elements in composite structures" will introduce a new computational method in composite shell structures. The proposed papers will focus on the development of DKMQ24 and DKMQ20 elements 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.

54 | Bending of FGM plates under thermal load: Generalized thermoelasticity analysis by a meshless method

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Thermal stresses, especially at the interface between two different materials, often play an important role in the failure of laminated composite structures. Thus, it is a strong motivation to replace laminated plate structures by FGM ones if possible. The functional gradation of material coefficients, however, yields new coupling effects between the in-plane deformation and bending modes. Therefore, the study of behavior of FGM plates under thermal loadings has become important. In the classical thermoelasticty, the temperature change does not propagate in a wave form, though the temperature field is coupled with elastic fields. However, the heat pulses at low temperature propagate with a finite velocity like waves. A great effort has been spent in this matter and there are two main generalized theories: Lord-Shulman theory and Green-Lindsay theory. In this paper, the bending of

thin and/or thick FGM plates under thermal load is considered within the generalized theory of thermoelasticity. The variable material properties of plate (such as the Young's modulus, thermal expansion coefficient, etc.) are allowed to be continuous functions of the position. The governing equations which are given by the 4th order partial differential equations (PDE) are decomposed into the 2nd order PDEs in order to overcome the inaccuracy of approximation of high order derivatives of field variables. The strong form meshless formulations for solution of thin plate bending problem is developed in combination with Moving Least Squares (MLS) approximation scheme. The attention is paid to the study of the influence of various parameters of gradations of material coefficients on the deflection of the plate.

ANALYSIS OF WOOD AND NATURAL FIBRE COMPOSITES

7 | Natural fibre reinforced composite as possible future earthquake-resistant construction materials

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The usage of glass or carbon fibre reinforced polymers in civil infrastructure is limited to retrofitting due to the high cost of the synthetic fibres. Conventional construction materials, i.e. steel or reinforced concrete, have the disadvantage of their heavy weight. The large mass of these materials attracts large inertia forces and thus a large impact of the earthquake loading. In addition, it is only a question of time that steel reinforcement will cause corrosion issue, i.e. a degradation of the structural members. The maintenance cost and the impediment due to replacement-induced downtime can be immense. In this contribution, natural fibre reinforced polymer-concrete composite is considered as possible future construction materials. The natural fibres considered are flax and coconut fibres. Flax fibre reinforced polymer (FFRP) has the tensile strength similar to that of glass fibre reinforced polymer. Coconut fibre reinforced concrete (CFRC) enhances not only the compressive strength of the composite, but it can also significantly increase the damping of the material. FFRP-CFRC composite thus has the enhanced dynamic properties in addition to less weight and without the issue of corrosion. A number of possible usages of FFRP-CFRC composite will be presented.

448 | Effect of silica fume content on compressive strength of natural fibre reinforced concrete

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In modern construction, the use of high strength concrete (HSC) and high performance concrete (HPC) has increased in high-rise buildings due to their enhanced mechanical properties. There has been a steady increase in the use of short and randomly distributed fibres to reinforce the concrete to produce high strength fibre reinforced concrete (HSFRC). Both HSC and HPC can be produced by using different materials like silica fume (SF) with addition of fibres such as glass, steel, nylon and natural fibres etc. Fibres alter the behavior of concrete when a crack occurs by bridging across the cracks, and thus can provide some post-cracking behavior in different properties like compressive strength (CS), flexural strength (FS) and splitting tensile strength (STS). The HSFRC can be used in high-rise buildings to reduce the size of structural members. Coconut fibres have the highest toughness amongst natural fibres and have potential to be used as reinforcement in composites. The overall aim of this research program is to produce HSFRC using mineral admixture for the application of high-rise buildings. The compressive strength of coconut fibre reinforced concrete (CFRC) with addition of different silica fume content (i.e. 5%, 10% and 15%) will be investigated in this work. The improvement in compressive properties of CFRC having silica fume content will be evaluated and compared with that of CFRC. The mix design ratio of CFRC is 1:2:2 (cement: sand: aggregate) with a water cement ratio of 0.50. Coconut fibres are added having 2% content by mass of cement and a length of 50 mm. The silica fume is added in CFRC mix design with different content for achieving high strength coconut fibre reinforced concrete (HS-CFRC). CFRC and HS-CFRC are prepared in layers i.e. one third aggregates are spread in mixer, followed by fibres, cement, silica fume (where applicable) and sand. For each batch, cylinders having size of 100 mm diameter and 200 mm height are cast. The workability of CFRC with different silica fume content is less as compared to that of CFRC. It is expected that, with increasing content of silica fume, there will be an increase in compressive strength of HS-CFRC as compared to that of CFRC. The next step is to evaluate the long term durability of HS-CFRC.

449 | Increasing splitting-tensile toughness index of concrete with natural fibres and silica fume

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There are many defects in bridge decks like early age micro cracks (EAMC), surface erosion, spalling and crazing. EAMC is the dominant defect as reported by many researchers. The main responsible property is tensile strength of concrete. Thus, EAMC can be reduced by enhancing its tensile strength because low tensile strength results in less resistance to EAMC in bridge deck. The use of fibres in concrete for the application of bridge deck has showed better performance against EAMC. On the other hand, use of silica fume also results in less cracking against EAMC. Therefore, EAMC can be controlled with the use of both silica fume and fibres. The question arises how much improvement can be achieved with these two materials in concrete? The overall aim of this research program is to explore new materials with addition of mineral admixture for the application of bridge deck. To check the influence of addition of silica fume and coconut fibres in concrete, the splitting-tensile toughness indices of plain concrete (PC), silica fume plain concrete (SF-PC), coconut fibre reinforced concrete (CFRC) and silica fume coconut fibre reinforced concrete (SF-CFRC) will be investigated in this research. The mix design ratio of both PC and CFRC is 1:2:2 (cement: sand: aggregate) with water cement ratios of 0.45 and 0.50, respectively. The coconut fibre content of 2%, by mass of cement, and length of 100 mm are added. The silica fume of 15% is added in PC and CFRC mix design for production of SF-PC and SF-CFRC, respectively. For each batch, cylinder of 100 mm diameter and 200 mm height are cast. The workability tests are performed for all mixes in fresh state. The slump of SF-PC, CFRC and SF-CFRC is decreased by 94%, 5% and 100% as compared to that of PC. It is likely that there will be an increase in splitting-tensile toughness indices of CFRC and SF-CFRC as compared to PC and SF-PC, respectively. This may ensure the reduction in EAMC in bridge deck. The next step is to evaluate the behaviour of SF-CFRC with flexural reinforcement.

34 | Development and characterization of hybrid green composites from textile waste

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Natural fiber reinforced composites (NFRC) are manufactured by the combination of natural fibers as reinforcement. They have received much attention because of their lightweight, nonabrasive, combustible, nontoxic, low cost and biodegradable properties. At the end of useful life, these composites can be easily disposed or decomposed without indulging the environment. Among the various natural fibers flax, bamboo, sisal, hemp, ramie, jute, and wood fibers are of particular interest. However, lack of good interfacial adhesion, low melting point, and poor resistance towards moisture make the use of natural fiber reinforced composites less attractive. Pretreatments of the natural fiber can clean the fiber surface, chemically modify the surface, stop the moisture absorption process, and increase the surface roughness. In the world, 16-17 % cotton fibers are wasted due to their short length that makes them unspin able for making fine and high strength yarn. The price of finished yarn is increased due to this 17% waste. These waste fibers can be used for making low strength yarn that can be used for making composite reinforcement. This reinforcement can be used along with other reinforcement in hybrid composites. In this way, cost of composites can be reduced. The aim of this study was to use textile industry waste (cotton and jute) as a replacement of virgin glass for the development of hybrid composites. Tensile and flexural properties were characterized to analyze the behavior of composite samples under certain loads. Results showed that, after some pre-treatment textile waste materials can be used along with virgin material. This usage of textile waste will be helpful for its value addition and solving the waste disposal problems. Mechanical properties of composites were also predicted by using regression equations. Due to huge application of composites, the cost and environment friendly disposal of composites after end use is a major apprehension. This study will be very helpful to solve this problem by using waste and low value materials for the manufacturing of composites. This study will also increase the value of textile waste and keep the environment hygiene by minimizing waste.

169 | Development of biodegradable micro- and nanocomposites from Brazil nut forestry waste

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There has been an increasing interest in using agro-forestry waste for the development of novel polymer composites. Agro-forestry waste has been used as a source of fibrous microreinforcements as well as nanoreinforcements and has been obtained from different resources such as leaves, grass, seeds, wood, among a variety of others ligno-cellulosic materials. The advantages of these reinforcing materials are their low density, biodegradability, renewability, low cost and the fact that they are considered environmentally friendly. The resulting composites have increased stiffness and sometimes increased strength with regard to the unreinforced polymer. In most cases, synthetic non degradable polymer matrices have been used to produce these so called green composites. Here we propose the development of fully degradable micro and nanocomposites using starch based biopolymers reinforced with waste from Brazil nut shells. The Brazil nut tree occurs in most of the Amazonian region in South America and it is considered one of the most valuable products that can be harvested from the undisturbed rainforest. It is interesting to notice that Brazil nut forests are conserved by local communities that harvest the fruits, preventing deforestation in a sustainable manner. Hence, it is important to develop byproducts for the parts of the fruit that have little or no commercial value. A Brazil nut fruit has three parts: shell, brown skin and edible part. A huge amount of waste (ca. 48 % by weight) is produced during the processing of the nuts. The shell and the brown skin are disposed as waste by the Brazil nut factories and find only few commercial applications. The present work reports the development of fully biodegradable micro- and nanocomposites from starch based polymers and Brazil nut wastes. The mechanical, thermal and morphological properties of the micro- and nanocomposites are characterized and the structure - property relationships that determine overall mechanical behavior are reported. The issues of interfacial adherence are discussed and assessed by microscopy as well as by infrared spectroscopy. The failure mechanisms of the composites are also analyzed.

211 | Wood laminated beams reinforced with sisal fibres

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Natural fibres have been applied in various fields of construction and recently raised attention for presenting adequate mechanical characteristics for reinforcement of wood structural elements. Sisal fibres, for example, have attracted attention for presenting adequate mechanical characteristics for such applications. In addition, the use of both natural fibres and wood from reforestation in laminated beams is in accordance with the current economic interest and sustainable appeal. This paper presents a theoretical and an experimental analysis of wood laminated beams reinforced by sisal fibres. The laminated beams used in this research were constituted by Pinus sp and were reinforced by sisal strips with a thickness of 2 mm glued by Epoxy adhesive on the bottom of the beam on the tensile region. Each lamina had the following dimensions: a width of 50 mm, a height of 20 mm and a length of 1.5 m. For the theoretical analysis of wood laminate beams, three models are carried out stress functions, classical lamination theory and the transformed section method. It was noted that the average differences between the theoretical and experimental results are given by 11% and 2% for normal and shear stresses respectively, and 8%, for displacements. As a conclusion, the strengthening of wood laminate beams with sisal fibres is effective in wood structural elements, in which the elastic modulus is at maximum equal to these fibres and prevents brittle failure in critical tensile regions.

214 | Physico-chemical characterization of date palm leaves (Phoenix Dactylifera–L) of Algeria

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The date palm (Phoenix dactylifera L.) is considered as one of the most important fruit crops in Algeria which is the dates' fourth world producer as of the year 2014. On the 25th of May 2016, Algerian Press Service reported that the date palm plantations in this country grew significantly over the last decade with a total of more than 20 million palm trees scattered over 100,000 farms. In 2011, botanic experts reported that one date palm tree can producefrom 6 to 12 leaves and petioles, and an average of 7 fruit bunches per year that have an average mass of 4 kg and 1.5 kg respectively. Considering that Algeria have more than 20 million palm trees, it can subsequently produce approximately 720,000 tons of date palm petioles and leaves, and 210,000 tons of fruit bunches.This enormous production is not exploited as it is actually considered as animal feed or waste, and thus rarely used in artisanal works.However and from thethe point of view of the interested researchers in lignocellulosic fibres, this production is a natural wealth that may be exploited in diverse ways such as the reinforcement for bio-composite materialsthat may be of interest to a lot of researchers and various industries. For a better valorisation of regenerated palms as a bio-resource, it is necessary to have a good understanding and a wide knowledge of the microstructure along with the chemical composition of the different parts of the tree. This is one of the objectives of this article in which the physico-chemical composition of the rachis and leafletare investigated. As in Algeria, many varieties of dates such as Deglet-Nour, Degla-Beida, Gears and Fergus are produced, this research work will focus on the experimental investigation of leaf samples (rachis and leaflets) of a palm tree collected from a Farm in El-Oued located in the south of Algeria. The aim of this investigation being the extraction of the fibres and the examination of their morphology (length and cross-section) along with their mechanical and physico-chemical characterization, the difficulty that facedus as it usually does with all researchers interested in lignocellulosic fibres has been represented by finding out a way of extracting the natural fibre from the plant (rachis and leaflets in our case) without damaging it. This is being performed, the diverse techniques used to characterize the extracted fibres are represented by the Scanning Electron Microscopy (SEM), the Infrared Fourier Transform (FTIR), the Thermal Gravimetric Spectroscopy (TGA), and the Differential Scanning Calorimetry (DSC). The results obtained were compared to those found in the literature.

Keywords: Phoenix Dactylifera–L., rachis and leaflets fibres, SEM, FTIR, TGA-DTG, DSC.

215 | Mechanical characterization of jute yarn and fabric fibres and bio-composites Jute/polyester

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Due to their interesting mechanical properties as well as their lightness and low production cost, composites reinforced with lignocellulosic fibres are of a particular interest for industrialists as well as for scientists who seek to integrate new ecological and biodegradable materials in order to substitute synthetic fibres, especially glass ones. The growing use of bio-composites in different areas such as automotive, woodworking, building and soon aeronautics for secondary structures raises the question of the reliability of the products that are made of. This reliability must be guaranteed during the design, by a good knowledge of the properties of the bio-composite materials and their constituents (i.e. reinforcement and matrix). In this context, this investigation focuses on the characterization of a laminate composite type with a polyester resin matrix reinforced with bi-directional fabric jute fibres with a surface density of 400 g/m2. Before developing composites, the constituents (resin, jute yarn and

fabric fibres) were characterized by tensile tests. The jute yarns fibre used were measured using an optical microscope and the mean diameter obtained varies between 600 and 1200 μm. The laminates composite plates are fabricated by moulding using the vacuum technique bag and then cut according to the ASTM D790-03. The specimens were dried in an oven and then tested under 3-point bending with three loading speeds: 2, 5 and 8 mm/min. The stress and strain at failure and Young's modulus values obtained from the tensile tests of the jute yarns and bidirectional fabric fibres as well as those of the bio-composite laminate tested in flexural are compared with the results reported in the literature.

Keywords: Lignocellulosic fibre, jute, polyester resin, tensile, 3-point bending.

125 | A constitutive relation of hierarchical fiber bundle materials

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Biological materials such as tendon and bone with collagen fibrils as main constituents are so organized in a hierarchical structure as to optimize their mechanical properties. In this paper, the influence of hierarchical structure on the mechanical properties of fiber bundle materials is studied through establishing a constitutive relation. Based on the Weibull distribution, the strength and standard deviation of single fiber is first obtained. Based on the Daniels fiber bundle model, given strain, the stress of the fiber bundle is derived by virtue of the ratio of intact fibers in terms of the Weibull distribution parameters, and then the constitutive relation is established for the fiber bundle material. Considering the relation of two neighboring hierarchical levels from the viewpoint of the Weibull distribution for a fiber and the Daniels theory for a fiber bundle, the constitutive relations are finally obtained for each hierarchical level by recursive Weibull distribution parameters. The constitutive relation is applied to the composite fiber bundle material composed of different type of carbon nanotube to evaluate the mechanical properties including stiffness, strength and toughness, and influences of hierarchical levels and modes are examined. The results show that, for one-type fibers, the stiffness of fiber bundle increases with the hierarchical level whereas the strength and the toughness decrease. However, for composite fibers, the situation is dependent on hierarchical case. So, the natural biomaterials are often composite while hierarchical.

Keywords: Hierarchical composite fiber bundle materials, Weibull distribution, Daniels theory, Constitutive relation, Mechanical property.
Acknowledgments: This work was supported by the National Natural Science Foundation of China (Grant Nos. 11672221, 11272245).

207 | Mechanical characterization of bio-composite laminates reinforced with date palm fibres under 3-point bending

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Natural fibres for composite reinforcements are low-cost, lightweight and biodegradable. They are available in fibrous form and come from renewable resources. In Algeria are currently present more than 18 million of date palm trees; this important natural resource gives the incentive to consider the use of products derived from date palm in bio-composites materials. Bio-composites reinforced with lignocellulosic fibres are of particular interest for many technological sectors like the medical, sports, automotive and green energy. Moreover, several industries are currently seeking to integrate new ecological and biodegradable materials. The present investigation is focused on the extraction and characterization of fibres from date palm fruit branches (FPD). In a typical date palm tree, it is possible to find five different fibres types based on their origin: the trunk, fibres surrounding the stems, fruit branches, leaflets and rachis. The fruit branches are either discarded or burnt annually after the maintenance phase of the tree or during the harvesting of the dates. Rather than disposing of the wood waste, it is conceivable to further develop ecological materials from this renewable source as reinforcement for structural bio-composites. The fruit branches contain between 500 and 700 elementary fibres with an average diameter varying between 330 and 560 μm and a length of 0.4 to 1.2 m. To show the morphology of the FPD structure, images were taken by electron scanning microscope (SEM). The fibres have been subjected to tensile loading, and the results obtained

show that the mechanical properties (tensile strength and Young's modulus) of the FPDs are comparable to those found in open literature for other lignocellulosicfibres. The fibres extracted from the fruit branches of the date palms are then used to manufacture bio-composites laminate plates with vacuum moulding (bag technique). Four configurations of bio-composites are made with parameters dictated by the number of plies and the direction of the orientation (unidirectional and cross ply). The specimens are tested under 3-point bending and the results obtained (stress and strain at breaking and the Young's modulus) are compared with the ones of bio-composites reinforced with other lignocellulosic fibres found in literature.

Keywords: Date palm fruit branches fibres, bio-composite, 3-point bending, static tensile loading.

208 | The effect of the gage length and diameter on the mechanical properties of a new lignocellulosic fibre (Juncus effusus L.)

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Natural fibres and especially lignocellulosic ones are beginning to have an extent in front of synthetic fibres and in particular glass ones, in many applications, such as automotive construction and packaging manufacture. They are renewable resources, naturally biodegradable and do not require much energy to be produced and have fairly good physical and mechanical properties and their price is relatively low. Several types of wild lignocellulosic fibres exist in nature, particularly in Algeria, and can be used as reinforcement in polymeric matrix composite materials and among these are those of Soft Rush or scientifically named as Juncus effusus L. (J.E). The Soft Rush is a plant species that is part of the Juncaceae family that grows in wet places such as (river, mountain, etc.) made up of hollow stems of cylindrical shape with diameters (4 to 8 mm) and a length up 1m. This study deals with the extraction and mechanical characterization under tensile loading of a new lignocellulosic fibre (J.E) in order to evaluate these mechanical properties according to its gage length (GL) and its diameter. The technical fibres were extracted by a traditional method which consists of boiling the stems of (J.E) in water for 3h. The extracted technical fibres may have a diameter variation along their entire length, however, their effective cross-section area has been determined using their average diameter, measured at nine different locations along the gage length (middle section and both ends), i.e. three measurements at each location. The fibre diameter was measured using an optical microscope (ZEISS) equipped with a Moticam 2500 digital control camera operated by Motic Images Plus V2.0 image processing software. The average fibre diameter of (J.E) is 280 μm. Tensile tests of five hundred randomly selected elemental technical fibres were carried out at an ambient temperature of 25 ° C and a humidity of 50% loaded up to failure with a constant speed of 1 mm/min over five gage lengths GL (10, 20, 30, 40 and 50 mm) i.e. one hundred tests per GL. The stress strain curves of (J.E) fibres exhibits a linear behaviour up to its ultimate stress where a sudden failure of the fibres occurring characterized by a rapid drops in the stress value. Due to the dispersion of the results obtained, which is indeed an inherent characteristic of lignocellulosic fibres, they have been analyzed using Weibull distribution laws with two and three parameters. The mechanical properties resulting from the experimental results, namely the ultimate stress and the strain and the Young's modulus of the JE fibres, have been the subject of this work. Analysis of the results obtained shows that the increase in the GL from 10 mm to 50 mm leads to a reduction of the ultimate stress and strain of the JE fibre by 23% (i.e. from 132 to 102 MPa) and 68% (i.e. from 8.55 to 2.71%) respectively, while Young's modulus increased by 60.5% (i.e. from 1.76 to 4.45 GPa). These variations are due to three factors: - parameters and test conditions - characteristics of the plant and, finally, surface determination. The morphology of the cross section of this new fibre has also been studied and analyzed by scanning electron microscopy.

Keywords: Lignocellulosic fibre, Juncus effusus L., tensile, Weibull distribution

150 | FE model to analyse impact on biodegradable composites including viscoplastic behavior

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During the last years, natural fibers have been introduced as reinforcements in order to develop biodegradable composites. These bio-composites can introduce advantages in terms of cost, weight and energy consumption, and

they can reduce the use of non-biodegradable materials and non-renewable resources. Composites based on natural fibers are characterized by viscoplastic behavior, in contrast to the linear-elastic up to failure behavior of traditional composites. This study presents a FEM model implemented in ABAQUS/Explicit software that predict the impact behavior of natural fibers based composites made of a combination of flax basket weave and 10361D poly-lactic acid thermoplastic resin. The non-linear mechanical behavior of the composite is defined as a function of strain-rate and a failure criterion based on maximum strains is included to delete damaged elements. The model analyzes the behavior of composite plates under low velocities impact using two different noses of 12 and 20 mm diameter at different impact energies. The maximum value of impact energy was below the penetration energy, so that all the specimen was damaged but not penetrated. This range of impact energies was selected because this is the critical impact condition in traditional composites, low-velocity impacts that produce a barely visible damage but leading to a significant reduction in residual strength. The numerical model is able to simulate the evolution of the impact force as well as the absorbed energy and the damaged area. Numerical model was validated by comparing the numerical results obtained with respect to experimental data in order to demonstrate the agreement between both. The development of numerical models for biodegradable materials can be a crucial factor for the increase of the usability of this kind of materials in different application areas, introducing all the possible advantages in terms of environmental impact, weight and cost.

109 | Hybrid short coir fibre reinforced composites containing portland cement particles

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The expanding use of lightweight components in automotive, aerospace, construction, sports and orthopaedic industries, has promoted significant advances in sustainable and renewable composites. A variety of natural fibres, including flax, hemp, jute, sisal, coir, piassava and others, has been used as reinforcing phase in polymeric composites. Natural fibres have attracted the interest of the research community due to their advantages over the synthetic ones such as low cost, low density, availability, biodegradability, recyclability, easy processing and moderate mechanical performance. Among natural fibres, coir is widely used to produce floor furnishing materials, yarn and rope because of its low cost, durability, versatility and abundance. The fibre is extracted from the coconut husk (Cocos nucifera), extensively cultivated in tropical regions such as Brazil, India, Sri Lanka and Southeast Asia. The annual world production of coconut is around 55 billion and just a small fraction of the fibres is recovered for use, while most of the husks are discarded, causing an environmental pollution. The use of coir fibres in composite materials can provide relevant characteristics, such as resilience, high elongation at break, weather, fungal and bacterial resistance besides a considerable toughness. In contrast, the main limitation of natural fibre reinforcements is the incompatibility between the hydrophilic nature of fibre and hydrophobic nature of polymeric matrices. In order to overcome this problem, alkaline treatment can be considered an economical technique to enhance bonding between fibre and matrix phase. The incorporation of rigid micro or nano-sized fillers has been used to enhance the composite stiffness, acting as a barrier for crack propagation. Additional effort is required when the crack propagates through the fibre-particle and particle-matrix interface, reducing its velocity and increasing the mechanical strength of the composite material. Characteristics such as, size, shape, amount and packing of the particles can directly affect the mechanical behaviour of hybrid composites. This work investigated hybrid short coir fibre reinforced composites (SCoirFRCs) containing Portland cement particles. A full factorial design (2231) was conducted to investigate the effect of the coir fibre alkali treatment (in pristine and treated conditions), cement particle inclusions (0, 5 and 10 wt%) and compaction (490 and 654 kPa) on the apparent density, apparent porosity, water absorption, impact resistance and mechanical strength/modulus under tensile and flexural loadings. The alkali treatment contributed not only to reduce the apparent porosity and water absorption, but also to increase the mechanical properties of SCoirFRCs. This behaviour was attributed to the higher adhesion at the interface due to the fibre treatment. In contrast, a strong interface led to reduced impact resistance through a fibre pull-out mechanism. The compaction factor significantly affected all physical properties of SCoirFRCs. In general, a high pressure level at 654 kPa enhanced the wettability of the fibres and, consequently, the mechanical performance of the composites. The cement inclusion did not provide considerable changes as a secondary reinforcement phase, decreasing the mechanical strength of the composites except for the flexural modulus, which can be attributed to the positive effect under compressive loadings. Enhanced mechanical and physical properties cannot be achieved simultaneously. In this case, the composite must be designed for a specific set of properties.

Nevertheless, the SCoirFRCs can be considered an economical and sustainable alternative for the future of secondary structural parts in the engineering field.

29 | Evaluation of jute based composites with infrared thermography

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The growing environmental awareness is driving attention towards the development of ever more ecological and friendly materials, demanding for the use of natural matrix and fibres in composite materials. In this context, the first step was to replace synthetic fibres with natural ones with jute the preferred candidate thanks to its low cost. Till now, jute has been embedded mostly in a polypropylene (PP) resins but, with the aim to develop new all-natural materials, a potential alternative is represented by the polylactic acid (PLA). Indeed, PLA/Jute materials are renewable and well comply with ecological requirements; but, they have till now received scarce attention and their characteristics are still not completely understood. The question which may arise is whether PLA may be the best solution for every application, or the partially natural PP/Jute has to be preferred. Of course, understanding the material characteristics and performance is important in view of a proper choice of the matrix and of the applications use. Infrared thermography (IRT) represents a viable means since it is non-contact, non-intrusive and can be used to monitor the entire existence of a product, from its manufacturing process to completion as well as in-service life. In this work, IRT is used to help investigate the performance of PLA against PP. Then, two types of tests are carried out: bending and impact tests. An infrared imaging device is used to monitor both tests. In particular, the visualization of thermal effects coupled with mechanical deformation allows to get information useful to understand more about the materials strength and performance.

AUXETIC MATERIALS AND STRUCTURES

445 | Auxetic sandwich panels: Meta-modelling and optimisation for protection against blast loadings

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Today there is a growing interest for novel and smart structures for energy absorption applications. In particular, complex challenges arise in the development of structures, which are lightweight and, at the same time, able to deflect both blast and localised impact. In this work, we address this problem and propose the use of auxetic sandwich panels. Auxetic structures present interesting properties, such as self-densifying and self-adapting mechanisms to different loads, which determine enhancement of various properties, such as fracture toughness and indentation resistance under quasi-static and dynamic loads. In this paper, the mechanical behaviour and energy absorption mechanisms of auxetic panels under extreme loadings are examined. Experimental and numerical activities have been conducted to evaluate these structures. Validated numerical models have been used to conduct a multi-objective optimisation adopting meta-modelling techniques. A Latin Hypercube Sampling has been adopted to create a design of experiment of the different geometrical parameters. The obtained results have been used to develop a meta-model, based on a Radial Basis Function (RBF). The use of RBF allowed to approximate better highly non-linear phenomenona, such as blast and dynamic compression. The developed RBF meta-model has been optimised using a genetic algorithm. The optimisation has been conducted evaluating the transmitted reaction forces and the absorbed energies. This study suggested the importance of the self-adapting mechanism, the material densification and the redistribution of the load on larger back-surfaces for auxetic structures under extreme loadings.

154 | Mathematical models of viscoelastic auxetics

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Nowadays material engineers are looking for the methods rising operating characteristics of traditional materials via creating the structures possessing essential abnormal deformational features. Materials with negative Poisson's ratios which are capable to extend (contract) in the direction perpendicular to the direction of their extension (contraction) belong to such abnormal materials and they are called 'auxetics'. There are a lot of papers devoted to auxetic materials, however, the majority of them are dealing with the internal structure of auxetics, experimental determination of Poisson's ratios, as well as with the description of features of different auxetics. The papers discussing the mathematical models describing the behavior of viscoelastic auxetics are rare, and there are no studies devoted to the solution of boundary-value dynamic problems with such materials. Two viscoelastic models are studied for the cases when the shear and bulk operators are set in terms of the simplest fractional derivative Kelvin-Voigt and Maxwell models. Using the algebra of dimensionless Rabotnov fractional operators it is shown that materials described by such models are viscoelastic auxetics, because Poisson's ratios of such materials are time-dependent operators which could take on both positive and negative magnitudes. It has been found that if the shear and bulk operators of the material are governed by the fractional derivative Kelvin-Voigt model, then such a material, being at the initial moment the auxetic, loses with time its auxetic properties and becomes the ordinary material with a positive Poisson's ratio. But when the shear and bulk operators of the material are determined by the fractional derivative Maxwell model, then at the initial moment such a material possesses the positive magnitude of the Poisson's ratio, and with time it loses conventional properties and become an auxetic material with the negative magnitudes of the Poisson's ratio.

Acknowledgements: This research has been supported by the Ministry of Education and Science of the Russian Federation.

BIO-INSPIRED DESIGN OF COMPOSITES

475 | Response of bioinspired composite structures under high velocity localised impact

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Nacreous seashells have evolved high energy absorbing armour systems over many years to protect their soft tissues from extreme loads arising from their environment, which are highly localised. The nacreous structure is analogous to a masonry wall, but exhibits a tremendous amount of toughness compared to its main brittle constituent (95% vol. calcium carbonate based ceramic) through highly effective crack mitigation and arrest mechanisms. The damage to critical structural elements and armour over the past decade due to high velocity localised impacts is profound. This preliminary research investigates the performance of a nacre-mimetic concrete panel under high velocity impact and compares this with its monolithic counterpart using a coupled Eulerian-Lagrangian (CEL) numerical approach. The projectile is modelled using a Lagrangian displacement-pressure formulation, with the Mie-Gruneisen equation of state (EOS) and a Johnson-Cook rate/temperature dependent constitutive law is employed as the strength model. The Jones-Wilkins-Lee (JWL) EOS for high explosives is used to model the driver pressure for launching the projectile. The nacre panel, which is built from brittle polygonal concrete bricks bonded by an elastomeric adhesive mortar, is simulated using a brittle damage model for the bricks and a cohesive traction-separation law to account for damage in the mortar. Preliminary results show that the nacre-like panel has significant potential in resisting high velocity localised impact loads through effective damage mitigation mechanisms.

460 | Comparison of micro/ nano- size ceramic reinforced 2D and 3D biopolymer scaffolds on the stem cells

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The tissue engineering scaffolds are a widely developed direction of the regenerative medicine that covers in vivo cultivation of stem cells, fabrication and restoration of damaged or lost tissue, control and testing systems, cell

biological studies and synthesis of new pharmaceutical products. The scaffold could be not only ensure a support function, but also determine the direction of the stem cells growth into the extracellular matrix. And the matrix structure strength, composition and dimensional effects will promote the artificial differentiation of cells and tissue regeneration. The vital current need for the regenerative surgery is the substitution of the cast implant materials with porous 2D (bio- membranes) and 3D matrix or scaffolds for living tissue. It is generally known, that the topography and dimensionality of a surface, has an impact on the morphological behavior of cells, while the stem cell proliferation is influenced by a synergistic effect of the micron and nano- scale topography. The advantage of the powder bed fusion technique as composite manufacturing technology, consists in the opportunities it provides to fabricate 2D and 3D objects additively, on a layer-by-layer basis, directly from a computer-aid designed model of the real organ, with no need in specialized moulds, dies or other tooling. The laser assisted sintering/melting able to rapidly and reproducibly synthesize highly complex three-dimensional data (mCT or MRS) for each patient and internal structural features as well. A controllable internal structure strength and dimensionality of the interconnected porous channels allows providing of a framework for the bone that ensures its growing into the matrix of the material, thus increasing the interfacial area between the scaffold and the tissue and thereby reducing the shift of the implant in the tissue. Some suitable porous channels must also be available for the blood or drug supply aimed to reach the connective ingrown tissue thereby preventing necrosis of the penetrating cells. The implant testing on cellular cultures is widespread as the first stage of biological testing for biocompatibility and toxicity of implants. Pluripotent mesenchymal stromal stem cells (MSSC) are the most promising autologous material for the cell therapy and tissue engineering, since they can be found practically inside any conjunctive tissue. The MSSC usage allows on the cell level to show the scaffold material properties, for instance its influence on the connective tissue cells. The opportunity emerges to study biological properties of scaffolds, such as a differentiation induction, stimulation and suppression of proliferation, their migration ability and mutagenic and toxic effects. The present study purpose was to compare the micro- and nano- size ceramic reinforced 2D and 3D biopolymer scaffolds on the stem cells viability, proliferative activity and phenotypic changes during the testing. We used the biocompatible and bioresorbable polymers (polyetheretherketone and polycaprolactone) and determined the optimal regimes of the powder bed laser sintering/melting. The powders of biocompatible micro- and nano- size reinforced oxide ceramics - TiO2, Al2O3, ZrO2, and hydroxyapatite were carried out as a basis of the additives.

142 | Measurement of strain and stress in the composite atherosclerotic plaque model

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Atherosclerotic plaque is composed of various tissues such as fibrous tissue, lipid, thrombus, and calcium deposit. Cellular elements experience mechanical stresses by the blood flow and arterial pressure, and cellular function is affected by physical stimuli. In order to study mechano-transduction pathway of cellular elements, complete information of the mechanical strain and stress acting on the tissues is important. Because in vivo characterization of mechanical parameters on a plaque wall is difficult, an atherosclerotic plaque model was developed using composite polymers, and strain and stress fields were estimated. PDMS (polydimethylsiloxane) rubber was used to model the composite atherosclerotic plaque model, because biological tissues and PDMS showed similar viscoelastic response for lower speed strain. PDMS rubbers with different elasticity were used to model the fibrous tissues and lipid pool, and the stiffness of PDMS was controlled by varying mixing ratio of a curing agent. Wall strain and shear stress under pulsatile flow were measured using a digital image correlation method. Wall strain measurement using a particle image correlation method agreed well with computational results based on the finite element method. Wall shear stress measured using the particle image correlation also agreed well with that calculated from computational fluid dynamics. Therefore, the stress and strain fields in a composite plaque model, which was designed to simulate physiological environment of arterial wall tissues, could be successfully measured using a particle image correlation method.

257 | Bioceramics with 3D Nanochannel Networks and capable of Self-Powered Fluidic Transport, Cooling, and Lubrication

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We designed and fabricated hierarchically organized channels with tapered cross-sections inside a bioceramic, inspired by composites in living organisms. A new sintering process with a pressure gradient was developed to enable the fabrication. The resultant composite showed a mechanical strength similar to that of human bone and

an ability to self-power the transport of fluids and nutrients and self-cool or self-lubricate. Notably, by tracing transport of radioactive fludeoxyglucose (18F-FDG), we directly demonstrated sustained cellular growth by self-powered uptake of nutrient via the nano-channels, replicating the function of nano-channels found in natural systems. The capability of self-lubrication and self-cooling extend the application of such a ceramic composite to mechanical rotors and bearings etc. It is known that ceramics can come with a modulus of elasticity higher than that of high carbon chrome bearing steel. As such, ceramic axes and ball-bearings would exhibit less deformation at contact points and therefore a greater stress under the same load. Combined with a lower thermal conductivity, their working temperature increases and their load capacity decreases more rapidly in operation. In nature, however, a ceramic composite system, e.g. bone joint, is known for its superior load-bearing capacity, and its self-protection at the high-stress moving-contact points. It does so with self-lubrication, through a built-in capillary network for self-powered supply of lubricants and coolants, as well as nutrient and growth factor. This inspired our efforts and led to the designs and demonstrations of multifunctional ceramic composites reported here. As a further extension, a self-regulation mechanism can be added into the design to enable temperature-activation of self-powered lubrication. A first design of this mechanism was tested in a model system, and is adaptable to various structural shapes, scalable in size, and applicable to both bio-physiologic and mechanic composite systems.

19 | Fabrication of bio-nanosilica, quartz and epoxidized plant oil based hybrid nanocomposite and their mechanical characteristics

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In this work, the hybrid bionanocomposites were fabricated from bionanosilica, quartz and epoxidized soybean oil. The nanosilica which were extracted from both rice husk and corn cob by thermal method have dimension in range 40-70 nm and in amorphorous state. Beside it, the epoxidized soybean oil was synthesized from soybean oil by using mixture of H2O2 in CH3COOH. Nanosilica and quartz were well dispersed in epoxidized soybean oil by using high speed mechanical stirrer and cross-linked with different of curing agent such as hexahydro-4-methylphthalic anhydride (MHHPA) and anhydrite phtalic at difference of temperature. The mechanical characteristics of hybrid nanocomposites were done by using different methods such as: tensile testing, flexural testing, impact testing as well as fracture toughness. The thermal properties and broken surface of hybrid nanocomposites were characterated with the help of thermogravimetric analysis (TGA), Dynamic-Mechanical Thermal Analysis (DMTA) and SEM image. The results showed that the tensile strength, flexural strength, impact strength as well as fracture toughness increased with content of nanosilica and reached the optimum at 0.2 phr of silica and 20 phr of quartz. The Tg of nanocomposites trend to higher corresponding of increasing content of nano silica particles. The nanocomposites also were coloured with different kind of orgarnic colour compound for artificial marble application.

66 | Optimum Design of Composite Slabs Using Brain Storming Optimization Algorithm

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In this study, new optimization program is developed to investigate the optimum design of steel-composite slab structures. An objective of an optimization problem is to minimize the cost of the composite slabs. Number of girder (secondary beams), type of steel profile used for the girder and main (primary) beam, outer and inner distances between shear studs for girder and primary beam, types of shear studs (diameter and class), type of sheet profile and height of concrete are treated as design variables in the optimization problem. 18 IPE sections from IPE80 to IPE600, six different types of shear studs (M19-100, M19-125, M19-150, M22-100, M19-125, M19-150), three different types of sheet profile (58/207, 30/190 and 27/200) are considered in the design of the composite slab. Design limitation functions of the optimization problem are formulated according to Eurocode 2, Eurocode 3 and Eurocode 4 design codes. In accordance with these codes, composite slabs should satisfy moment resistance (both for construction and final stages), shear resistance and serviceability limitations. Brain storming optimization algorithm is utilized in order to find optimum solution of the optimization problem. The brain storming optimization algorithm is a recent bio-inspired based optimization technique developed via using the simulation brain storming activity of a group of people in order to generate great ideas for the solution of their problem. In the algorithm, people with different knowledge background gather and generate a group. In the group,

people generate different ideas resulting in an idea database. The ideas are evaluated according to their greatness and clustered in subgroups. Subsequently, new ideas are generated using the idea database and the knowledge background. These procedures continue until the satisfactory great ideas are found. For the optimum design of composite slabs, the idea represents the slab design, the greatness of the idea represents the fitness value of the slab which is equal to multiplicative inverse of the objective function value. Three real-size design examples are solved by the developed program. The first two examples are taken from the literature study which is previously optimized using genetic and harmony search algorithms according to LRFD-AISC design code. The last example is taken from an applied project. Obtained results from the developed program are compared to results of the literature study and the project. As a result of the comparison, the brain storming optimization algorithm and the developed program have performed well for the presented optimization problem.

67 | Optimum design of a space frame structure with concrete filled steel tube composite columns using social spider optimization

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In this study, an algorithm is developed for the optimum design of a space frame structure having concrete filled steel tube composite columns. Optimization problem is defined as the selection of steel sections for beam members from steel section tables and cross sectional dimensions (depth, width and thickness of steel) of the composite columns available in standards. The selection should satisfy serviceability, strength and geometric limitations specified by the code of practice as well. The objective function of the optimization problem is defined as minimizing a material cost of the structure. The strength limitation functions of the structure are implemented from the AISC 360-10 design code. The serviceability limitations are formulated according to Ad Hoc Committee report. The beam members of the frame structure are selected from the set of 272 W-sections from W100 × 19.3 to W1100 × 499 mm as given in LRFD-AISC. Social spider optimization algorithm is utilized in order to find optimum solution of the optimization problem. The social spider optimization algorithm, one of the newest swarm intelligence based meta-heuristic optimization algorithm, is developed in 2013. This algorithm mimics the natural behaviors of the spider colony which are the cooperative movement towards the food source position and mating. The algorithm performs these behaviors according to genders, positions and weights of the spiders. In the algorithm, each structure design is represented by one spider. The weight of the spider represents the fitness value of the structure which is equal to multiplicative inverse of the objective function value. The spider position represents values of design variables for the structure design. Two real-size frame structures are optimized in the present study. The first structure is selected from the literature which is modelled and optimized by considering all the members as steel. The second structure is considered as a high rise building. This example is also optimized by considering all the members as steel. According to results, designing space frame structure with concrete filled steel tube composite columns provides material cost advantage with regards to steel structure. In addition, the social spider algorithm has satisfactory performance for the presented optimization problem.

BUCKLING AND POSTBUCKLING OF COMPOSITE STRUCTURES

388 | Geometric nonlinear analysis of relatively thick composite plates containing circular/elliptical holes using Ritz method

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Plates and plate structures are increasingly used as structural components in various branches of engineering such as aerospace and marine engineering. These components are usually employed in situations where they are subjected to in-plane compressive loading. Therefore, it is important to accurately predict the buckling and post-buckling behavior of such structures. It is well known that plates may sustain additional loads even after buckling takes place and hence the post-buckling behavior of such plates has been of considerable research interest. The objective of such studies is to fully utilize the stability of the plate. In such studies, the critical value of load given by linear buckling analysis may not accurately represent the carrying capability of a plate. Due to the weight optimization and practical concern, the need of holes in such structures is typically required. For instance, cutouts or holes in wing spar and cover panels are needed to access to hydraulic system and maintainability. Also the wing ribs are lightened by holes. In such cases, the presence of these holes redistributes the membrane stresses in the plates and may reduce their stability significantly. Therefore, in this paper the post-buckling analyses of laminated plates are investigated. The plates modeled here are rectangular shaped with circular/elliptical holes and

the out-of-plane boundary conditions are selected as simply supported on all edges. All edges of the plates are kept straight for in-plane movement and the plates are subjected to uniform end compression. This is achieved by restraining the one edge and applying a mean compressive loading in the opposite edge. In this regard, the displacement fields are selected to satisfy the boundary conditions and the principle of minimum potential energy is applied to obtain a nonlinear equilibrium equations system. Thus, the Ritz method is applied in this paper. It is also noted that the Legendre polynomials are used as basis functions for displacement fields and First-order Shear Deformation plate Theory (FSDT) is used wherein a basic assumption is that lines through the thickness which are initially straight and normal to the flat middle surface remain straight during deformation, but are not constrained to remain normal to the deformed middle surface. This type of theory was introduced by Reissner [1] and Mindlin [2] for homogeneous plates and later extended to embrace heterogeneous laminated plates by Yang et al [3]. The potential energy form obtained by above assumptions can be written as quadratic, cubic and quartic energy terms and the related integrals are taken using a standard numerical procedure such as Gauss method [4]. As mentioned above, the final system of nonlinear equations is obtained by partial differentiation of the plate potential energy with respect to each unknown parameter in the displacement fields. These equations can be solved using an iterative procedure and here it is the Newton-Raphson procedure. Several key findings and behavioral characteristics are discussed. These findings include the effects of cutout size, shape and location. It is seen that, the stiffness of the prebuckling of the plate with cutout to the prebuckling of the perfect plate has a considerable reduction by increasing of the cutout size, and similarly the stiffness of the postbuckling of the plate with cutout to the postbuckling of the perfect plate have a noticeable decrease.

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318 | Imperfection sensitive analysis of variable angle tow curved panels

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An Imperfection Sensitivity Analysis (ISA) of Variable Angle Tow (VAT) curved panels subject to different load/boundary conditions is presented. The ISA described in [1] is performed using a fast-running software that employs a Koiter asymptotic approach in FEM context [2] and a Monte Carlo simulation to test a large number geometrical imperfections. The finite element implementation of Koiter's asymptotic approach allows the pre-critical and post-critical behavior of slender elastic structures to be evaluated in a computationally efficient manner. Its implementation uses a fourth-order expansion of the strain energy, and requires both the structural modeling and finite element discretization procedures to be geometrically coherent. The corotational approach [3] adopted in the MISS-4 finite element [4] fulfills this requirement by starting from a linear finite element discretization. Numerical results, compared with those obtained by Riks analysis using the finite element implemented in Abaqus [5] and DQM approach [6], show good accuracy. Finally, for each investigated panel, the worst cases, in terms of load carrying capacity, are detected among the thousands imperfection considered during the analysis.

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172 | The influence of fibre orientations on thermo-mechanical buckling of multilayered plates – curved fibre format

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A semi-analytical method is developed for pre-buckling and buckling analyses of thin, symmetrically laminated composite panels under general thermo-mechanical loading conditions. Both the pre-buckling and buckling analyses are based on the principle of stationary potential energy. Thermal and mechanical buckling analysis of rectangular composite laminates with constant or variable stiffness properties is presented. The buckling analysis is conducted with the use of the Rayleigh quotient and symbolic computations (Mathematica). Various laminate stacking sequences are studied, i.e.: angle-ply, discrete (cross-ply and having the orientations 0/±45/90) and curved fibre orientations with general nonlinear fiber path functions. A multiobjective optimization problem is presented to determine the optimal layer thickness and optimal fibre orientations for the analysed laminate stacking sequences subjected to thermo-mechanical loadings. The optimization procedure aims to maximize the critical combination of the applied edges load and temperature levels and to minimize the laminate dynamic response subject to constraints on the thickness and control energy. The objective of the optimization problem is formulated based on a consistent Love-Kirchhoff deformation theory without.

164 | Experimental verification of numerical studies on the postbuckling behavior of the thin-walled columns with Z-sections made of a general laminate using Aramis system

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The experimental studies on the thin-walled structure made of a general laminate were conducted using ARAMIS Digital Image Correlation (DIC) system. The static compression test was performed. The samples were simple supported. The specimens were manufactured from a carbon-epoxy unidirectional prepreg tape in an autoclaving procedure. The initial imperfections were small, but nonzero. The walls of specimen were plane and perpendicular to each other. The rounding of the corners were small. They were cut to a definite dimension using laboratory circular saw. The ARAMIS system collected all displacements of selected walls of the structures during the compression. Using the data from an universal testing machine, it was possible to determine the buckling loads and postbuckling equilibrium paths. The following experimental methods of determining the buckling loads were employed: the Koiter's method, the curve inflection point method, the load vs. square deflection method. Finally, numerical calculations using finite element method and one-mode approach based on the Koiter's asymptotic method were performed. The first order approximation of the Koiter's method allows to solve eigenvalue problem. The second order approximation describes the postbuckling equilibrium behaviour of the thin-walled column. In the finite element analyses, the Lanczos method was used to solve the linear problem of buckling. The simulations of non-linear problem were performed using the Newton–Raphson method. This paper was financially supported by the Ministerial Research Project No. DEC-2013/11/B/ST8/04358 financed by the Polish National Science Centre. The general laminate has many layers and the arrangements of layers are non-symmetric. The main disadvantage of a general laminate is that mechanical couplings effect occurs. In this case, the different types of coupling between the extension/compression, shearing, bending and twisting can take place. The constitutive equation includes a stiffness matrix, which defines the relationship between section forces/moments and deformations/curvature. The stiffness matrix can be divided into three submatrices: extensional (denoted as A), coupling (denoted as B) and bending (denoted as D). The elements of the A-submatrix denoted as A16 and A26 describe the in-plane coupling effects. In this case, the interaction between shearing and extension or compression takes place. Whereas, the elements of the D-submatrix denoted as D16 and D26 describe the out-plane coupling effects. The interaction among bending and twisting can be observed. If elements of the B-submatrix are nonzero, the in-plane and out-plane coupling effects can be noticed. There are many combinations of a interaction. Detailed calculations were performed for the short columns with Z-sections made of the general laminates subjected to shortening. The classical lamination theory (CLT) was applied to determine the value of the stiffness matrix. Three different arrangements of the laminate layers were used. A laminate with shear-extension coupling, a laminate with twisting-bending coupling, a laminate with shear-extension and twisting-bending coupling were considered. Only, the twisting-bending coupling effect had a significant influence on the buckling behaviour of the compressed structures.

8 | Analytical and finite element buckling solutions of simply supported anisotropic laminated composite wide plates under axial compression

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Limited number of research has addressed the topic of buckling of anisotropic laminated composites, if any. A generalized analytical buckling formula for simply supported anisotropic thin plates under axial compression is developed herein using Rayleigh-Ritz approximation. Following the generalized constitutive relationship, the effective axial, coupling, and flexural stiffness coefficients of the anisotropic layup is determined using dimensional reduction by static condensation of 6x6 stiffness matrix. The resulting explicit formula has an additional term which is a function of the effective coupling and axial stiffness. For isotropic and certain classes of laminated composite, the analytical buckling formula reduces down to isotropic buckling formula once the effective coupling stiffness term vanishes. The analytical results are verified against finite element Eigen value solutions for a wide range of anisotropic laminated layups yielding high accuracy. A brief parametric study is then conducted to examine the effect of ply orientations and material properties including hybrid carbon/glass fiber composites. Relevance of the numerical and analytical results is discussed for all these cases.

COMPOSITE STRUCTURES

477 | Collapse mechanism under in/out-plane loadings of calcareous masonry panel retrofitted with FRP

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An experimental study of the mechanical behaviour of calcareous brick masonry elements under in and out plane increasing loads is presented in this paper. The study is mainly oriented to the identification of the elementary mechanisms involved in the response of masonry elements retrofitted with carbon fibre reinforced polymers (CFRP) under 1- vertical load normal and parallel to bed joint compression 2- diagonal compression 3- out-plane load and constant vertical load applied normal and parallel to the bed joints Masonry specimens are reinforced or repaired with a grid of C- FRP. For comparison, some of the specimens were tested up to failure without reinforcement, others were reinforced with CFRP. The retrofitted panels exhibited and enhancement of the collapse load up to 10-20% in respect to the URM panel in terms of bearing capacity under vertical loads as well as of the axial deformation capability. The stiffness longitudinal modulus slightly increases because of the buckling of the vertical strips otherwise the transversal stiffness modulus greatly increases due to the effectiveness of the to the horizontal strips. At failure, the retrofitted panels have shown similar pattern regardless by the in plane loading direction. Stretching of the horizontal strips increased the tendency for web splitting of the masonry; at failure wide cracks ran in a stepped pattern through the wall thickness, however, the integrity of the walls at ultimate stage was ensured by the FRP reinforcement. In the case of out-plane load the CFRP reinforcement causes an increase of both the elastic limit and of the ultimate load up to 7 times. Besides, the final deflection is deeply smaller.

228 | Dynamic stiffness formulation for free vibration of composite joined cylindrical-conical shells containing fluid

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A dynamic stiffness or continuous element (CE) formulation has been presented in this paper for the vibration analysis of cross-ply composite joined cylindrical-conical shells containing fluid. The dynamic stiffness matrix has been built from which natural frequencies have been calculated. A matlab program is written using the CE formulation in order to validate our model. Numerical results on natural frequencies are validated with the available results in other investigations. To compare with the theoretical solutions, detailed experimental results have been obtained for the free vibration of a clamped-free cylindrical-conical shells partially filled with water by using a multi-vibration measuring machine (DEWEBOOK-DASYLab 5.61.10). Two different types of glass fiber/polyester composite cylindrical-conical shells with the radius of the larger end 285mm, thickness 2mm, and the cone lengths along the generators are 285 mm and 427.5 mm with the semi-vertex angles 27 degrees and 14 degrees respectively were in investigation, and the filling ratio of the contained water was 0, 0.25, 0.50, 0.75 and 1.0. The results calculated by proposed computational model for studied composite cylindrical-conical shells are

in good agreement with experiments. The effects of density of the shell materials and fluids density on the natural frequencies and circumferential wave number of joined composite cylindrical-conical shells are also numerically studied.

459 | A numerical study of the impact behaviour of a sandwich panel with a natural fibres honeycomb core

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The adoption of natural fibres as low-cost fillers in the plastic industry has been assessed for long time. Nowadays, they are starting to replace glass fibres in composite materials thanks to their advantages in terms of weight, cost, and environmental (biodegradability) behaviour. Among the others, an application of natural fibre composites is their use in the manufacturing of honeycomb cores for sandwich panels. This can lead to an improvement in terms of weight saving. Moreover, mechanical properties and functional capabilities, such as vibration control, heat and energy dissipation, can be improved as well. In this work, a numerical model, able to predict the behaviour of a sandwich panel with a natural fibres honeycomb core, has been assessed. An explicit impact analysis has been conducted. The results, in terms of fibre breaking and matrix cracking, have been carried out. Moreover, the study of the inter-laminar damage behaviour is allowed by the introduction of a cohesive zone model between the elements of the honeycomb core. The model has been validated by means of a numerical-experimental correlation. In particular, the peak force and the maximum displacement obtained by the numerical analyses have been compared to the experimental ones. The results have demonstrated the validity and the robustness of the numerical model.

471 | Bird-strike simulation on a composite wing section

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Bird strike represents a source of major risk for aircraft structures. Indeed, an impact with a bird during cruise or during take-off and landing phases can lead to serious structural damages threatening passenger safety. Currently, certification tests are required to demonstrate that the airplane can safely operate after a bird strike event. For this reason, the need of accurate numerical models able to predict the structural response under a bird strike event can be of significant help in order to reduce the certification time and costs. In this paper, numerical simulations of a bird impact event on the leading edge of a composite wing section are presented. An approach based on Coupled Eulerian-Lagrangian (CEL) formulation has been adopted and, considering the high velocities of interest, the bird has been modelled as a soft body acting as a fluid on the target structure. The aim of this work is to assess the influence of the adopted numerical model in terms of finite element formulation and failure criteria on the bird-strike phenomenon including impact induced damage onset and evolution. The FE software ABAQUS/Explicit have been used to perform two different numerical simulations with different FE formulations. In the frame of the first simulation, the composite laminates have been simulated by using continuum shell elements and ABAQUS standard composite damage initiation and evolution criteria. In the frame of the second simulation, solid elements (C3D8R) have been adopted in conjunction with a user-defined material subroutine (VUMAT) based on Hashin and Puck damage criteria. The results obtained by means of the two proposed formulations have been compared in terms of damage extension in order to assess the robustness of numerical bird strike simulations and, hence, the dependence of the numerical outputs from the adopted FE formulation.

263 | Self-reinforced thermoplastic polypropylene composite face sheets/EPP foam core sandwich panels for vehicle light-weighting

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The weight reduction studies have a huge precaution to decrease vehicles' CO2 emissions and increase range on electric vehicles. For this reason, Thermoplastic Sandwich Composites, which have high specific strength and high rigidity as well as low cost and recyclability properties, continue to gain increasing attention, especially in the automotive, marine and aviation industries. In addition to the properties mentioned, corrosion resistance and high toughness properties make them an ideal material for use in exterior panels in the automotive industry. In the presented study, the sandwich structures were produced by using Polypropylene (PP) based self-reinforced thermoplastic composite face sheets and Expanded PP foam cores. The self-reinforced PP composite materials are one step ahead with low cost and easy formability. The expanded PP foams have low velocity and high strength. Also, they can join easier than the other polymer foams with Self PP composite face sheets. The material properties of the sandwich structures' each component was experimentally examined. The structural behaviors of the developed ALL-PP sandwich panels were determined experimentally and also studied by Finite Element Analysis. The sandwich assemblies produced using two different hot-melt adhesive materials have been comparatively examined. It has found that produced ALL-PP sandwich composites are an ideal structure for utilization in the automotive industry with significant weight reduction.

463 | Natural-based polyurethanes reinforced with agroindustrial wastes

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In this work six samples of composites were synthesized using two types of polyurethanes with reinforcements of oil palm and coconut fiber in different concentrations. One type of polyurethane was synthesized using a commercial polyol, and the other was synthesized using a polyol obtained from natural sources. The composites were prepared with three variations of the fiber: loose fibers, nonwoven pieces and complete nonwoven matrix, each corresponding to 50% by weight of the polyol. Furthermore, the fibers were pretreated with sodium hydroxide (NaOH) solutions at concentrations of 10, 15, 20, 25 and 30%. The objective of synthesizing polyurethane composites using a commercial polyol was to be able to have a reference value to compare and evaluate the performance of polyurethanes from natural sources. A polyurethane from natural sources without any reinforcement was also synthesized to compare if there was an improvement in the properties of the polymer when the fibers were added. The mechanical properties of the composite were measured and evaluated by tensile, compression and shear tests.

433 | Developing of an axial stress-strain model of square concrete columns confined with lateral steel and FRP

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Due to its efficiency, Fiber Reinforced Polymers (FRP) jacketing has become a common practice for confining concrete columns that need increased axial strength or shear capacities. The presence of confining lateral steel in columns, when externally retrofitted with FRP, changes the mechanism of concrete behavior. The interaction between lateral and longitudinal steel and FRP jacketing redistributes stress concentrations in concrete and yields more complex effective confined area compared to that of plain concrete confined with either FRP or lateral steel. Square columns confined with lateral steel and FRP are not well-addressed in the literature compared to circular columns. Therefore, this research focuses on square columns confined with lateral steel and FRP sheets through reviewing existing models in the literature and benchmarking their performance against experimental cases of square columns using axial stress-strain diagrams. Moreover, statistical analysis conducted for theoretical peak strength and ultimate strain obtained from the available models evidenced their comparative performance which can be further improved. Therefore, this paper proposes a new model that overcomes shortcomings found in the reviewed models and predicts peak strength and ultimate strain more precisely.

293 | Size effects in nano-beams: An innovative nonlocal approach

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Carbon nanotubes and graphene sheets are structures at nano-scale of wide interest in the current literature, due to the prominent applicative potentialities in Nanotechnology [1]. Size-effects are usually assessed by making recourse to theoretical and computational methods of Continuum Mechanics. The basic point of this approach consists in defining suitable constitutive laws which lead to reliable results. Nonlocal strain-driven elastic theory proposed by C. Eringen [3] is certainly the most commonly adopted strategy to investigate bending, buckling and vibration of nano-structures [4]. Notwithstanding this, for all structures of applicative interest, such a model is in contrast with equilibrium equations. Applicability of Eringen theory to nano-bars and nano-beams is discussed in the recent papers [5-7]. These difficulties can be overcome by adopting the new nonlocal stress-driven integral theory proposed in [8]. Such a methodology is exploited in the present paper in order to investigate size-dependent behavior of functionally graded Bernoulli-Euler nano-beams. Effectiveness of the proposed nonlocal approach is shown by examining simple case studies for NEMS applications.

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290 | Study on the carbon fiber reinforced phenolic composite material stitched with PTFE fibers in thickness direction for journal bearing applications

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Carbon fiber reinforced phenolic (CF/phenolic) composites have been mainly investigated for bearing materials because the phenolic resin operates satisfactorily with steel and bronze rotors with lubricants such as oil, water or other lubricant liquids due to its high thermal stability and chemical resistance. CF/phenolic composites, however, have low interlaminar shear strength due to high void volume content and low mechanical properties of the phenolic resin. The brittleness of the resin can cause the abrupt crack propagation of the composite and generate sharp wear debris which can accelerate the wear volume of the composite at the friction surface. According to previous our studies, a main cause of the CF/phnolic composite journal bearing failure was the delamination occurred by frictional torque transmitted from the shaft. In this work, composite journal bearings were fabricated using a carbon fiber/phenol composite stitched with a low friction thermoplastic fiber (PTFE fiber) along the thickness direction to enhance the interlaminar shear strength (ILSS) and tribological properties of the composite material. Based on the ILSS and tribological properties of carbon fiber/phenol composite with respect to the stitching pattern, the optimum stitching pattern were selected to fabricate the composite journal bearing.

291 | Optimization of operating parameters of a hybrid composite tilting-pad journal bearing for turbine generator applications

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Tilting pad journal bearings (TPJB) has been employed to turbines, compressors, pumps and electric generators because of its high loading capacity, excellent stability and service durability at high operation speed compared to conventional journal bearings. Composite materials can be used as the face materials of the tilting pads to enhance the dynamic characteristics and durability of the bearing system. Until now, design criteria and suggested operating conditions has been focused on metal TPJBs. Accordingly, the appropriate design parameters and operating conditions are needed to maximize the performance of a hybrid composite tilting pad journal bearing (HCTPJB). In this work, the optimized operating conditions of the HCTPJB were suggested based on the hydro dynamic lubrication analysis. The damping coefficient and stiffness of fluid film were calculated with respected to operating conditions such as lubricant properties, oil supplying conditions, operating speed, and preload. To verify the analytical results, the hydrodynamic lubrication tests of the composite and white metal tilting pad journal bearings were conducted using the industrial test bench.

137 | Progressive failure analysis of a composite force-bearing joint

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This work concentrated on the failure modes of a composite force-bearing joint designed to replace the metal joint in aircraft structures. The composite joint consists of three main parts - a force transferring loop, an inner ring and a central laminate. Three-dimensional (3D) progressive damage constitutive models for each part of the composite joint were presented considering cohesive zone models at each interface. Hashin failure criterion and Camanho degeneration law were adopted to predict the initiation and progression of multiple failure in the composite joint under a tensile load. The numerical results show that when the composite joint loaded in tension, the interface failure occurs incipiently, leading to the delamination between each part. The force transferring loop becomes the only one to carry additional loads. The final tensile strength of the composite joint depends on fiber fracture in the loop, which is in good compliance with the theoretical result.

130 | Failure analysis of multilayer-winding braided composites under tensile load: Experimental and numerical study

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Tensile properties of three-dimensional (3D) multilayer-winding braided composites were investigated numerically and experimentally. Based on their braiding process, the spatial configurations of 3D multilayer-winding braided composites were proposed. To predict the tensile modulus, strength and the progressive damage behavior of this material under axial tension, the representative volume element (RVE) model was established. Puck failure criterion and Mises stress criterion were employed as damage initiation criterion for fibers and matrix, respectively. The numerical results show that the yarns are subjected to the main load and the stress concentration occurs at the interlacement of yarns. The effects of braiding angle and fiber volume fraction on tensile modulus were also studied. The composite specimens were manufactured by resin transfer molding (RTM) followed by the tensile tests. The predicted results agree well with the experimental data.

123 | Mechanical properties prediction of needle-punched carbon/carbon composites

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A method to predict the mechanical properties of needle-punched carbon/carbon composites is elaborated in this paper. Based on the observation by optical microscope, the meso structure of the composite is found can be classified as five typical unit cells charactering the patterns of mutual alignment relationship of planar fiber tows and needle fiber tows. Hashin criterion was employed to predict the failure of fiber bundle in unit cells and the local stress concentration at stitch bundle was described by elliptical inclusion theory. Progressive failure of unit cells in the composite under increasing loading represents the non-linear stress-strain curve of needle-punched composite. The numerical and experimental results prove that the needle-punched carbon/carbon composites mechanical behavior rules in microscopic structural features by the influence in manufacturing technique.

424 | Analysis and simulation of vibration behaviour of fibre composite guitars

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This paper contains an evaluation about the suitability of fibre-reinforced polymers in the construction of acoustic guitars. Initially, the specific material characteristics, the vibration analysis methods and the properties of acoustic guitars are presented. Afterwards, the influence of material properties, structure und top-geometry on the vibro-acoustic behaviour is identified by means of several fibre-reinforced soundboard models. A comparison with two wooden models shows the differences to traditional instruments. For this purpose, modal analyses and harmonic response analyses are simulated to evaluate furthermore the effects on the guitar sound. The suitability of the alternative material in the construction of guitars is approved due to the exact adjustability and reproducibility of vibro-acoustic properties of fibre-reinforced structures. Also, the regulation of sensitivity regarding temperature and moisture is one of the advantages over wooden materials. So far, the capability of fibre-reinforced guitars still has further potential for development and improvement.

457 | Lateral side impact performance of rubber based syntactic foam core sandwich panels

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Sandwich panels have been preferred many applications due to the high energy absorbing, high bending rigidity structural and material performances. Syntactic foam cores present various physical advantages than the conventional foam cores, such as high temperature and moisture resistivity. Their closed-cell structure made them suitable especially for marine and underwater applications. In the presented study, syntactic foam cores were produced by the contribution of glass bubbles into the natural rubber. Natural rubber is dissolved under room temperature with chemical solvents and mixed with different (%10, %20, %30 by weight) glass micro balloons percentages. After dried rubber-glass micro balloons mixture at 70 C, rubber based syntactic foams and sandwich panels were vulcanized in a hot mold under pressure. A very low density (~0.8 g/cm3) and high compressible foams were obtained depend on glass bubble content percentage. The most of the sandwich panel studies with syntactic foam core were performed through the thickness directions. In this study, the sandwich panels subjected to in-plane compressional impact load to determine the dynamic buckling of sandwich panels, face sheet-core separation and core compression performances.

159 | Behaviour of designed and premature modes of failures in RC beam plated at its soffit: Numerical study

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External plating method is generally used on reinforced concrete beams largely to overcome a faulty design or to retrofit a deteriorating structure. However, initially designed to achieve a desired capacity in flexure, the plated beams prematurely fail in undesirable modes of failure, such as debonding and peeling. The uncertainty of occurrence attached with such premature modes of failure has continuously challenged researchers and is far from being understood. Therefore, realising the need to characterise and quantify modes of failure, the present work demonstrates the relative behaviour of failure modes and their influence on each other through a finite element model, utilizing a combination of continuum and discrete models. The model is validated through test literature and presented in terms of multiple failures and corresponding capacities. In addition to studying the behaviour of modes of failure, the core findings indicate that their formation to propagation are largely interconnected through material and geometrical properties of the composite section.

467 | Experimental tests of optimally designed composite corrugated web beams

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Over the past few years there has been sustainable development in the steel and composite construction technology. One of the recent additions to such developments is the I-girders with corrugated web beams. The use of these new generation beams results in a range of benefits, including flexible, free internal spaces and reduced foundation costs. Corrugated web beams are built-up girders with a thin-walled, corrugated web and wide plate flanges. The thin corrugated web affords a significant weight reduction of these beams, compared with hot-rolled or welded ones. In this paper, experimental tests of optimally designed corrugated composite beams are presented. For this purpose, six corrugated beams are tested in a self-reacting frame to determine the ultimate load carrying capacities of mentioned beams under loading conditions. The tested corrugated beam specimens are designed by using one of the recent stochastic search techniques called hunting search algorithm. In the optimisation process, besides the thickness of concrete slab and studs, web height and thickness, distance between the peaks of the two curves, the width and thickness of flange are considered as design variables. The design constraints are respectively implemented from BS EN1993-1:2005 (Annex-D, Eurocode 3) BS-8110 and DIN 18-800 Teil-1.

429 | Water molecules diffusion into smart composite materials measurement using polymer matrix embedded LPGFS

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Simulation results obtained in analyzing an important mechanical and chemical functional parameter of smart composite materials during exploitation in various research, medical, industrial and security applications namely the concentration of infiltrated water molecules by using long period grating fibre sensors (LPGFS) are presented. LPGFS are fabricated by inscribing Bragg diffraction gratings into or on single mode (SM) commercial communication optical fibres. The LPGFS are used into smart composite materials as signal generators of their feedback loop being embedded into the polymer matrix for a large number of ambient stimuli applied on the composite such as force or pressure, temperature, mechanical load but including also, humidity, change of aggregation state, chemical structure modifications, even at micro-scale. LPGFS operation is accomplished exploiting the coupling process between the incident fundamental mode with core guided propagation and co-propagating through the core and cladding modes by scattering on the diffraction Bragg grating having a 10 - 1000 μm period. Such diffraction Bragg gratings are denoted as long period gratings (LPG). LPG are fabricated into SM optical fibre with 3-10 μm core and 125 μm cladding diameters by inscribing over a 10-75 mm length a periodic variation of core refractive index with UV laser point-by-point irradiation or by inducing with CO2 laser (10.6 μm wavelength) or electric arc discharge point-by-point applied thermal processing periodic small depth tapers of basic optic fibre. The coupling between co-propagating core and cladding mode represents an energy

transfer from the fundamental core mode to the cladding modes. This energy transfer is observed as absorption bands induced into the transmission spectrum of the SM optic fibre. The induced absorption bands have peaks at Bragg resonance wavelengths which have values depending on SM optical fibre geometry (core and cladding diameters) and spectral characteristics (core and cladding refractive index values). The resonance wavelengths can be split by the induced SM optical fibre birefringence. The resonance wavelengths and absorption bands bandwidths depend also on the ambient refractive index being shifted and enlarged by ambient refractive index variations. The LPGFS can be used as they are or mounted into interferometric setups such as SILPG (self-interference LPG), CASCADE or TWIN (successive different or identical LPG) schemes. In the case of an interferometric setup, the LPGFS operation is based on the hyperfine line structure induced into the absorption bands having peaks at Bragg resonance wavelengths. Generally speaking, LPGFS are exploited as chemical sensors by using its ambient spectroscopic characteristics. In the investigated case of water molecules infiltrated into composite materials, the numerous absorption lines of the water characteristic NIR spectrum are exploited. There are investigated the modifications of LPGFS as they are or mounted into interferometric setups absorption bands having peaks at Bragg resonance wavelengths situated in the NIR water characteristic absorption spectral domain. An evaluation method of composite infiltrated water molecules concentration as function of LPGFS as they are or mounted into interferometric setups Bragg resonance wavelengths variation is investigated. The simulation results are compared with experimental ones reported in literature, a fairly good agreement being observed.

422 | Effect of fastening conditions of composite prosthesis on the healing of weight bearing fractured bones

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Bone plates and intramedullary nails are commonly used for the treatment of long bones fractures. The basic purpose of any fixation technique is to maintain the alignment, stability of the fractured bones to facilitate the healing and load carrying capacity during rehabilitation. Although design methodologies and techniques of internal fixations have been developed and continuously enhanced, there are still many complications such as non-union, delayed bone union, stress shielding and implant failure. Biomechanical environment at the fracture site controls the mode of bone healing and the appropriate mechanical stimulus at the fracture site covered with calluses for the best healing can be controlled by changing the fastening conditions like number of screws, fastening angle or position of the screws. The goal of this study is to examine the different fastening conditions for appropriate load-sharing mechanism between implant and bones with suitable biomechanical environment at fracture site. Fastening conditions should be different for different types of fractures to heal the bone fractures efficiently. So, the 3D modeling of fractured bones and composite prosthesis was done using finite element code ABAQUS and iterative simulations were carried out using python script to estimate the bone fracture healing. Types of fractures were created in the bones and fixed with various configurations of prosthesis. Healing process was estimated for different types of fractures fixed with various composite and metallic prostheses. Finally, the results of various fixation techniques were compared and the best case favored the ideal conditions for promoting the fracture healing was suggested.

Acknowledgements: This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIP) (No. 2017R1A2B2005261).

298 | Modelling of transversal crack and delamination under traction with XFEM

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This paper presents a new investigation on the computational modelling of crack and delamination on laminates composite. Extended Finite Element Model (XFEM) is used to model the transversal cracks (intralaminar) and delamination (interlaminar). The integration of fracture laws and constitutive equations are applied to assist the initiation of crack and delamination, and their subsequent evolution. Size effect study for the increment of composite volume on blocking ply is also included in this investigation. The results show very good agreement

with the previous experimental and analytical data of each specimen and comparable with the previous literatures by Hallet et al. (transversal crack and delamination) and by Wisnom et al. (laminates size effect study).

Keywords: crack, delamination, XFEM, composite, fracture.

276 | The study of selected mechanical properties of the composite sandwich with aerogel mat

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Aerogel material is used in various industries, among others in the aerospace industry. Application of this type materials increase thermal resistance of the structure parts (low value of thermal conductivity) particularly exposed to high temperatures ranging up to 800 °C, making them high-quality thermal insulators in a wide range of temperatures. In addition, they are used as a particles catcher in outer space in the Aerogel pores (inside the structure of the material) in the immediate vicinity of the satellites in order to protect them from the damage. Therefore, to develop a wider range of applicability of sandwich composite mat using Aerogels for the purpose of aviation engineering should be carried out a number of thermal and mechanical engineering tests. The following study focuses on performing selected strength tests of this type of composite material. For the study, some samples were prepared to the preliminary tests of Aerogel mats reinforced with fiber glass (one layer on each opposite surfaces of the Aerogel mat). For comparative purposes, the Aerogel mat, the one impregnated with resin and sandwiched composite consist of the Aerogel mat and the fiberglass were tested. Static tensile test, three-point bending tests and impact properties research were conducted. The structure of the test material using a scanning electron microscope after strength tests was illustrated. On the basis of preliminary tests a significant improvement in strength properties and rigidity of the composite sandwich was observed. The study proved that the sandwiched Aerogel composite has a few times (about ten times) greater impact strength than the Areogel mat, and some-times (about three times) greater impact strength than the ones saturated with epoxy resin. In addition, the tensile strength of the composite is several times higher than the Aerogel mat itself and the one saturated with resin. The study can be considered as preliminary and repeatability of the results should be verified.

261 | Finite element investigation on the structural behavior of deficient steel beam-columns strengthened using CFRP composite

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In recent decades, carbon fibre reinforced polymer (CFRP) is one of the materials used to strengthen steel structures. Most studies on strengthening steel structures have been done on steel members without deficient. No independent study, to the researcher's knowledge, has studied the effect of CFRP strengthening on deficient steel beam-columns, and it seems that there is a lack of understanding on the structural behavior of deficient steel beam-columns strengthened with CFRP. However, this paper presents the finite element investigation on the structural behaviors of SHS steel beam-columns having initial longitudinal or transverse deficiencies which were strengthened using CFRP sheets. To study the effects of CFRP strengthening method on recovering the strength lost in the deficient specimens, one non-strengthened specimen without deficient as control deficient steel beam-columns, four non-strengthened specimens with different lengths, width, and orientation of deficiencies, and twelve strengthened specimens with different lengths and orientation of deficiencies were analyzed. To analyze the specimens, three dimensional modeling and non-linear static analysis methods using ANSYS software were applied. The results indicated that application of CFRP sheets for strengthening of deficient steel beam-columns could recover the strength lost due to deficiency, significantly.

152 | Structural behaviors of deficient steel members strengthened using CFRP composite subjected to torsional loading

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In recent years, strengthening of steel Square Hollow Sections (SHS) using Carbon Fiber Reinforced Polymer (CFRP) has attracted the attention of many researchers. Most previous research, in this field, have done on strengthening steel members without deficient in bending, shear and compression. Few studies have been conducted on steel torsional members strengthened using CFRP, and to the author knowledge, no research on

behavior of CFRP strengthened deficient steel members subject to torsional load has been presented. The deficient in steel members may be created due to the errors caused by construction, fatigue cracking, drilling after building for passing of building installation, corrosion, earthquake damage, and so on. However, this paper presents the numerical investigations on the structural behaviors of SHS steel torsional members having initial longitudinal or transverse deficiencies which were strengthened using CFRP sheets. To study the effects of CFRP strengthening method on recovering the strength lost in the deficient specimens, one non-strengthened specimen without deficient as control column, four non-strengthened specimens with different lengths, width, and orientation of deficiencies, and twelve strengthened specimens with different lengths and orientation of deficiencies were analyzed. To analyze the specimens, three dimensional (3D) modeling and non-linear static analysis methods using ANSYS software were applied. The results indicated that application of CFRP sheets for strengthening of deficient torsional steel members could recover the strength lost due to deficiency, significantly.

145 | Free vibration analysis of FG plate on elastic foundation using an exact Spectral Element Method
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In this study, Spectral Element Method (SEM) is utilized for free vibration analysis of functionally graded (FG) plates resting on elastic foundation. The foundation is described with either the one-parameter Winkler-type or the two-parameter Pasternak-type model. Using Hamilton's principle, equations of motion of Mindlin plate are derived based on first-order shear deformation theory assumptions. Differential equations of moderately thick Levy type plates are transformed into frequency domain, using Fast Fourier Transform (FFT) and then a closed-form solution in frequency domain is presented. The force-displacement method is utilized to formulate dynamic stiffness matrix in frequency domain. Obtained results are compared with exact solutions and those predicted by a higher-order shear deformation plate theory. Effects of different parameters such as thickness-to-side ratio, aspect ratio, power law index, Pasternak and Winkler foundation parameter and type of boundary conditions on the results are investigated, too. In this method, in absence of discontinuity on plate, only one element is used to obtain an accurate result which is impossible in other numerical methods like FEM. It is concluded that, besides accuracy and efficiency of SEM in predicting natural frequencies of plate on elastic foundation, saving in computational cost is one of the most interesting features of present method.

146 | Free vibration analysis of FG plate with piezoelectric layers using an improved refined plate theory
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This study presents an analytical solution for free vibration analysis of functionally graded plate integrated with piezoelectric layers using an improved refined plate theory. This theory which accounts effect of transverse shear deformation and transverse normal strain/stress, satisfies zero traction conditions on the plate surfaces and does not need the shear correction factor. Equations of motion for simply supported rectangular plates are derived using Hamilton's principle and Maxwell's equation, and then the Navier method is employed to solve the governing equations. The electric potential is assumed quadratic along the piezoelectric layers thickness and both closed-circuit and open-circuit electrical conditions are considered. Several examples are solved to compare the accuracy of various refined plate theories with different shape functions in predicting natural frequencies of simply supported rectangular plate with piezoelectric layers bonded at top and bottom surfaces. Also, effects of power law index, thickness ratio and foundation parameter, on the results are investigated. The results demonstrate the simplicity, accuracy and efficiency of the method in predicting natural frequencies of investigated problems.

406 | Structural and aeroelastic analyses of a large composite wind turbine blade
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This work implements a methodology based on the Finite Element and multi-body dynamics approaches to conduct structural and aeroelastic analyses for composite wind turbine blades. The 13.2 MW reference wind turbine designed by Sandia National Laboratories (SNL) is chosen as a case-study. The structural properties calculated by the utilized methodology are validated against those published by SNL that uses a different methodology based on non-finite element and modal reduction tools instead of the Finite Element and multi-body dynamics. Five Design Loading Cases (DLC) as described in the IEC standards for wind turbine design are

simulated. The simulations allow the prediction of the turbine characteristics such as the natural frequencies, tip deflections, load distributions, and life time equivalent loads. After validation with SNL results, the proposed methodology is utilized to study the effect of relocating shear webs position inside the blade. Results show that varying the locations of shear webs improves the stiffness of the blade significantly, upto 50% at the maximum chord location in the different directions the flapwise, edgewise, torsional and axial directions. The proposed methodology can be further utilized to improve the design of wind turbines by being incorporated with optimization models.

226 | Development and experimental characterisation of CNT-PEK composite produced by calendering

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A carbon nanotube reinforced PEK material was developed with many times higher damping capacity and at the same time stiffness than the top thermoplastic PEEK (or PEK). The tensile strength of the nanocomposite is lower than PEEK at room temperature but its performance is superior at elevated temperature, under shear and creep conditions. The material is brittle but its elastic domain (up to 1,4%) is wider than PEEK. It is expected that the material will be also suitable for long duration fatigue loading due to the presence of the CNTs network. Extensive testing and observations (AFM, FTIR, DSC, DRS) indicate that the CNTs were disentangled – dispersed-aligned. It was also indicated that the interphase bonding was covalent. Suitable production equipment was designed and constructed. This study presents the special calendering method and apparatus developed for this purpose and reports the large body of experimental characterisation results obtained with regard to the disentanglement, dispersion, and alignment of the CNT fibres in the PEK matrix, and the resulting physical and mechanical properties of the nanocomposite.

227 | Comparative simulations of stir-, sonication, and extensional flow mixing methods for molten aluminium and fly ash nanoparticles

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For the production of cast fly ash -aluminium nanocomposites it is necessary to achieve good dispersion of the fly ash nanoparticles inside the molten aluminium matrix. Stirring by means of an impeller and sonication are two popular methods for achieving this. Direct use of positive-displacement-forced extensional flow is also a possibility, i.e. by use of a pulsating perforated piston, based on prior experience with mixing plastic matrix- CNT composites. While all three methods have been verified in various studies to achieve the intended mixing results, there is no common benchmark established on their relative effectiveness: i.e. in terms of mixing efficiency (time, energy) and uniformity of dispersion. This study addresses this gap by performing multiphase CFD and coupled mechanical-CFD simulations of an aluminium melt containing an initially poorly dispersed fly ash nanoparticle phase, which is subjected to mixing using alternative stir-mixing, sonication, and extensional flow methods. The flow mechanisms at play leading to the eventual fly ash particle dispersion are observed and compared. The sensitivity to various process parameters is determined. Because of the use of the same general model parameters, these benchmarking results can be considered valid even when the real properties of the melt, i.e. temperature, viscosity, particle shape and size distribution, original particle dispersion/ agglomeration, etc, deviate from the values used here. The pros and cons of each mixing method with regard to set metrics for efficiency and dispersion uniformity are identified and the implications to the industrial upscaling of the studied methods are discussed.

114 | Fabrication of bio-nanosilica, quartz and epoxidized plant oil based hybrid nanocomposite and their mechanical characteristics

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In this work, the hybrid bionanocomposites were fabricated from bionanosilica, quartz and epoxidized soybean oil. The nanosilica which were extracted from both rice husk by combining the acid-pretreatment and thermal method have dimension in range 40-70 nm and in amorphorous state. Beside it, the epoxidized soybean oil was synthesized from soybean oil by using mixture of H2O2 in CH3COOH. Nanosilica and quartz with and without treatment with silan coupling agent were well dispersed in epoxidized soybean oil by using high speed mechanical stirrer and cross-linked with different of curing agent such as hexahydro-4-methylphthalic anhydride (MHHPA) at difference of temperature. The mechanical characteristics of hybrid nanocomposites were done by using different methods such as: tensile testing, flexural testing, impact testing as well as fracture toughness. The thermal properties and broken surface of hybrid nanocomposites were characterated with the help of thermogravimetric analysis (TGA), Dynamic-Mechanical Thermal Analysis (DMTA) and SEM image. The results showed that the tensile strength, flexural strength, impact strength as well as fracture toughness increased with content of nanosilica and reached the optimum at 0.2 phr of silica and 20 phr of quartz. The Tg of nanocomposites trend to higher corresponding of increasing content of nano silica particles. The nanocomposites also were coloured with different kind of orgarnic colour compound for artificial marble application.

141 | Open hole tensile strength of quasi-undirectional glass-fibre NCF/epoxy composite laminates

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Open holes/notches are required to access the cables or pipes in the structure. In this research, the open hole tensile (OHT) strength of quasi-unidirectional (quasi-UD) non-crimp fabric based composites was studied. Therefore, cross-ply and quasi-isotropic layups were manufactured with the vacuum assisted resin transfer moulding (VARTM). Holes were drilled with the carbide tipped drills. The tensile tests were conducted in accordance with the ASTM D5766 test standard. The failure modes and maximum load values were recorded and compared. Furthermore, the OHT strength of the tested layups was estimated by a three-dimensional (3-D) progressive damage model.

402 | Multi-objective optimization of sandwich composite deep submarine pressure hull, for maximize the operating depth, deck area and minimize buoyancy factor

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The sandwich composites of deep submarine pressure hull appear to be a promising choice because of their structural efficiency and functional integration advantages. However, the design of sandwich composites is more complex than other structures because of many involved design variables, constraints and multi objective functions. Also, the optimum structural design of sandwich composite submersible pressure hull is known to be a challenge for designers. The major challenge in the coupled design problem is to handle multiple conflicting objectives. This paper presents a methodology for the multi-objective optimization of non-circular cross-section sandwich composite pressure hull for deep submarine. Maximize the operating depth, deck area and minimize buoyancy factor of the submersible pressure hull, under hydrostatic pressure is considered as objective function. Finite element analysis of sandwich composite pressure hull is performed using ANSYS parametric design language (APDL). Optimization of the radii of the ellipse, core thickness, ply sequence and thickness of composite submersible pressure hull subjected to hydrostatic pressure is investigated and are taken as design variables. The constraints include structural stability and the composites failure criteria are considered in the optimization problem, stress and failure analyses of the hull were carried out using the global model. Additionally, a sensitivity analysis was conducted to evaluate the effects of geometric parameters on the optimal structural design.

The results of this study provide a valuable reference for designers of sandwich composite pressure hull of underwater vehicles. This paper also proposes that this underwater vehicle should be able to operate up to 7500 m depth.

403 | Maximizing the buckling load capacity and minimizing the weight of composite deep submarine pressure hull

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Recently, the use of sandwich composite materials in many structural applications is found to be very advantageous as they provided high strength to weight ratio. The optimization design plays an important role in obtaining successful composite structures with high efficient and safe use of materials. Also, submersibles and submarines are particularly weight sensitive. This paper presents a methodology for the multi-objective optimization of sandwich composite pressure hull of deep submarine in order to increase the buckling load capacity, minimize drag force and the weight/displacement ratio. Multi-objective optimization of deep submarine pressure hull under hydrostatic pressure is performed using ANSYS parametric design language (APDL) to reach the maximum operating depth. FEA models of submersible pressure hull have been developed using sandwich construction having composite face sheets and a foam core. The constraints based on the failure strength of the pressure hull, incorporating both the Tsai-Wu and the maximum stress failure criteria to predict the first-ply failure. The fiber orientation angles and the thickness in each layer, the radii of the ellipse, the ring beams and the stringers dimensions are taken as design variables. Also, the performances of the optimization procedure are discussed. Additionally, a sensitivity analysis is performed to study the influence of the design variables up on objectives and constraints functions.

224 | Forced vibration of functionally graded beams with an edge crack in thermal environment

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Functionally graded materials (FGMs) have been drawing great attention in various engineering fields due to their ability to withstand severe high temperature gradients while maintaining structural integrity. It is known that FGM structures are inhomogeneous composites characterized by a smooth and continuous variation in material composition profile as well as material properties in one or more directions within the structure. In addition to mechanical loads, FGM structures are often subjected to thermal loading due to a temperature change. The presence of crack defects makes FGM structure more vulnerable to failure than its intact counterpart because of the local flexibility introduced by the crack which in turn reduces the structural stiffness. This paper investigates the forced vibration characteristics of an FGM beam with an open edge V-shaped crack under a uniform temperature change. The material properties of the beam are assumed to be graded following an exponential law through the thickness direction. The dynamic analysis is based on the finite element method by using commercial software ANSYS. To approximate the FGM structure, the inhomogeneous FGM beam is modelled by a multi-layered structure in which material properties in each individual layer are considered to be constant. The transient deflection response is obtained for cracked FGM beams with clamped-clamped end supports. Convergence study shows that the FEM model with 30 layers is accurate enough to approximate an ideal functionally graded structure with smooth and continuous variations in material properties. The effects of the gradient in material properties, crack location, crack depth, and temperature change on the deflection time history are investigated in detail through a comprehensive parametric study. Numerical results show that the dynamic deflection decreases as the material property gradient increases. In addition, the dynamic deflection is the maximum when the open edge crack is located at the mid-span of the beam and is the minimum as the crack is located at the beam ends of the beam. The thermal compressive stress induced by the temperature rise weakens the beam stiffness which in turn leads to a bigger deflection of the cracked beam.

329 | Manufacturing and properties of pre-stressed GFRP composites

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The concept of increasing strength capacity of structural elements by introducing preliminary stresses, counteracting the exploitation stresses, is known for years. Large number of applications of pre-stressed materials in civil engineering proves that proper compression of material can effectively increase the strength of structural elements. Because of the rapid development of composite materials, and growing demand for light materials with particularly high stiffness and strength properties, the pre-stressed FRP composites application in industry seems to be a question of time. This assumption is confirmed by increasing number of publications concerning the problem of mechanical characteristics for such materials. This paper presents the results of preliminary research on the pre-stressing of the FRP composite structures, while the term pre-stress indicates initial tensile stress applied to the fibres embedded in selected layers of the composite material. Manufacturing process and shape forming possibilities as well as short-term static and dynamic behaviour of the pre-stressed composites are discussed. Presented results are achieved by the use of the experimental methods (three-point bending tests and Experimental Modal Analysis) and experimentally verified Finite Element Method model of pre-stressed structure.

323 | Bond behaviour of PBO-FRCM composite for the strengthening of masonry structures. Experimental campaign and numerical investigation

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Innovative strengthening intervention strategies for the protection of existing masonry structures are increasingly replacing traditional approaches, which have relied on the use of steel and concrete. Fast proliferation of research investigations on composite materials has enabled the development of specific applications for existing masonry and concrete structures consisting in an organic-modified cement-based matrix associated to either organic or inorganic fibre nets characterised by loose weft-warp layouts. Fibre Reinforced Cementitious Matrix (FRCM) technologies overcome one of the major disadvantages of FRP applications, i.e. deterioration of the reinforced area due to debonding phenomena at the composite\substrate interface. FRCM systems are more suitable than FRP for interventions on existing masonry structures since the driving failure mechanism invests the fibre-matrix interface leaving the substrate untouched, [1-2]. However, results already available are inadequate to develop a robust characterization, qualification and safety assessment of the FRCM system. Mechanical models capable of tackling the matrix-fibre interface failure are migrated from FRP failure analysis and built on experimental strain profiles calibrating fictitious smeared bond-slip relations that synthesise the more complex phenomena involved to deduce basic design parameters, [3-4]. Numerical modelling of the stress transfer mechanism has been pursued as well, through specifically designed or commercially available finite element codes on 1-D to 3-D models, [5]. In this framework, this paper report results of an experimental campaign carried out on a poly-benzoxazole (PBO) FRCM system through tests on standalone constituents and composite adhered to brick elements (double shear and three-point bending). Three specimens of mortar matrix and PBO nets have been subjected to three-point bending and direct tensile tests respectively. Adhesion capacity of the reinforcement system to the substrate was tested on two layouts. (i) Double shear test (9 specs) on a specifically designed apparatus consisting of a double steel frame, which permits to overcome drawbacks connected with the efficacy of the grip system. (ii) Beam test (24 specs) built through two bricks linked by a steel hinge on extrados and reinforcement through the whole width of the bricks at intrados. Test results revealed an undisturbed substrate and a failure mechanism at fibre matrix interface. Damage propagation followed a three-step evolution: first linear branch until tension levels in the order of tensile strength of matrix, subsequent loss of stiffness due to crack mouth increase and final softening branch with evident matrix-fibre slippage. Results confirmed the efficacy of FRCM systems for repair and strengthening purposes, especially on historical buildings, given the increase in ductility and load carrying capacity that they can provide. Besides, a simplified model to investigate the response at the fibre-matrix interface defining a limited number of parameters is proposed and investigated through an analytical formulation and a commercial FEM

code. In particular, the matrix layer interlocked between the substrate and the single longitudinal fibre warp is idealised as a continuous framed structure consisting of stocky elements representing respectively matrix and fibre warp.

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324 | Experimental investigations on sustainable and innovative strengthening systems for masonry arches

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Seismic events highlighted the high vulnerability of arch structures if not appropriately retrofitted. This problem increased the interest of the scientific community towards new repairing and strengthening solutions to be applied on masonry arches to improve their structural capacity, regarding both loads carrying capacity and ductility. In fact, innovative strengthening methods, mainly derived from the recent huge development of composite materials for constructions, have been substituting the traditional techniques, based on steel profiles or reinforced concrete hoods, which have revealed many negative aspects. Innovative Composites made of a fabric embedded in a cement-based matrix (FRCM, Fabric Reinforced Cementitious Mortar) have been proposed, [1–5], as an alternative to FRP (Fiber Reinforced Polymer) composites, especially for the strengthening of historical constructions. When compatibility with the original material is a specific requirement, as for restorations of monumental buildings, natural lime mortar is an effective alternative to cement-based matrix. In the paper, the structural behaviour of masonry arches strengthened at the extrados by using a basalt fabric embedded in lime mortar matrix composite (Basalt-FRLM) is investigated through an experimental approach. The innovative strengthening system used, marketed by KeraKoll SPA, consists of a basalt bi-directional balanced textile with an alkali-resistant solvent-free coating and a water-based resin and AISI 304 stainless steel micro-threads welded together to guarantee a stable sheet. The matrix is an NHL 3.5 natural lime mortar, contains only raw strictly natural and recycled minerals (low CO2 and volatile organic compounds emissions) and is recycled as inert at the end of life. The response of Basalt-FRLM system was compared to those determined by un-strengthened masonry arches and strengthened using a poly benzoxazole (PBO) fabric reinforced cementitious mortar composite (PBO-FRCM) and by a Carbon Fiber Reinforced Polymer (CFRP) composite. Mechanical properties of masonry constituent materials, cement-lime mortar and bricks, and as a whole system were also determined. The experimental campaign addressed two specimens in the un-strengthened configuration and three with Basalt-FRLM, PBO-FRCM and CFRP composite sheets. Tests have been carried out to observe the whole loading history, up to the point of a conventional test-end corresponding to a residual strength equal to 80% of the peak load. As expected, the un-strengthened arches exhibited a collapse mechanism with four alternate (intrados/extrados) hinges, while the application of Basalt-FRLM strengthening composite at the extrados prevented the formation of inner hinges, where instead only superficial cracks on lime mortar were visible. The experimental results pointed out the contribution of Basalt-FRLM material in increasing the maximum load (about 80%) and kinematic ductility (about 400%) in comparison to un-strengthened arches, although it offered a lower peak load and higher ductility about other tested systems. The test highlighted the excellent adhesion between both masonry-lime matrix and lime matrix basalt textile. Additional tests are needed, but we believe that the use of this type of composite is of particular interest and efficacy for masonry buildings of historical interest.

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301 | Dielectric behavior of structured magnetorheological elastomers

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Composites based on an elastic polymer matrix filled with magnetic microparticles represent a new class of materials whose mechanical properties (e.g. viscoelastic moduli) can be precisely controlled via an external magnetic field. These intelligent systems known as magnetorheological elastomers (MREs) are used mainly in civil engineering as dampers or vibration isolators. Apart from the filler loading also its spatial distribution within the matrix critically affects the response of the MRE to the external magnetic stimuli and hence the performance of the system can be affected. The composite anisotropy can be achieved by filler orientation during the curing process in various intense magnetic fields. In this contribution, we attempted to determine the degree of anisotropy of the fabricated MREs indirectly by means of dielectric relaxation spectroscopy (DRS) in terms of recorded relaxation processes and their corresponding activation energies. The MREs comprising the carbonyl iron particles embedded in the polydimethylsiloxane matrix varying in filler concentration were cured in magnetic fields of two different intensities as well as in the absence of an external magnetic field in order to obtain their isotropous analog. The discoid samples were thereafter placed into dynamic electric field (0.1 to 10 MHz) of low intensity (1 V amplitude) and their dielectric response was investigated within a broad temperature range. Registered relaxations related to charge transport/hopping within and/or among particle clusters differed substantially with composite's degree of filler spatial inhomogeneity depending on intensity of magnetic field employed during curing. We were able to evaluate the filler concentration and its distribution based on the obtained DRS spectra. It was found, that the level of particle alignment into clusters tend to decrease with the filler concentration. Thus, the DRS was proven to be an effective tool suitable for non-destructive testing of particle concentration and particle spatial distribution of the MREs.

196 | Debonding of SRP/BFRP strips in compressed homogenous beam models

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Few experimental investigations on de-bonding process of FRP strips in compressed beams strengthened with FRPs have been carried. Many studies have focused on the aspects of de-bonding due to bending and/or shear in steel/concrete beams strengthened with FRPs. This research work is based on the analysis of slender homogeneous beams under compression strengthened with SRP and BFRP strips. Several experimental tests have been done considering beam models made of homogeneous material (marble) without tensile resistance; the specimens strengthened with a double layers of FRP strips glued on both up and down surfaces were tested under increasing compressive force until the failure due to detachment of strengthening. Two different composite materials have been used to strengthen the marble beam models: steel reinforced polymers (SRPs) and basaltic reinforced polymers (BFRPs). A comparison between un-strengthened and strengthened response of beam models has been carried out and results of theoretical analysis have been compared with experimental data and discussed.

Keywords: Uniform beams; Compression tests; SRP/BFRP strips; Debonding.

338 | Local blast wave interaction with tire composite structure

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The genesis of the study is related to the recent events including many world military operations, where IEDs are commonly used in the battlefield and their explosions can destroy wheels or even the suspension system. Their destructive effect results in tire tearing followed by a large deformation of other elements of the suspension system. Therefore, the authors have focused on modelling and testing of tire of a logistic truck supporting military operations under strongly dynamic loading conditions. At first glance, the tire does not resemble a composite. However, it consists of rubber parts (tread, sidewall, etc.), which can be considered as the matrix. Additionally, it is reinforced with cords, which, depending on tire application, can be made of different materials and can have various configurations. Taking all this into consideration such a structure can be treated and analysed as a specific

composite. During the very first stages of the development process of the tire numerical model, its geometry was achieved with the use of the reverse engineering technology. Moreover, both the tire cords size and their arrangement were verified with the use of the computed tomography (CT) scan. Finally, a detailed discrete model of a tire was developed and validated with the actual one. In the finite element modelling, the Simplified Rubber constitutive model, available in commercial LS-Dyna code, was implemented with material characteristics obtained experimentally. Moreover, an original method of modelling of tire composite structure was proposed, in which nodes of the truss elements were constrained to remain in the same parametric positions within the solid elements using the special feature based on the penalty method. The method is dedicated to simulate coupling between gaseous medium and solids, however it can be modified to couple beams in brick elements. The main advantage of such an approach is that the meshes of the cords and tire rubber do not have to coincide and can separate from each other. Based on the developed finite element model of the tire a parametric study was conducted to analyse influence of different cords parameters, i.e. their arrangement, angles orientation and tread geometry on obtained results. Tire composite structure destruction was compared and such characteristics as tire internal energy, destruction-damage evaluation, pressure distribution and flow-around effect were also discussed.

Acknowledgements: This research was carried out with the support of the Interdisciplinary Centre for Mathematical and Computational Modeling (ICM) University of Warsaw under grant no GB65-19.

184 | Magnetorheological elastomers with tailored performance and stability properties based on multifunctional core-shell particles with different shell thicknesses prepared via SI-ATRP

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Magnetorheological elastomers (MREs) are a new kind of composite materials consisting of magnetic micro-particles embedded in an elastomeric matrix. These material systems possess the capability to rapidly and reversibly tune their viscoelastic properties upon the application of an external magnetic field. Due to their unique field-induced property changes, the MREs have been widely applied in many areas including damping devices, adaptive vibration absorbers, engine mounts, or magnetic field sensors. However, the conventional MREs suffer from several drawbacks such as poor particle/matrix interface adhesion and hence insufficient mechanical properties and damping, or low thermo-oxidation and chemical stability. High magnetorheological (MR) effect is also very important requirement, which can be affected by the stiffness of the employed matrix. The plasticity of the matrix can be enhanced by introducing the plasticizers or by the incorporation of the particles treated with various surfactants, however these low molecular species have a tendency to migrate through the polymer matrix, which causes problems with the MRE durability. Recently, we have shown that the carbonyl iron (CI) particles with covalently grafted poly(trimethylsilyloxyethyl methacrylate) (PHEMATMS) polymer chains (CI-g-PHEMATMS) via surface-initiated atom transfer radical polymerization (ATRP) possessed the plasticizing effect in silicone-based MREs while increasing their relative MR effect, damping and stability properties. The goal of this study was to investigate the effect of different polymer graft lengths on mentioned characteristics, and thus to be able to tune the behavior of the MREs through controllable coating of the filler particles, which is to the best of our knowledge a concept that has never been published elsewhere. Herein, two types of CI-g-PHEMATMS particles varying in shell thickness (indexes 1, 2) were synthesized using different monomer/initiator ratios during ATRP, and the multiple function of polymer grafts on the mentioned properties was systematically investigated. The successful grafting process was proved via energy-dispersive and Fourier transform infrared spectroscopy techniques. The thicknesses of grafted PHEMATMS layers were further studied using transmission electron microscopy. The grafted layers were uniform with thicknesses of around 15 nm and 30 nm, which was in accordance with theoretical estimations. The modified particles exhibited slightly decreased magnetization, but significantly improved thermo-oxidation stability, as revealed by vibrating-sample magnetometry and thermogravimetric analysis, respectively. Moreover, the antiacid/corrosion stability of the particles was extremely enhanced. The particles were mixed into polydimethyl siloxane (PDMS) matrix and the isotropic MREs were fabricated. It was found, that the presence of covalently-bonded PHEMATMS chains increased plasticity of the systems, avoiding a migration as a serious drawback of common low molecular weight plasticizers resulting in

systems with better durability. This phenomenon was more pronounced in the MRE based on the CI particles with longer chains that have higher plasticizing effect. Enhanced plasticity was reflected in considerably increased relative MR effect. The MRE based on bare CI possessed the MR effect of 42.8 %, while their analogues based on CI-g-PHEMATMS-1 and CI-g-PHEMATMS-2 exhibited 66.0 % and 76.2 %, respectively. The results further indicate that the damping factor increased with increasing PHEMATMS molecular weight as the longer grafts have a greater ability to develop shell entanglements with PDMS chains and thus soften the fabricated composite structure. Therefore, using surface-initiated ATRP we were able to tailor MR performance and damping of the MREs as well as increase particles' stability against high temperatures and acidic environment at the same time, which make the presented strategy an effective tool to prepare MREs promising for practical applications.

376 | Fatigue characteristics of scarf-joint composite laminate in various thermal environments

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Recently, composite structures used in aircraft have been enlarged and integrated due to the development of the manufacturing process. However, if a large structure such as a wing or a fuselage of an aircraft is integrally formed, it becomes difficult to replace the structure when local damage occurs during operation. Therefore, in this case, a repair method in which the damaged area is limitedly removed and replaced with a scarf patch is often used. The use of scarf patch repair minimizes changes in aircraft exterior shape and weight. Therefore, it is necessary to secure a database for design through various studies on the characteristics of the composite structure after the scarf patch repair. The purpose of this study is to obtain design data for scarf patch repair of composite structures. The fatigue behavior of composite scarf joints with temperature changes was studied. The scarf joint specimens were fabricated using cocuring and secondary bonding methods. Considering the glass transition temperature (123℃) and curing temperature (150℃) of composite USN-200A, and curing temperature of adhesive FM300 (121℃), the atmosphere temperature for the fatigue test were 25℃, 75℃, 100℃, and 125℃. The stacking sequence of the laminate is [45/0/-45/90]2S. The atmosphere temperature was measured through a thermocouple mounted on the surface of the specimen. The fatigue test was a tensile-tensile test, with a stress ratio of 0.1 and a frequency of 5 Hz. The fatigue strength was determined based on the one million cycles. The test consists of three types, including one perfect laminate specimen and two scarf joint specimens. As a result of the static strength test as a reference of the fatigue strength, the tensile strength of the composite laminate did not substantially decrease at 100°C, but the tensile strength at the temperature exceeding the glass transition temperature of 125°C. was decreased by 20%. In the case of scarf joints, the strength deterioration was observed clearly at 75°C regardless of the bonding method, and it was confirmed that at 125 C higher than the glass transition temperature, it fell below half of the room temperature strength. The fatigue strength at 25℃ atmosphere for the perfect laminate specimens, secondary bonding specimens, and cobonding specimens was 61%, 35%, and 33%, respectively, based on static strength.

Acknowledgements: This work was 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). This study was supported by the "Advanced Scarf Repair Method and Equipment Development for Aircraft MRO" through the Ministry of Trade, Industry and Energy (R0004399-2).

371 | An experimental demonstration of pressurizer for repairing composite structures

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Once an aircraft is made, it is used for at least 20 years. During the operating period of more than 20 years, various types of external load are encountered which lead to large and small damage to the structure. Composite aircraft are not exceptional and experience various types of damage during operation such as matrix cracking, delamination, and fiber breakage. In the case of composite structures, if the damage exceeds the allowable range, the damaged area may be removed and replaced with a new structure, or the reinforced plate may be installed inside or outside the damaged area. In any case, when using mechanical fasteners such as bolts or rivets, stress concentration and weight increase due to fastening holes and fasteners cannot be avoided. Recently, researches on

repairing damage of composite structures using only scarf patches and adhesive materials without mechanical fastening are being actively conducted. However, the scarf patch repair method has problems such as a long working time and a large loss of material, and particularly, there is a problem that a device that can apply temperature and pressure like an autoclave is required. This is because the adhesive for attaching the scarf patch exerts its original adhesive strength only when a certain temperature and pressure are applied. Unfortunately, recent aircraft composite structures are becoming larger, and once they are built, it is impossible to use the autoclave again for partial repairs. Therefore, it is very important from a practical point of view to repair the damage of the aircraft in the field by applying local temperature and pressure so that the composite patch or the reinforcing plate can exhibit the original strength of the material. In order to immediately repair the composite damage at the outdoor site where the aircraft operates, adequate temperature and pressure must be applied. The problem of applying heat to a composite patch is easily solved by using a heat blanket. The key is therefore to develop a technique for applying the required pressure for bonding. In case of repairs in the field, only vacuum process is applied now. Therefore, in this study, we developed a device that can apply external pressure up to 2 atmospheres besides vacuum in order to attach a composite patch. The pressure is applied mechanically and is designed to be applied externally to real structures. In order to verify the performance of the developed device, damaged laminated composite structures were repaired with scarf patches, cured using autoclave and the developed device, and tensile tests were conducted. As a result of the test, it was confirmed that both the static and fatigue strengths of the specimen using the developed equipment and autoclave exhibited the same level of performance.

Keywords: Out-of-Autoclave (OOA), Scarf Repair, Composite Material.
Acknowledgement This study was supported by the “Advanced Scarf Repair Method and Equipment Development for Aircraft MRO” through the Ministry of Trade, Industry and Energy (R0004399-2). This work was supported by the Human Resource Training Program for Regional Innovation and Creativity through the Ministry of Education and National Research Foundation of Korea (NRF-2015H1C1A1035655).

372 | Buckling behavior of delaminated composite laminates after microbolt-repair

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The application range of carbon-epoxy composite has been continuously expanded due to its excellent mechanical and chemical properties. For weight-sensitive composite structures including aircraft, thin prepreg tapes with reinforcing fibers and polymer resins are used by laminating it. The resin supporting the reinforcing fibers changes into a solid matrix with high brittleness through curing process, which is vulnerable to external load. Particularly, delamination is likely to occur between the prepreg layers when the impact load or a local bending moment are applied to the structures. It is the most fundamental problem of the composite structures. In the past, if the composite structure had a delamination greater than the allowable range, the damaged part was removed and a new plate was installed using a fastener, or a repair method of installing additional reinforcing plates to both sides of delaminated area was used. In recent years, however, scarf-patch bonding repair methods have been used in order to minimize the weight increase. It is a method removing the damaged area as a scarf shape and installing the new scarf-shaped laminate using adhesive. However, while repair method using fasteners such as bolts is simple process, the in-plane strength of original structure is lowered due to stress concentration around the fastening hole, and the weight increase due to the metal fastener can not be avoided. In the case of the scarf-patch bonding repair method, it has problems of consuming lots of materials and a long working time and it is vulnerable to tensile fatigue load. In this study, we propose a new repair method using micro bolts that can minimize the stress concentration and the degradation of the in-plane strength by the fastening holes while taking advantage of traditional mechanical fastening repair method. In the first step, the failure loads of the composite laminates having holes of different diameters were evaluated by analysis and experimental study. From this test results, it was confirmed that the failure loads of the laminates increased as the hole sizes became smaller and it approaches to the failure load of the sound laminate without holes. Based on the test results of the micro holes effect on in-plane strength of laminates, the compression buckling test of laminates reinforced by nine bolts of 0.6 mm diameter and 0.008 g weight was conducted. While the average buckling load of undamaged laminate was 22.4 kN, buckling loads of micro bolt-repaired and non-repaired laminate were 21.9 kN and 16.1 kN. It shows that the buckling load recovery rates were 98% and 74%, respectively. The total area of the nine fastener holes is

about 2.54 mm2, which is only that of a bolt with a diameter as about 1.8 mm. Nevertheless, it can be seen that the buckling load is recovered to almost 100%. Although area of the delamination becomes large, it is presumed that the same effect can be obtained by making more fine holes and repairing them with the fasteners. Through this study, it was confirmed that micro-bolt repair is an effective method to repair composite structures with delamination which can minimize in-plane tensile strength decrease, weight increase, material consumption, and working time. It is hard work to fabricate holes with fine diameters in thick composite laminates through the machining technology to date. However, as the hole machining technology develops, it is expected that the use of the repair method using micro holes and fasteners will increase.

Acknowledgements: This study was supported by the "Advanced Scarf Repair Method and Equipment Development for Aircraft MRO" through the Ministry of Trade, Industry and Energy (R0004399-2).

373 | A novel repair method for delaminated composite laminate using micro-bolts

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Recently, as the design and fabrication techniques of composite materials have been developed. However, since the composite structure is generally manufactured by laminating thin prepreg, there is a disadvantage of being vulnerable to damage in the thickness direction. Especially, aircraft are frequently exposed to low-velocity impact such as collision with various ground equipment and tool drop during maintenance work. The failure mode of composite structures caused by such low-velocity impacts is mostly delamination, which significantly degrades the performance of the structure. In the past, if a delamination is detected in a structure, the structure was removed and replaced with a new structure. However, as the composite structure is integrated, this method is rarely used. Instead, a method of mechanically fastening the reinforcing plate over the damaged portion is used more frequently. In this method, however, the increase of the weight due to the plate and the fastener is inevitable. The stress concentration around the fastening hole is another problem lowering the tensile strength. Therefore, recently, scarf-patch repair method is widely used with an adhesive. However, this method has a drawback that it takes a very long time to remove the scarf from the original structure. It is also reported as well that the recovery rate of tensile fatigue strength is lower than that of compressive load. Therefore, this study suggests a new method to effectively repair the delamination inside the structure while minimizing stress concentration and weight increase. First, finite element analysis was performed for composite laminates having several holes with the same total area but different diameters. Through analysis, it was confirmed that the failure load of laminates with several fine holes with the same area but smaller diameters is higher than the failure load of laminates with one large hole. Theoretically, the smaller the hole diameter, the closer the failure load of the laminates becomes to the failure load of the perfect laminates. The results of this analysis show that if very small holes are drilled through the delamination area and bolted with small diameter, the degradation of the in-plane tensile strength of the laminate can be minimized while repairing the damage without additional reinforcement plates or patches. In addition, if the adhesive is injected into the delamination area before mechanical fastening, leakage of oil or fuel due to delamination can be prevented. Based on the results of the study, the composite laminate with the actual delamination was fabricated and then repaired with scarf patches and micro-bolts, respectively, the tensile strengths of the two cases were compared. For scarf-patch repair, the damaged area was removed with a scarf angle of 1.9° from the top surface to the delamination surface and replaced with a new patch using a film adhesive. In the micro-bolt repair, three brass bolts of 0.6 mm in diameter were installed in the delamination area without removing the laminated plate. The micro-bolt repair method showed the results confirming the superiority of the micro-bolt repair method compared to the scarf-patch repair method. In the future, fatigue strength is to be confirmed by performing tensile fatigue test, and improvement of fatigue performance is expected to be more remarkable Additional studies will be carried out on the number, arrangement and materials of the bolts. If bolts are manufactured with higher strength materials or the number of bolts is increased, the effect of repairing and thickness reinforcement is expected to be further improved.

Acknowledgements: This work was 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)

216 | Understanding and modelling the bi-axial response of tow-based discontinuous composites

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Tow-based discontinuous composites (TBDCs) are a recently-developed class of high-performance material composed of carbon-fibre tows randomly oriented and placed in a polymeric matrix. This architecture improves the manufacturability of the composite, while preserving a high fibre content (up to 60%), hence leading to good mechanical properties of TBDCs. However, the random microstructure of TBDCs leads to heterogeneity on their local mechanical properties, as the local fibre-content and local fibre alignment vary significantly in the material. The effect of this intrinsic variability in the strength of TBDCs, especially considering their application to structural components, is yet to be analysed. Therefore, this work aims at developing a strength model for TBDCs under in-plane bi-axial loading, taking into account the intrinsic variability of the material, and to validate the model experimentally. To model the strength of TBDCs, a deterministic equivalent ply-by-ply laminate is used to idealise the architecture of the material, accounting for a quasi-isotropic orientation of the tows. A multi-scale approach is adopted, and three sub-models are considered for the different scales: (i) a stochastic non-linear shear-lag model at the micro-scale, to predict the uni-axial tensile strength of a UD discontinuous ply, taking into account brittle matrix cracking and the stochastic location of tow-ends; (ii) a novel interactive tension-shear failure criterion at the meso-scale, to predict the failure envelope of a ply with a given off-axis orientation, taking into account the interaction between tow pull-out (due to longitudinal loading) and transverse failure; and (iii) a first-ply-failure methodto predict the failure envelope of the material. The modelling predictions for the uni-axial strength of TBDCs considering a deterministic quasi-isotropic distribution of the orientations of the tows are compared against the strength experimentally measured for equivalent laminates and actual TBDCs. The deterministic model shows a good agreement with the equivalent laminate experimental data, but cannot capture the strength reduction in TBDCs due to the intrinsic variability of the material. A stochastic model considering the local orientation of the plies is therefore developed; by running a large number of realisations of tow orientations, a cumulative distribution function (CDF) of the failure strength of TBDCs is obtained. Under bi-axial loading, the deterministic model predicts a strengthening effect under combined in-plane tension-tension; this agrees with experimental data from continuous-fibre quasi-isotropic laminates, but it is yet to be verified for TBDCs, for whose bi-axial data has never been reported. Ongoing experimental work using cruciform specimens under different tension-tension loading ratios will be used to validate the model further, and to provide the first measurements in the literature for the bi-axial strength of TBDCs. In conclusion, the deterministic strength model developed for TBDCs generates accurate predictions when compared to equivalent laminates, whereas the stochastic model further developed considers the intrinsic variability of the material. The experimental results give further insight on the mechanical performance of TBDCs and prove the reliability of the models. This study therefore contributes towards shorter design cycles of structures manufactured with TBDCs.

192 | Effects of macro steel fibers on water permeability of cracked concrete

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In this work, the water permeability of the concrete with cracks has been investigated. The cylindrical specimens were pre-cracked by the feedback controlled splitting test. The water permeability of the specimens with different crack width were measured using a constant head equipment. The splitting tensile properties of the specimens with or without macro steel fibers were analyzed. The tortuosity and roughness of the cracked surfaces were quantified. The results showed that with the addition of macro steel fibers the splitting tensile toughness and deformability of the specimens were improved significantly. The macro steel fiber increased the tortuosity and roughness of the cracked surface. The coefficient of the water permeability of the specimens followed the Poiseuille law by considering of the influence of the crack tortuosity and roughness.

193 | Cementitious composite with multiphase conductive materials for sensing of crack subjected to bending

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In this work, carbon fiber and micro steel fiber as well as carbon black were added into the cementitous material to improve the conductivity of the composed mortar specimens. The effect of the multiphase conductive materials on the self-diagnosing performance of beams under bending were investigated, including the pre-crack and post-crack electrical behaviors. The result shows that a linear relationship exists between the fractional change in resistance (FCR) and tensile strain, crack opening displacement (COD). Compared to the carbon fiber/carbon black, steel fiber can enhance the flexural property, meanwhile providing good self-monitoring performance of cracking of the specimen.

258 | Modelling vibrations of the housing for the power steering system

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The application of analysis of vibrating subsystem of complex mechanical systems by means of the different methods were the main purposes of work to solve the task of assignment of frequency-modal analysis and characteristics of the system. The problems concerned of classical and nonclassical methods to solve this problem have been used to obtain the dynamical characteristics in the Gliwice research Centre. Other diverse problems have been modeled by different methods and next they were examined and analysed. Analysing the diagrams of characteristics of confirmed system it has been determined that in case of approximate method the resonance frequencies cover with those which have been determined with the exact method. However, the values of the characteristic in other areas were different. The main aim of this paper is to compare the transients of characteristics of mechanical subsystem of the vibrating discrete – continuous complex system, obtained by the exact and approximate method, that means and to answer the question – if the method can be used to nominate the characteristics of the systems. The main subject of deliberation was to determine the dynamical characteristics of the mechanical system using the exact and approximate method. The problems presented in this paper, that means the analysis of subsystem of mechanical complex systems is however the introduction to the of synthesis of vibrating mechanical complex systems with assumed frequency spectrum.

Acknowledgments: This work has been conducted as a part of research project PBS3/B6/37/2015 (PST-41/RMT2/2015) in 2015-2017.

128 | A new fatigue life model for 3D four-directional braided composites

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A representative volume cell (RVC) FE model for 3D four-directional braided composites with octagonal fiber cross sections was established. Based on the theory of stiffness and strength degradation in unidirectional composites, a new fatigue life prediction model for 3D four-directional braided composites was proposed by considering fatigue failure criteria, damage area criteria and performance damping method of component materials. The fatigue life prediction and progressive damage analysis programs were conducted to simulate the life and damage propagation process of 3D four-directional braided composites under tension-tension cycle loading by using the Abaqus/Standard with the UMAT function. The results show that the proposed fatigue model can adequately describe the fatigue damage behaviors and predict the fatigue life of 3D four-directional braided composites.

136 | Design and manufacturing of novel concepts of car doors

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Future electric cars will require multimaterial lightweight solutions based on composite materials, to meet specific design requirements and also to be cost effective and sustainable throughout their lifecycle. Thermoplastic matrix composites reinforced with carbon fibres are potential candidates, if manufacturing feasibility and the required properties can be demonstrated. This paper reports design studies carried out, within an EU funded project ENLIGHT, to evaluate the feasibility of manufacturing car doors for electric vehicles, using thermoplastic matrix composites reinforced with carbon fibres. Doors are highly complex structures. Customers interact intimately with them along many dimensions. Doors comprise both interior and exterior elements, causing them to be links between these two domains of the car. Many of the attributes conflict: for example, better water leakage and wind noise behavior will make it more difficult to close the door; better side intrusion protection will make the door heavier. The design of the door was based on FEM simulation and optimization analysis using weight reduction attributes. All simulations were carried out in accordance with target behaviours and load cases defined by the JLR and were were benchmarked with an aluminium alloy door developed within the EU funded project ALIVE. The adopted strategy for the weight reduction was the utilisation of composite materials for all structural components. The CAD geometries for the composite model were provided by JLR. The FEM analysis results were carried using commercial finite-element-software Abaqus. The Hashin criteria (Hashin, and Rotem, 1973; Hashin, Z., 1980), already implemented in the ABAQUS software code, was used to assess the composite material structural behaviour. For the aluminium model, the criteria used was the comparison of the Von Mises stress with the yield strength of the material. All the connections between the parts of the model were made by “ties”, which are rigid connections available on the FEM software. The contact option in some zones to avoid interpenetration of the parts and allow stress concentrations due to contacts was also used. The composite material used was a spread tow TeXtreme® 0/90 fabrics, with carbon fibre and a nylon matrix. The mechanical properties were obtained experimentally within the ENLIGHT project. The aluminium alloy properties were obtained in the ALIVE project. The overall aspect of finite element mesh for composite model is shown in Figure 1. The finite element model of the door model, contained 110198 quadrilateral shell elements (S4R) and 1486 triangular shell elements (S3R). Shell elements with reduced integration were chosen, which have 6 degrees of freedom at each node of the element and these elements have bending and membrane capabilities both in-plane and normal loads. The load cases were defined by the OEM partners, and they consist on 6 different load case scenarios: a) Door Sag. b) Window Frame Stiffness. c) Door Belt Static Strength. d) Door Over Load at Opening. e) Door Primary Mode. f) Door Oil Canning Load Deflection. In order to validate the hot stamping of continuous fibre thermoplastic composites for complex parts, a door demonstrator has been made. The door is composed by several components, namely the door inner, door outer, outer door skin and waist rail. All of them were produced with Oxeon’s Spread Tow Carbon thermoplastic prepreg by hot stamping process at INEGI. A final door demonstrator was assembled on an assembly jig as illustrated in figure 3. Through ply optimisation, the selected failure criteria for the carbon composite materials and target behaviours set by the OEMs were. The results obtained show that is it possible to optimize the structural behaviour of the door, meeting all the requirements and simultaneously achieving a weight reduction of ~53% over the original steel door, or ~20% over the highly optimised Aluminium door developed as part of the ALIVE project.

Acknowledgements: The work reported has been carried out within the project ENLIGHT, grant agreement nº SCP2- GA-2012-314567-ENLIGHT-314567.The EU support is gratefully acknowledged.

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118 | A nonlinear viscoelastic constitutive model of propellant composites

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Propellant composites are typical viscoelastic materials and often suffer from a complex loading. In this paper, a nonlinear viscoelastic constitutive relation is studied for this kind of composites. First, the linear viscoelastic constitutive relation is exposed, and a nonlinear viscoelastic constitutive model is proposed by replacing the relaxation modulus with a nonlinear one. The parameters in the nonlinear relaxation modulus are then obtained by fitting the tensile stress-time curves under constant strain rates, and therefore depend on strain rate. The constitutive model is finally extended to the two-dimensional and three-dimensional case, and incorporated to the UMAT of Abaqus package in the manner of incremental finite element method. The numerical simulations to tensile tests are carried out for various strain rates to validate the present constitutive model.

Keywords: Propellant composites, nonlinear viscoelastic, nonlinear relaxation modulus, UMAT, tensile tests.
Acknowledgements: This work was supported by the National Natural Science Foundation of China (Grant Nos. 11672221, 11272245).

89 | Thermal conductivity and elasticity of reinforced plates with applications to T-ribbed, II-ribbed and I-ribbed plates

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Currently, the preponderance of uses of composites is in the form of laminated or reinforced beams, plates and shells. It is clear that the elaboration of micromechanical models that accurately predict the properties of these structures at the design stage, preferably by means of closed-form design-oriented equations, offers significant advantages to the designer and is more likely to promote the use of a new composite/nanocomposite material system in new applications. Because laminated and reinforced plates and shells are often characterized by a periodic or nearly periodic configuration the method of asymptotic homogenization has been at the forefront of the pertinent analytical and semi-analytical modeling efforts. One of the main advantages of asymptotic homogenization is that it successfully decouples the microscopic (fast) and macroscopic (slow) scales characterizing the aforementioned structures; the microscopic scale “zooms in” on the periodicity unit of the composite and deals only with the geometrical and structural features therein, whereas the macroscopic scale “zooms out” on the overall structure and handles the global formulation of the problem. The specific mathematical details of asymptotic homogenization may be found in Bensoussan et al. [1] and others. This paper determines accurate expressions for the effective thermal conduction properties of T-Ribbed, Π-Ribbed and I-ribbed reinforced plates as well as the effective elastic properties of I-ribbed plates. All structures considered are made up of arbitrary orthotropic constituents. To evaluate these properties, the authors invoke general, previously developed asymptotic homogenization models pertaining to a thin magnetoelectric composite plate with rapidly varying thickness, see Hadjiloizi et al [2], [3]. In general, the geometrical and material complexity involving reinforced plates, particularly in the case that some or all of the constituents exhibit piezoelectric, piezomagnetic or some other sensor/actuator behavior (which brings coupling of different fields into the foray), renders analytical modeling rather troublesome. In this work, the authors show how to overcome associated problems and effect accurate closed-form expressions for the elasticity and thermal conduction properties of reinforced plates. It is

shown in this work that the results obtained can be successfully employed to tailor the effective thermal conduction and elastic properties of composite T-, Π- or I-ribbed plates to the requirements of a particular engineering application by changing certain geometric or material parameters of interest. The validity of the results is illustrated via comparison with other models. Finally, it is shown that in the limiting case of a thin elastic plate of uniform thickness the derived model converges to the familiar classical plate model. The recent emergence of additive manufacturing and 3-D and 4-D printing technologies, see Ge et al., [4], render fabrication of structures with arbitrary complexity more viable than ever before; thus, micromechanical models that can design and analyze such structures as the T-ribbed, Π-ribbed and I-ribbed orthotropic plates considered herein are very important.

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337 | Numerical simulation for the yield behaviour of stochastic fibre reinforced composites with overlap

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The transversely isotropic stochastic fibre reinforced composites with a novel geometry is proposed in the present work and the 3D representative volume element (RVE) has been generated for the study. Compared to conventional stochastic fibre reinforced composites, fibres in the present geometry are bonded together due to the process of sintering, thus constructing a network among fibres and enhancing the stiffness and strength of the composites. The number of over-linking and degree of overlap are two key factors in determining the volume fraction of fibres which is the crucial parameter of fibre composites. In order to avoid the over constraint caused by embedded element technique (EET) while applying periodic boundary conditions (PBC) to the RVE, the automatic searching and coupling technique (ASC) is applied to couple the corresponding nodes between fibres and matrix. The finite element analysis has been conducted to study the yield strength of the RVE under uniaxial, biaxial and triaxial tension/compression. The results indicate a relatively higher stiffness but lower yield strength transversely and lower stiffness but higher yield strength longitudinally. The yield surface has also been obtained in this research.

340 | Modeling of low velocity impact barely visible damages - Numerical and experimental investigation

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Fibre-reinforced composite materials are known for their high weight-specific mechanical properties and are therefore used in numerous lightweight engineering applications, in particular in aircraft design. However, a constant concern for such laminates – much more than for similar metallic structures – are impact loads of foreign objects, which can cause internal material damage. This damage can significantly reduce the strength, in particular with the temperature, and it can grow under load and may be difficult to detect. The special case of occurring damages are Barely Visible Impact Damages (BVID) which 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 area of fiber failure does not appear. On the impacted surface, a small impact mark appears but on the opposite surface, the damage area is considerably more extended. 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. Typical impact scenarios in aircraft design range from a tool dropped on the laminate surface (high mass, low velocity), over runway debris thrown up by the tires or hail (low mass, high velocity) to bird strike during flight (high mass, high velocity). At present, the phenomenon of the impact with low velocity, in which the material is not perforated, is generally modeled using the decomposition law at the interfaces of the composite layer and with the use of the progressive failure algorithm, where the algorithm can be based on the Material Properly Degradation method (MPDG) as well as on

the approach Continuum Damage Mechanics (CDM) approach. The objects of the analysis are composite thin-walled plates. The discussed plates were made of eight-layer Glass Fiber Reinforced Polymer (GFRP) laminate with quasi-isotropic, quasi-orthotropic and angle ply systems and are predefined to conduct the Impact and the Compression After Impact (CAI) tests. The purpose of this work is to arbitrarily model the low velocity impacts effects and to analyze the behavior of composite plates as well as to check the evolution of the damages 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. The obtained results were compared with the results of the experiment.

52 | Low-velocity impact behavior of hot compacted polyamide 6 based laminates

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Nowadays composite materials are widely used to replace traditional ones thank to their functional and structural properties. Potential uses of these materials combining at least three phases: matrix, reinforcement and interface, is influenced by many factors including manufacturing conditions and poor compatibility between base constituents. Moreover, their inherently complex structure prevents their recycling and leads to a relevant environmental impact at the end of their useful life. Recently, an alternative family of composite systems, best known as single polymer or self reinforced composites, overcoming all these drawbacks, has earned a special interest. In this case, both the reinforcing and the matrix phase are constituted by the same polymer even if in different form (i.e. films and fibers). In this contribution, self reinforced polyamide 6 (PA6) laminated structures, obtained by a conventional hot-compaction technique, are subjected to low-velocity impact tests. In particular, plates consisting of 24, 30 and 36 layer of two commercial PA6 clothes (yellow and red) were impacted up to perforation and results were discussed in terms of typical load-deflection and impact energy-time curves as well as of impact parameters as the so-called ductility index. Taking into account that the yellow fabric is totally made by PA6 fibers while the red one contains, as specified by the supplier, 1% of polyurethane fibers, experimental evidences have confirmed mechanical benefits related to these latter hybrid structures. In all cases, damage mechanisms, also affected by the sample thickness, are mainly dominated by the fiber breakage, as also confirmed by morphological analyses and visual inspection of the impacted areas.

210 | Bauxite red mud utilization as principal component for red ceramics production

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The waste of Bayer refining thermo-chemical process of alumina production has red color because of high content of iron oxide and named as “red mud” (RM). From 6 tons of bauxite ore is produced about 1 ton of aluminum (DMM, 2013). By producing 25,461 million tons of bauxite a year, Brazil has the potential to produce about 17 million tons of red mud per year. Infamous environmental tragedy in Hungary on the 7.10.2010 demonstrated in practice the real danger of red mud and acuteness of the problem of it utilization. Only industrial use of so huge and the constantly growing deposits of waste as raw materials for a variety of applications in an amount equal to its production could prevent these types of disasters with high economic benefits and solve a grave world environmental problem. The main goals of this research work were to propose new economically efficient solutions for ecological hazardous waste of bauxite treatment this environmental problem, i.e., to utilize as high percentage of industrial waste (RM, FS and LPW) as possible; to study the possibilities of heavy metal binding in waste processing; to obtain new environmentally clean construction materials with suitable mechanical properties; to study the structural formation processes of new materials in order to increase their valuable properties. All

materials under study were chartered by different complementary methods: granulometric composition - by Laser Diffraction Particle Size Distribution Analyzer; mineral composition – by X-ray diffraction (XRD); chemical composition by X-ray fluorescence (XRF) method; morphological structure – by scanning electron microscopy (SEM); solubility and lixiviation of metals from liquid extracts - by method of atomic absorption spectrometry (AAS); chemical composition micro analyses by micro-mass analyses through laser micro-mass analyzer LAMMA-1000 and by method of energy dispersive spectroscopy (EDS); mechanical resistance – by axial compression strength; were studied also water absorption and linear shrinkage of the developed materials. Were developed composites from hazardous waste red mud (52 – 78wt %) of bauxite processing for aluminum production with pH value near 13.5, ground cooled ferrous slag (20–45%) and lime production waste (2%). Different humid mixes of these tree wastes were compacted with a force 10 MPa in cylindrical form of 20 x 20 mm, hardened at air-humidity conditions (94-96% humidity) and tested at the ages of 3, 7, 14, 28, 60, 90, 180 and 365 days. The materials have axial strength 3.9 MPa on the 14th day and 9.1 MPa on the 365th day and a coefficient of linear deformation between 1.5-2.0%. The hardening process monitored by XRD, SEM, EDS and LAMMA demonstrates that mainly amorphous new formations are responsible for the materials' structure formation. Leaching and solubility tests show that their level is far below the demands of the environmental standards. The results of the present study demonstrate that RM as the main component in mixtures with other two industrial wastes – ground cooled ferrous slag (FS) and lime production wastes (LPW) - can be used as materials for road and airfield runways, levee cores, industrial and municipal waste dumps, in the foundations of buildings, in the production of tiles, bricks, etc. In addition to the economic benefits accruing from its use, RM is easy to apply, adapting to local industrial waste dumps without creating new residues.

284 | FE analysis of pultruded FRP built-up columns

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Presently, very few research papers concerning built-up members made of Pultruded FRP (PFRP) material are available and no technical standard reports recommendations and design rules specifically suited for these members. Dicuonzo et al. (4th Int. Conf. on FRP Comp. in Civil Eng., CICE 2008) presented a temporary, modular all-GFRP structure designed for an expo fair stand. In this structure, the 3 m-high columns are comprised of two standard PFRP C-shaped profiles with dimensions 203 ′ 56 ′ 9.5 mm, connected with one another through 500 mm-spaced bonded battens. The modular, 6 m-span roof girders allow for covering 12 m-span lengths without requiring intermediate columns. Top and bottom chords of the roof girders are comprised of two standard PFRP equal-leg angles with dimensions 102 ′ 102 ′ 9.5 mm, once again connected with one another using bonded battens. Bai et al. (Mater Struct 2013; 46: 1143-54) performed four-point bending tests on built-up members used in the five-storey GFRP Eyecatcher building in Basel, Switzerland. That structure, built in 1999, still remains the tallest FRP building in the world. Its structural skeleton is comprised of three parallel trapezoidal GFRP frames connected by wooden decks. The various members of the frames were designed by assembling individual standard PFRP shapes by continuous bonding. Boscato et al. (Compos Struct 2015; 121: 46-63) presented experimental results on PFRP built-up columns comprised of four standard C-shaped profiles mutually connected at discrete points either by bolting or by bonding. In a first attempt to interpret the experimental results with simple closed-form equations, the authors compared the experimentally evaluated buckling loads with those estimated using (1) Euler's and (2) Engesser's equations (applied to the built-up columns considered as members with uniform cross-section) and (3) an expression typically adopted for steel built-up members. Unfortunately, none of these expressions was capable to predict the experimental buckling loads and the authors concluded that geometrically nonlinear FE analyses are necessarily to be performed to capture the actual column behavior. The previously quoted papers do not raise the issue of a systematic approach to the design of PFRP built-up members, which should consider: various basic profiles (C- and L-shaped, etcetera); different types of connection between basic profiles (battens and or lacings, connected by bolting and/or bonding, etcetera); changes in geometric characteristics (member total length, spacing of the battens, etcetera); and various types of loading. In this context, the present paper deals with a series of parametric analyses of PFRP built-up columns comprised of two closely spaced C-shaped profiles. Numerical models of the columns are developed using bidimensional orthotropic finite elements. In order to define the maximum distance between the battens that ensures an overall buckling behavior, linear buckling analyses are carried out for different spacings of the battens. Moreover, to investigate the influence

of the batten stiffness, both rigid and deformable battens are used in the models. Finally, geometrically nonlinear analyses of the coumns with initial imperfection are carried out to capture the ultimate resistance. In these analyses, the ultimate conditions are located either by a peak in the load-lateral deflection column response or by the attainment of the limiting material strenght at some point of the column. Since several battens spacings are considered, the numerical results obtained could be used, in analogy to the case of PFRP I-section columns (see National Research Council of Italy, CNR-DT 205/2007), to define a buckling design curve for built-up columns.

205 | Influence of temperature on the impact behavior and damage tolerance of hybrid woven-ply thermoplastic laminates for aeronautical applications

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Impact damage tolerance of hybrid carbon and glass fibers woven-ply reinforced PolyEther Ether Ketone (PEEK) thermoplastic (TP) laminates obtained by consolidation process is investigated. Service temperature being one of the most important parameters to screen TP or thermosetting matrix for aeronautical purposes, impact testing at room temperature (RT) and near the glass transition temperature (Tg) has been conducted. From the results, it turns out that temperature has little influence on the impact behavior in terms of maximum force developed or maximum deflection, though it reduces the dissipated energy especially at lower impact energy. However, temperature has a strong effect on the internal and external damages caused to the plate, as it increases the permanent indentation and it limits the projected delaminated area. As for the influence of temperature on the compressive residual strength of the laminates, it also appears that the classical experimental set-up for CAI tests is not completely appropriate to draw a clear cut conclusion. At last the obtained results show that the considered TP-based laminates are characterized by a very good impact behavior and a high-degree of damage tolerance.

131 | Fatigue characterization of Nomex honeycomb composite sandwich beam and tomography analysis

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This paper concerns the experimental examination of the mechanical behaviour of a honeycomb sandwich structure under two different axes. The first one is the fatigue behaviour of the sandwich structure. The second axe is the tomography analysis of the honeycomb sample. The first part of this paper examines the fatigue behaviour of honeycomb sandwich used in the field of aeronautics under four point bending test. An experimental study has highlighted the influence of cell's direction fabrication on the behaviour of such material. The first S/N curves are presented. The second part discusses the resin density distribution along the sandwich specimen and cells deformation comparison with tomography analysis.

110 | The effect of portland cement inclusions in glass fibre reinforced composites

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Composite materials have been considered as substitutes for metallic materials, owing to their conformability and good specific mechanical properties. Particulate composites exhibit, in general, higher compressive stiffness and strength while fibrous materials exhibit higher tensile stiffness and strength. In order to achieve higher mechanical performance under tension and compression, hybrid fibrous-particulate composite materials consisted of glass fibre fabrics (200 g/m2 grammage and 2.54 g/cm3 density) and Portland cement particles (diameter < 44 μm and 3.17 g/cm3 density) were investigated. The epoxy matrix is composed of RenLam-M resin and HY 951 hardener (supplied by Huntsman-Brazil). The specimens were manufactured with nine layers of glass fibre fabrics joined together with the epoxy matrix by hand lay-up and cured at room temperature. Three-point flexural tests were

performed according to the ASTM D790/2010. Two experiments were conducted based on a full factorial analysis in order to evaluate the flexural stiffness and strength of the hybrid composites. Experiment I investigated the effect of the location of particle inclusions (no particles, particles in four upper layers, in four lower layers or all layers), curing time (7 and 28 days) and manufacturing technique (vacuum or uniaxial pressure) The fibre-matrix volume fraction and the mass particle fraction were fixed at 49/51% and 10% respectively, based on a previous work published elsewhere by this group (Journal of Research Updates in Polymer Science, 2016, 5, 108-113). Experiment II investigated two distinct fibre-matrix volume fractions (49/51% and 30/70%) and various particle mass fractions (0, 2.5, 5.0, 10.0%), with particles only in the upper (under compression) four layers of the samples, 28 days curing time and uniaxial pressure (no vacuum). The 49/51% fibre-matrix volume fraction was determined through preliminary tests so as to identify the lower matrix content enough to visually laminate all nine glass fibre layers with adequate rheology and finishing. The 30/70% fibre-matrix volume fraction was the upper matrix content at which resin leakage occurs with no uniaxial pressure or vacuum applied. The results were analysed via Analysis of Variance (ANOVA). It was observed (experiment I) a significant increase in flexural strength (approx. 20%) and stiffness (approx. 8%) for 28 days curing time. The flexural strength was also higher when cement particles were included only in the upper four layers or in the whole composite. The stiffness, however, was higher when particles were included in all layers. In both cases, values were approx. 5% higher relatively to the condition without particles. Vacuum manufacturing expels a significant amount of resin when particles were included, leading to lower interlaminar adhesion and hence, lower stiffness and strength, so that uniaxial pressure (no vacuum) is more adequate in this case. In the absence of particles, however, vacuum reduces voids and enhances flexural properties. The mechanical efficiency of particle inclusions in the upper four layers was further investigated with Experiment II. It is worth noting that higher flexural strength (stiffness) was achieved for composites manufactured with 51/49 % fibre-matrix volume fraction and 2.5% (5.0%) of particle mass fraction.

43 | Load-carrying behavior of highly anisotropic corrugated laminates

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Anisotropy, apparently a material property, can be traced back to geometry. The geometry of singly-curved corrugations of periodically corrugated laminates effects extreme anisotropy beyond of what the sheet material by itself can offer. Such corrugated laminates exhibit interesting mechanical effects on local and global structural scales. Simulation of the global structural response of large plates with many periodic corrugations by using the finite-element method tends to result in very large numerical models as each corrugation must be mapped with a sufficient number of finite elements. This problem is mitigated by representing the corrugated laminate with a homogenized flat substitute plate, where corrugated laminate homogenization models have been contributed to the literature. Presently we will investigate the load-carrying characteristics of corrugated laminates on a structural scale and suggest simplified methods for efficient preliminary design of plates under uniform pressure. For motivation we refer to the practical backdrop of having the corrugated laminate serve the purpose of morphing wing of large aircraft. We consider a corrugation pattern consisting of circular segments and show that in the limiting case of maximum corrugation amplitude the center deflection of plates with aspect ratios on the order of one is dominated by the highest bending stiffness value only. In fact, on a global scale, the plate carries the load quite similar to a beam and we verify, starting from plate theory, that formulas from beam theory can be used for preliminary sizing. We also point out that in the described situations plate shear effects contribute significantly to the plate deflection and suggest a simple procedure for estimating the shear stiffness of corrugated laminates. The plate and beam theory predictions are verified with finite-element simulation of the structural response of the substitute flat plate.

44 | Analytical model for non-linear stiffness prediction of corrugated laminates in tensile loading

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Corrugated structures can achieve highly anisotropic structural stiffness properties due to their geometry and hence they are interesting candidates for flexible skins in adaptive structures such as morphing wings. Especially in tensile loading the corrugated laminates can undergo large global deformations while the local strains remain relatively low. Therefore, geometric non-linearities can occur and efficient modeling techniques are required. While many models exist to calculate the initial linear stiffness of corrugated laminates, there is a need to develop new models which account for geometric non-linearities since the modeling by use of commercial FEM software leads to enormous computational costs. The structural response mainly depends on the geometry parameters, namely corrugation amplitude and laminate thickness and also on laminate design. Close to the reference configuration the local internal bending moment dominates the stiffness response. As the corrugated laminate deforms, the corrugation amplitude decreases and the local internal normal force becomes more and the bending moment less important. In the present work an analytical model is derived which calculates the non-linear stiffness response of corrugated laminates which are loaded in tensile direction. We focus on structures made from circular sections. The model is based on a simplified mechanism consisting of stretchable rods and discrete torsional springs. As input parameters only the initial linear stiffness of the corrugated sheet and the membrane stiffness of the flat sheet are needed. The analytical model is numerically verified with a non-linear structural analysis using FEM. Furthermore, it is experimentally validated using samples manufactured by 3D printing. The test samples were tested in a tensile machine measuring the non-linear stiffness response. The verification and validation of the model shows that the analytical model, numerical solution and experimental results agree very well. Furthermore, the analytical model was verified for different thicknesses and the calculations show that the model is able to reproduce accurate non-linear stiffness results for both thin and thick corrugated laminates. A parametric study illustrates the valid solution space for linear models and indicates for which global displacements the use of non-linear models is required. Thanks to its low computational costs the model is very well suited for design purposes for instance in morphing wing applications.

111 | Composite soils acting on Rayleigh waves

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The high density of deep foundation or ground reinforcement techniques in urban area, leads searchers to believe in a significant interaction of these buried structures with a certain component of the seismic signal. A promising way to cause a modification on the seismic disturbance is to create a complete artificial anisotropy by implementing geometrical elements, full or empty, in the soil. The physical process is the interference of waves (body or surface waves) scattered from surfaces or objects. The effects of the anisotropy are reinforced by the local resonance of implemented elements which are disposed along a grid according to transformation elastodynamics and morphing tools that could theoretically lead to an ideal cloak detouring waves around a protected area. In this periodic or non-periodic media, the desired effects are total reflection (Bragg's effect), band-gaps, wave-path control, attenuation by energy-dissipation, etc. Another way to act on the seismic signal is to investigate the effects of a 3D-grid of specific tuned resonators in the soil. For instance, these resonators could be spheres connected to a bulk of material via ligaments and moving freely within a surrounding air cavity. The objective is to obtain stop-bands for seismic waves with the aim to avoid the cases of resonance of the soil with the main vibration modes of the buildings. Another promising avenue is the studies led for auxetic metamaterials buried in the soil, bringing band gaps at frequencies compatible with seismic waves when they are designed appropriately.

49 | Post-failure behaviour of laminated glass beams

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An experimental study investigates the properties of progressively damaged laminated glass (LG) beams made with modified PVB interlayers. Previous research demonstrated how ionoplast interlayers significantly improve the load-bearing capacity, the dynamic response and the residual stiffness of damaged LG structural elements. As all of these key elements in architectural glass design depend on the ability of the interlayer to allow for coupling effects between the glass plies or the glass fragments, it is important to test, model and understand the significant differences between plastic materials used for glass lamination. As new polymers are being developed and come to the glass industry, the development of reliable testing procedures is needed to assess benefits and differences among them. For instance, previous research demonstrated how dynamic and static tests can be performed for evaluating and comparing Ionoplast Interlayer properties, the aim of the present research is to assess whether or not similar procedures can be reliably carried out for different materials. The ‘‘tension stiffening” effect is also a key element in understanding the characteristics of the composite glass-interlayer elements; the study of this property and its evolution with time allows for more reliable post-breaking design and maintenance plan for damaged structures.

80 | Buckling analysis of composite mesh reinforced inflated arch

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The inflatable membrane structure has been widely used in aerospace spacecraft, ground construction and other fields, due to its light weight, high load capacity, inflatable deployment and reusable. The inflated arch is typical used to support space inflatable membrane structures, such as inflated ring, truss and airships. The structural bearing capacity is the key to the application of such structures, in which the weak structural stability restricts its application in the inflatable membrane support structure. The overall buckling triggered by local wrinkle is one of the main failure modes of the inflated arch. The concept of composite mesh reinforced inflated membrane structure has been raised, in order to improve the carrying capacity of the inflatable membrane structure. Both in plane and out-of-plane buckling behavior of composite mesh reinforced inflated arch are derived based on pseudo-curved-beam model (PCBM) which is established in this paper. All these results within this paper will give a reference to optimization design of inflated structure. Pseudo curved-beam model. A thin film inflatable beam is subjected to internal pressure and external load. The deformation of inflated beam consists of two successive states: the initial state with zero stress, and the inflated state. In this paper, the deformations are derived based on the inflated state. Based on Власов assumption that the projection of the cross section of the inflated beam in its original plane during deformation is kept constant. Then the geometrical relationship of the space arbitrary curved beam is obtained. The finite element method was used to analyze the buckling behavior of composite mesh reinforced inflated arch structure. In order to simplify the calculation and consider the influence of the mesh and charging on the bearing performance structure, homogenization processing was applied to obtain the tensile, compression, torsion and bending stiffness of the structure under inflated state. Buckling analysis. The buckling behavior of composite mesh reinforced inflated semi-circle arch structure with 4 meters in structure radius and 0.1 meters in section radius was analyzed by using both simulation and pseudo-curved-beam model. comparison of the two results showed that the two kinds of results are consistent with the in/out-of-plane buckling modes, and the buckling load errors are as follows: out-of-plane symmetry buckling 2.835%, out-of-plane anti-symmetry buckling 2.835% and in-plane anti-symmetric buckling 2.835%. The accuracy and efficiency of the PCBM method are proved. Conclusions. In summary, pseudo-curved-beam model was established to simplify in/out-of-plane buckling analysis of composite mesh reinforced inflated arch. The result comparison with simulation demonstrates the effectiveness of the pseudo-curved-beam model. The results provide a good reference to design the inflated structures.

69 | Strength and stiffness design of laminates via Singular Values

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The singular value decomposition (SVD) is a very powerful tool that is utilized for studying input-output properties in multivariable systems. This phenomenon is applied to the laminated composites. The SVD based analysis is well suited input-output directional relationships, associated singular vectors tell us how the outputs (strains or stress) are related to inputs (load). In a laminated structure, when a service load is in the direction of left singular vector, the output stress is in the direction of right singular vector and the gain of the structure for stresses is related to singular values. Subsequently, each right singular vector tells us how we would place an input into the structure to produce a gain equal to the associated singular value and the left singular vector tells us how the response to this input is distributed among the different stress components. In practice, a structure to be designed however is subjected to given loads and boundary conditions and a multitude of stress and strain states may exist in a structure; hence, the optimal constitution of a laminate in a structure cannot be sought by considering the laminate subjected to a priori stress and moment resultants. Therefore another design objective, called minimization of stiffness or stress for the worst possible load case, emerges to take into account all possible load cases. Using the SVD has the following some advantages also in this area. Firstly the largest singular value and associated left and right singular vectors give the worst possible load case to which the laminate can be subjected and associated strains of the laminate respectively. Secondly, minimization of the largest singular value guarantees the minimization of strains in response to the worst possible load case. In the study, it is shown that, shaping the singular values of a composite material is equivalent to shaping the response of the material. Numerical examples and finite element analyses are also presented for some test problems.

61 | The formation of grain boundaries and their influence on the elastic and thermophysical properties of metal-ceramic composites

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Cermets (metal-ceramic composites) are modern construction materials used in different branches of industry. Their toughness and heat resistance are determined by their elastic and thermophysical properties. In addition, these properties are significantly dependent on the grain boundaries in the material. These boundaries are formed in the sintering process. In this work, cermets based on corundum and stainless steel (sintered in a high vacuum at temperatures of 1500–1600 °C) are investigated. The volume of steel in the samples varies between 2 and 20 vol.%. The elastic moduli were measured by the ultrasonic method at room temperature, measurement of the thermal conductivity coefficient was carried out at temperatures of 100 and 200 °C, by a method of continued heating in an adiabatic calorimeter. We found two extremes for the dependence of the elastic moduli (E and G) on the stainless steel concentrations, the nature of which is unknown. The moduli values changed in the ranges of E = 110–310 and G = 60–130 GPa (for different temperatures of sintering). Similar dependence is observed for the thermal conductivity coefficient with values varying by 10 to 40 relative units. A discussion of the results based on the structure cermet model as multiphase micro heterogeneous media with isotropic physical properties is also presented.

56 | Investigation of the interfacial fracture toughness of the sandwich materials

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Composite materials used are on the rise in different engineering fields. Following this trend the wind turbine industry has adopted composites as their primary material of choice. For wind turbine blades having large unsupported functional aerodynamic surfaces, the structural stiffness is very important. Stiffness is required to keep the deformations to a minimum under aerodynamic forces. The blade is thus stiffened using sandwich structures at high strain locations within the structure. The lightweight foam cored sandwiches add stiffness at the same time pose a challenge for design as the difference in stiffness of both the face-plate and the foam core is very high. The resistance to fracture in any part of the structure is an important design parameter to be determined. The determination of fracture resistance quantified here as the Strain Energy Release Rate (SERR) poses some unique challenges when dealing with highly heterogeneous materials in terms of their stiffness. The fracture resistance of sandwich structures will be discussed here. In this study some approaches have been analyzed while others are developed to tackle this problem and to measure the Mode I & II SERR of the face-plate foam-core interface. The

sandwich core varies in both thickness and density depending on the loading and thus the location along the blade length. However for this study we have used a single density of foam core for the most part of the turbine blade. Different thicknesses of the foam cores are used to determine the effect of scale on the calculated SERR.

12 | Estimation of local permeability/porosity ratio in resin transfer molding

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Resin transfer molding (RTM) is one of the most promising techniques for manufacturing high-performance fiber-reinforced composites (FRP) with respect to cost. In RTM, the permeability/porosity ratio of the fiber preform inside the mold is a critical process parameter, which varies with the geometric formation of the fiber reinforcement. This parameter dominates the property of resin flow and hence influences the final product quality. Various measurement systems have been developed for permeability estimation. However, most of them assume that the material porosity is a constant and estimate the permeability of the entire fiber preform as a single value, while the local variations are often ignored. In this work, a measurement system is developed to estimate the local values of the permeability/porosity ratio in RTM, which does not require to mount a large number of pressure sensors in the mold to obtain the local pressure gradients. Instead, at each sampling time point, the equivalent permeability/porosity ratio of the fiber preform between the injection gate and the flow front is calculated using Darcy's law. In the formula, the pressure difference along the flow path is known when the constant-pressure injection is employed, while the position of the flow front is acquired by a visualization system. Then, the local ratio can be derived based on the relationship between the equivalent values and the local ones. The feasibility of the proposed method is illustrated with the experimental results.

15 | Convergence and accuracy of discrete singular convolution and harmonic differential quadrature for vibration analysis of composite conical shells

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Shells and plate structures have wide applications in different engineering components such as aerospace, civil, petro-chemical and mechanical engineering and structural efficiency necessitates a vibration and buckling analyses for design. By this time different analytical and numerical methods have been used for analysis of plates and shell structures such as circular shells, conical shells and panels, circular and annular plates and rectangular plates. In the present work, an approximate numerical solution of the FSDT type governing equations for the free vibration analysis of conical shells is presented. For this purpose, discrete singular convolution (DSC) and harmonic differential quadrature method (HDQ) have been used for discretization of governing differential equations of problem. The performances of these two methods have been compared for isotropic, composite laminated and FGM cases. The effect of some parameters related to HDQ and DSC methods on results and accuracy have also been tested. It is found from the results that the both methods have same accuracy. However, the method of DSC needs relatively less grids for higher modes of frequency of free vibration. But the CPU time is nearly same for equal number of grid points.

40 | Multiscale models of imperfect interfaces in composites

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In composites, the interfacial load transferring mechanics plays a crucial role in determining the failure of the component. The presence of debonding between the reinforcement and the matrix is classically modeled by using an imperfect interface law prescribing the continuity of the traction vector and a jump in the displacement vector proportional to the traction. In the present contribution, we report on some recent results proposing multiscale imperfect interface laws describing the behavior of soft and hard interphases in composites and able to take into account more general effects, like higher order terms arising from the elasticity properties, non linear and damaging behavior of the interphase. Some examples are provided in order to illustrate the applicability of the proposed interface laws.

23 | Multi-sensor measurement integration of photogrammetry and three dimensional laser scanning technology

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This manuscript focuses on a statical experiment of composite arch structure based on terrestrial laser scanning (TLS) and photogrammetry measurement. The proposed method can especially figure out deformation of occluded area of the arch structure, which is not easy to measure with instruments. Point clouds data from raw scanning is processed to extract the surface of the composite structure, where there is the most significant deformation behavior. Surface approximation of the point clouds is implemented based on recursive polynomial approximation, and its uncertainties are investigated and improved. The point clouds extraction is also optimized and a comparison of the surfaces from the original and optimized extraction of point clouds are presented. The results of surface approximation based on TLS have certain relation with surface roughness of specimen, which can be eliminated by subtraction in deformation calculation.

36 | Optimal surface deformation analysis for measurements of arch-based composite structures

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In the nowadays constructions, arch based structures play an important rule and need to be significantly understood for their mechanical and physical properties. Due to varies loads and influencing factors on the stability and reliability of such structures, only a theoretical numerical analysis is sometimes difficult. Therefore, measurements can assist the theoretical analysis in several manners. One of the most important issues is the deformation analysis within load experiments. This paper will focus on the presentation of new possibilities for surface based measurement techniques and their applicability in deformation analysis of arch structures. 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 an arch 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. Finally, the 3d surface based deformations are analyzed with an uncertainty estimation to decide about the quality of the results. The theoretical procedure is applied to a practical example for a stability analysis of an arch structure in a laboratory.

COMPOSITE STRUCTURES IN CIVIL ENGINEERING

345 | Dynamic analysis of base isolated structures subject to extreme seismic events

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An innovative seismic isolator called high damping hybrid seismic isolator (HDHSI) is analyzed. The high damping hybrid seismic isolator (HDHSI) is obtained by the assembly in series of a lead rubber bearing isolator (LRB) and a friction slider isolator (FS) characterized by a high friction coefficient. The base isolation system has been designed according to the European seismic codes EC2 and EC8. The base isolation system is adopted for the passive control of structures and the base isolation for the earthquake resistance of reinforced concrete (RC) buildings. In the analysis the seismic response of a multi-storey reinforced concrete (RC) building base isolated by the proposed isolation system is compared with the seismic response of the same structure base isolated by lead rubber bearing isolators (LRB). The considered HDHSI base isolation system is compared to a traditional LRB base isolation system for the seismic protection of structures. A nonlinear dynamic analysis is performed for the base isolated multi-storey RC structure. In the analysis different extreme seismic events have been considered.

The considered extreme seismic events are characterized by extreme values of peak ground acceleration and frequency content. Accordingly, the considered seismic events are characterized by anomalous values of intensity and frequency content. The reported nonlinear dynamic analysis investigates the multi-storey RC building base isolated by the considered HDHSI system. The time history of the base shear and the time history of the base displacement of the superstructure are shown for the multi-storey reinforced concrete building subject to the considered extreme seismic events. Accordingly, the features of the considered HDHSI base isolation system are shown for the seismic protection of multi-storey reinforced concrete buildings under extreme seismic events.

336 | A dynamic nonlinear analysis for multi-storey reinforced concrete buildings with base isolation systems

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A dynamic nonlinear analysis is illustrated in the present paper for multi-storey reinforced concrete (RC) buildings with different base isolation systems. The seismic performance of the base isolated structure is analyzed with respect to multi-storey reinforced concrete buildings. The considered base isolation systems have been designed with reference to the European seismic codes EC2 and EC8. In the dynamic analysis a building is considered which is characterized by strong irregularity in plan. The dynamic behavior of the base isolated structure subject to seismic actions is performed by illustrating a comparative analysis for two different base isolation systems. In the comparative analysis two base isolation systems have been considered: the High Damping Rubber Bearing isolators (HDRB) actuated in parallel with Friction Sliders (FS) and the Lead Rubber Bearing isolators (LRB) also actuated in parallel with a Friction Sliders (FS). The three-dimensional base isolated structural frame of the considered RC building is studied by performing a dynamic nonlinear analysis. In the analysis bi-directional ground motions compatible with the reference elastic response spectrum have been adopted together with the corresponding recorded accelerograms. The seismic assessment and the dynamic response of the base isolated structure are determined. The structural performance of the building is described and the dynamic nonlinear analysis is performed by illustrating a comparative analysis of the seismic behavior of a traditional fixed base structure and the seismic behavior of the base isolated structure with the two considered base isolation systems.

3 | Structural improvement of AMS fibre cementitious composite concrete beams

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Keeping step with the growth of new material technologies, several researches about the applications of high performance fibre-reinforced concrete composites have been interested in the field construction of building and civil structures in order to improve structural characteristics. Recent concrete and composite structural members have been required to have more high-ductile, high-performance, and high-durable characteristics. Amorphous micro-steel (AMS) is manufactured by rapid cooling process of liquid pig iron at the bottom of a furnace that don't make crystalline grain boundaries. Therefore, AMS is solely isotropic like liquid characteristic in solid, called as a liquid metal, so that AMS has high strength and toughness with relatively lightweight in mechanical characteristics as well as high durability against corrosion. The current research is firstly an attempt to newly manufacture AMS fibre reinforced cementitious composites and to present their appropriate mixing design varying with the amount of AMS fibres. Secondly a series of flexural tests of reinforced concrete composite beams applying with AMS fibre cementitious composites has been carried out in order to evaluate the structural characteristics of AMS fibre cementitious composites in terms of capabilities of crack control under bending or shear cracked regions as well as enhancements of load carrying capacities of the beams. From material and mechanical test, such as slump flow test, compressive strength test, direct tensile test, and shear transfer test, with AMS fibre length of 15 mm and 30 mm, it was known that 1.0 ~ 1.25 % fibre volume fractions were suitable for the AMS fibre cementitious composites. From four-point beam tests, reinforced concrete composite beams applying with AMS fibre cementitious composites exhibited excellent enhancements in control of bending and shear cracks to compare with conventional reinforced concrete beams.

81 | Analysis of push-out specimens with different group studs in ABC Steel and concrete composite bridges
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Steel beams of steel-concrete composite structures are temporal supports of the precast concrete decks under the construction and a part of load carry members in the finished bridges. The steel beams and deck plates can work together through the connection of grouped studs in the steel beams and filling HPC in reserved holes in concrete deck plates and realized accelerated bridge construction of steel-concrete composite bridges (ABC-SCCB) by pre-casting concrete deck plates and manufacturing steel beams. Considering the nonlinear behavior of the structure, the shear capacity and shear stiffness of the different grouped studs under complex stress condition for ABC-SCCB are investigated by FEM. After the comparison between testing values and analysis obtained by FEM for a typical steel-concrete composite push-out specimen and determining the parameter's model of the composite structures and calculating patterns, the behavior of five steel-concrete composite push-out specimens with different grouped studs are analyzed. The influence of stud size, stress condition on the shear capacity and shear stiffness of steel-concrete composite push-out specimens with the different grouped studs are explored. The results showed that: 1) the plastic-damage constitutive model of concrete and steel proposed by this paper can simulate and predict the nonlinear behavior of steel-concrete structure well. It can be used in the parameters analysis and studies of steel-concrete structures. 2) The transverse bending forces and prestressing forces can largely improve the performance of concrete surrounding studs for the steel-concrete structures. They can also effectively reduce the damage of concrete around studs. 3) For different size of group studs, with exerting the transverse bending forces and prestressing forces, the average shear capacity and shear stiffness of studs can be significantly improved. 4)Once the height of stud reached four times of its diameter, it has little influence on the average shear capacity and shear stiffness of stud.

446 | Damping ratio of polyurethane-based composite incorporating aggregates
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The noise and vibration arising in floors of buildings are important factors in serviceability and residential satisfaction. Previous study reported that the damping ratio of concrete is below 5 %. Although many researchers tried to increase the damping ratio of concrete by incorporating rubber particles, the damping ratio of rubberized concrete was still same order of magnitude to that of normal concrete. The purpose of this study is to propose a preplaced aggregate polyurethane matrix based composite that has a high damping property compared with cement based concrete. The two-stage casting process is as follows: A formwork is filled with interlocking aggregate for maximum packing density, then a liquid polyurethane paste having a high damping property is poured into the formwork until it completely fills the void between the aggregate. Impact resonance test was performed in order to characterize the damping ratios of the composite. The test results showed that the composite, which is composed of preplaced aggregate and polyurethane matrix, and produced by manufacturing process proposed in this study, showed significantly improved damping ratio up to 18.1 %.

Acknowledgements: This research was supported by a grant (15CTAP-C097490-01) from Technology Advancement Research Program funded by Ministry of Land, Infrastructure and Transport Affairs of Korean Government.

432 | Crack-healing characteristics of fiber-reinforced alkali-activated cementless composite
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Alkali-activated cementless composites reinforced by synthetic fiber have many advantages including high tensile ductility, high tensile strength, controlled crack width and material greenness. The purpose this study was to investigate the crack-healing characteristics of fiber-reinforced alkali-activated cementless composites. The calcium hydroxide (CH) and ground-granulated blast furnace slag (GGBFS) were used as binder. The weight ratio of CH to GGBFS was 0.1/0.9 and the water-to-binder ratio was 0.3. Polyethylene fibers were used as reinforcing fibers. Cracks below the crack width of 80 μm were created using the uniaxial testing machine at the age of 14

days and the changes of crack widths were measured at 0, 4, 7, 14 and 28 days after creating cracks. Test results showed that the cracks were completely healed within 28 days curing after pre-cracking event and the crack-healing performance increased with a decrease in the crack width.

404 | Aging effects on moment-rotation response of the in-plane FRP beam-column bolted and glued joints

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All-FRP (Fiber Reinforced Polymer) structures have a specific role in the civil engineering field thanks to its lightness, ease of assembly and durability. The frame configuration of this technology makes the beam to column joint the most important part since it ensures the integrity, the structural stability and the dissipative capacity nevertheless the absence of ductile behaviour of pultruded FRP material. The web and flange cleats for bolted beam-column joints are widespread for FRP structures; this paper proposes a new in-plane joint designed through the pultruded FRP plate between column and beam. This latter configuration assures a better structural continuity and integrity than the web and flange cleats joints. Through the hierarchy of strength, the FRP plate in the in-plane joint plays the main role absorbing most part of stresses and involving the failure mechanisms of joint. Two joint configurations have been analyzed changing the thickness of FRP plate in order to understand who changes the hierarchy of strength considering both the bolted and glued joints. To predict the moment-rotation performance of this new beam-column joint in a long time the cyclic tests have been carried out considering the effects of aging. The numerical analysis has been carried out through the commercial finite-element code and analytical approach. The comparison between experimental and numerical results allows defining the structural behaviour of the in-plane FRP joint in the short and long time.

200 | Experimental investigation on the stress-strain behavior of steel-polypropylene hybrid fiber reinforced concrete subjected to uniaxial cyclic compression

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This paper investigates the cyclic stress-strain behavior of steel-polypropylene hybrid fiber reinforced concrete (HFRC) subjected to uniaxial cyclic compression. A total of 48 prism specimens are fabricated and tested for different fiber volume fractions and aspect ratios. The results show that the introduction of hybrid fibers has a synergetic effect on improving the cyclic behavior of concrete in terms of peak strength, post-peak ductility, hysteretic dissipative energy and stiffness degradation. Moreover, the increase in volume fraction of both steel and polypropylene fiber can lead to a remarkable decrease in plastic strain accumulation. Meanwhile, the stress deterioration ratio of HFRC can be significantly alleviated in comparison with those of plain concrete, notwithstanding that degradation amount is insensitive to the variation of fiber parameters. Subsequently, based on the test results, a damage elasto-plastic constitutive model is developed to generalize the cyclic stress-strain responses of HFRC, with the contributions of hybrid fibers taken into account. The developed model is then verified by independent experimental results and other test data reported in literatures, it is observed that the prediction yields a close estimation of the cyclic compressive behavior of HFRC with varying fiber parameters.

Keywords: steel-polypropylene hybrid reinforced concrete; stress-strain behavior; cyclic loading; damage; constitutive model; Synergetic effect

240 | The study of a novel FRP self-floating arch anti-collision facility of arch bridge

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A novel FRP self-floating arch anti-collision facility for arch bridge was proposed. Anti-collision ability and security was evaluated by numerical simulation and model experiments respectively. In finite element analysis, a bulbous bow ship loaded 5000 Ton impacted the anti-collision facility with the speed of 3.5m/s in the normal direction of arch of 1/8 of arch. As a result, 59.2% of kinetic energy was transformed into elastic deformation energy. In interaction area, 10.1% and 2.6% of kinetic energy was dissipated by plastic deformation of facility and ship respectively, and the remaining was transformed into kinetic energy of ship and facility after flicked the ship. The scale model 1:100 and 1:25 was established according to similarity theory to verify the reliability of finite element analysis and anti-collision facility's self-operation. The collision results of 1:100 model experiments showed that the error of displacement, collision force and reaction force between numerical simulation and model experiments is 7.4%, 10.4% and 8.63% respectively. Moreover, 1:25 model experiment was done to determine whether the device will be locked or not when it operated in the guide well. In the 1:25 model reliability experiment obtained that the facility operated normally with the change of water level.

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165 | Comparison of three approaches to free vibrations of laminated glass beams with polymer interlayer

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Laminated glass is a multi-layer sandwich composed of a few glass sheets connected with compliant foils. These polymer layers provide improved post-breakage behavior and damping. In this contribution, we study free vibration of laminated glass beams with frequency/temperature-dependent viscoelastic behavior of the polymer layer represented by a generalized Maxwell chain model. The results of the modal analyses are determined using the dynamic effective thickness method and two finite element approaches, the real-frequency modal strain energy method and the exact complex-frequency approach based on the Newton method. The natural frequencies and loss factors are compared for these three iterative approaches. We show that under certain conditions, the dynamic effective thickness approach is a useful analytical tool for the design and the response prediction of laminated glass structures. However, we also present examples where the errors in natural frequencies and especially in loss factors are significant for the simplified methods and we discuss how they depend on the ambient temperature and the applied boundary conditions.

156 | Viscoelastic properties of polymer interlayer of laminated glass: experminent and model calibration

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The present contribution is devoted to the experimental derivation of viscoelastic properties of polymer interalyer of laminated glass and subsequent calibration of a suitable constitutive model. In this regard, the generalized Maxwell chain model enhanced by the temperature shift factor through the application of the William-Landel-Ferry (WLF) equation has proved satisfactory. To provide the necessary input data needed for the model calibration several cylindrical samples drilled out of the laminated glass were tested in shear using dynamic shear rheometer testing device. In particular, the measured storage and loss moduli obtained for a regular sweep of frequencies between 0.001 to 50Hz at selected temperatures were adopted in the combined two-step optimization method to predict the moduli of the Maxwell chain model for the selected retardation times together with the

parameters of WLF equation. The results are presented for two glass samples with ethylene-vinyl acetate and polyvinyl butyral interlayer.

330 | Selected mechanical properties of polymer composites with reinforcement of fiberglass and quartz

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A variety of components of composite materials (reinforcement, matrix, fillers) makes it possible to create any configuration of the components of the composite depending on individual needs. The nature of the filler and its volume fraction in the structure determine a number of properties including, among others, impact resistance and three-point bending strength, which is particularly important for materials used for floor structures. The composites of this type are exposed to loads as a plate. The aim of the study was to determine the selected properties of hybrid polymer composites reinforced with fiber glass and quartz filler (99.57% SiO2, 0.12% Al2O3, 0.31% other oxides) of grain from 0.1 to 0.3 mm with the participation of mass share 0%, 1%, 3%, 6% and 10%. The preparation and conducting of the experiment included the manufacture of laminates differing in the type of the reinforcement mats, with 300g/m2 basis weight, with regard to the technique of bonding the glass fibres (emulsion mat - EM 1002 and powder mat - EM 1004) and the number of layers (2 or 4). Two kinds of epoxy resins were applied: MC-Dur 1200VK and Sikafloor 156. The properly prepared (by hand lay) hybrid composite structures were tested with the Charpy impact test and the three point bending test. The bending tests were carried out with 80 mm support spans with the lowering rate of 20 mm/min. The impact test results show that Sikafloor 156 resin composites are characterized with slightly increased impact loading. In the case of this resin, the application of powder mat EM 1004 improves the resistance of the composite to the dynamic force, which indicates better adhesion at the interface of the resin and fiberglass. The binder used in the glass mat does not affect the mean impact strength of the composites with Mc-Dur 1200VK resin. We observed that in most of the combinations of factors, the addition of 1% of quartz causes an increase in impact loading, while with 3% of quartz and above the values decrease. At 10% of quartz, it achieves a lower value than for the composite without a filler. The choice of resin exerted a limited impact on the measurement result in bending. We noticed that the application of powder mat leads to an increase in the flexural strength compared to the emulsion mat composite; in the case of Sikafloor 156 the increase in the strength reached as much as 20%. As expected, the maximum strain and stress increased together with an increase in the number of layers from 2 to 4. On average the strength is one third higher for the 4-layer laminate. It appears that the increase in the participation of quartz initially causes an increase in the flexural strength which reaches the peak for quartz between 1 and 3%. In this range, the average values of the strength reach the value of approximately 80 MPa for the 2-layer laminate and 110 MPa for the 4-layer laminate irrespective of the type of resin applied. With a further increase in the participation of quartz, the maximum flexural stress decreases. On the other hand, the maximum deformation increases with the growth of quartz up to 6% mass share, after which it decreases visibly or remains unchanged. In the light of the obtained results, it is possible to conclude that this type of hybrid composites proves little sensitivity to changes in the structural composition and ratios for flexural strength and impact strength. Therefore, they are quite promising in terms of their application as structural components such as the plate.

364 | Crack propagation in the interfacial transition zone at a sharp aggregate tip in cement-based composites

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Fracture behaviour of cement-based composites is influenced by many parameters. Material properties of matrix, aggregate and interfacial transition zone together with geometry of the aggregate belong to the most important ones. While a crack propagates through the matrix, it meets material interfaces, takes the most advantageous crack path, kinks, and accelerates and decelerates. This complex process can be understood by description of the crack behaviour in particular places of material and geometrical changes in the composite. The paper presents behaviour of the crack with its tip in a corner of polygonal aggregate (AGG) in silicate based matrix (MTX). The interfacial transition zone (ITZ) is included in the numerical model. Two material interfaces (AGG–ITZ and ITZ–MTX) occur near a vicinity of the crack tip. Thus, the crack surfaces and polygonal interfaces create sharp bi-material notches with singular stress concentration in their tips. As the power of the stress singularity differs from 1/2 (the value valid for a crack in homogeneous material), the situation is evaluated by means of generalized fracture

mechanics approaches. The influence of materials combinations given by varying AGG/ITZ/MTX elastic properties and the influence of presence of the ITZ is evaluated and quantified. Varying input parameters lead to varying stress state that influences direction of further crack propagation and mainly the level under which the crack will further propagate. A model situation has been tested experimentally and it has proved strong influence of ITZ. This paper correlates theoretically and experimentally obtained results and contributes to better understanding of toughening mechanisms and fracture behaviour in quasi-brittle composites.

Acknowledgements: The authors would like to thank the Czech Science Foundation for financial support through the Grant 16-18702S AMIRI.

379 | Development of wood based composite structures – introduce an EU Interreg project

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The use of adhesives in timber construction industry is dated from the 1960. For long time, the negative health and environmental impacts of these adhesives are minor when compared to the positive impact of building with engineered wood products (EWPs) like glulam and cross-laminated timber (CLT) instead traditional materials (steel and concrete). However, the negative impacts will increase proportionally in the context of more and more intensive use of EWPs in construction. More than 5 million m3 of EWPs were produced in the EU in 2013/2014 and the market is expected to increase, as EWPs provide a 'green' alternative to steel and concrete in construction. In the North-West Europe, the majority of EWPs is produced, which goes to landfill at the end of a life cycle because of the difficulty to recycle them due to heavy using adhesives leading to an incineration contribution to about 15 million tons of timber construction waste across Europe each year. To tackle this problem and to enhance the positive environmental and health impacts by minimizing use of adhesives in EWPs, a research project called "Towards Adhesive Free Timber Buildings" (AFTB NWE348) has been funded by the FEDER in the context of the Interreg VB North-West-Europe programme. This research project aims to address the wasteful and harmful use of toxic adhesives in the manufacturing of Engineered Wood Products (EWPs) by the construction industry. University, industry and the public sector are cooperating to demonstrate novel adhesive free EWPs using new technology, encouraging and enabling market uptake across North West Europe (NWE). Providing confidence in the structural properties of adhesive free EWPs using compressed wood dowels is the key to this market uptake. The project aims to move the Technology Readiness Level (TRL) from 4 to 7. The project is a multidisciplinary research covering several topics: (1) structural testing and modeling new timber connections and multi-layered beams and flooring panels connected using high strength compressed wood dowels, (2) modelling of creep/relaxation behavior of the new products, (4) experimental and numerical investigations of the behavior of the new systems in fire to provide their quantitative assessment of their relative performance with respect to other more conventional systems, (5) Experimental and numerical assessment of the vibration serviceability of CLT floors under surface impacts like footfalls that cause out-of-plane low amplitude motions.

280 | Fatigue damage analysis of steel-concrete composite bridge deck by FEM

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Fatigue damage processes of the steel-concrete composite deck supported by two main girders were investigated by Nonlinear FE analysis. In particular, stress state of headed stud welded on bottom steel plate of deck was studied in detail. The full scale three dimensional analyses demonstrated the difference in failure mode of composite deck under the fixed point load and repetition of moving load. Furthermore, it was shown that the stress state of headed stud under fixed point load and moving load was different. The analyses could point out the possibilities of both yielding and fatigue failure of headed stud subjected to repetition of excessive heavy traffic load in service life of bridge.

235 | Hysteretic shear model for perfobond rib shear connectors

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This paper aims to formulate the hysteretic model for perfobond-rib shear connector (PBL) under unidirectional shear loads. Static push-out tests of the PBL using cylindrical test specimens were carried out under several unloading and reloading conditions to examine the shear force-slip displacement relations. The specimens were cast inside steel pipes in order to restrain expansion of concrete associating with pushing perfobond-rib plate. The experimental data were analyzed after normalization because the sizes of the hysteresis loops were different at the slip displacement. The constitutive models including partial unloading and reloading were derived from the experimental results. The proposed model enables to predict hysteretic behavior starting form arbitrary unloading points.

22 | Statical experiment investigate of composite structure in civil engineering based on terrestrial laser scanning measurement

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The focus of this manuscript is that the measurement based on terrestrial laser scanner (TLS) was conducted for concrete arch structure, and it is verified that an arch structure can withstand a surprisingly greater load than a beam structure under the same conditions. RC structures are regularly required to satisfy the high demands of comfort and security and nowadays reinforced concrete (RC) is ubiquitous and indispensable building materials and is diffusely applied in various types of engineering structures, so an accurate estimation of the ultimate load is essential in order to monitoring the deformation and assess safety of RC structures.

COMPOSITES IN INNOVATIVE APPLICATIONS

310 | Structural design and manufacturing process of a low scale bio-inspired wind turbine blades

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Renewable energy has gained so much interest in the past few years, due to the necessity of generate electric energy ecologically making use of renewable resources. Situations such as global warming and contamination have cause the wind to be used in order to generate electricity, avoiding the emission of polluting gases. From that circumstances, the interest of wind turbines emerge as a clean power source. Nevertheless, due to wind conditions of the Andes region topography and other regions with low eolic resources, it is necessary to develop wind turbines capable of operating under low wind speeds in an efficient way. The wind turbine blade design presented in this article, was inspired by the fall movement of a seed called Triplaris Americana, this seed belongs to a tropical tree that grows up along the South America equatorial region. The result is a non-conventional horizontal axis wind turbine design to operate at low wind speeds with high conversion efficiencies. Once the aerodynamic design emulating the seed was ready, it was necessary to conclude a detailed design by means of composite structural design and later the design of the manufacturing process. During the design process an aerodynamic simulation was performed and from this one, it was calculated the pressure distribution throughout the blades. The simulation was validated employing an existing commercial model of a horizontal axis wind turbine for which

experimental data is found in the literature. Then, the results were compared with literature data. Later, a fluid-structure simulation was initialized, coupling the aerodynamic effects into a structural simulation. The result allowed getting a design in which the aerodynamic and inertial loads counteract each other in a way that the blade geometry did not deform considerably, so it is not modified the wind blade aerodynamic. Once the composite laminated for each blade section was defined in the last step, a design of the manufacturing process was performed from liquid composite molding; the mold and the resin infusion sequence also were set. The mold resin filling was simulated according to VARI (Vacuum Assisted Resin Infusion) process, through the use of a Finite Element Method based software and a previous permeability and viscosity characterization of fabrics and resin respectively. In the analysis, six filling strategies was taken into account, and three of them resulted in a successful mold filling, considering a full mold filling without imperfections and within a prudent time in which the resin is workable.

260 | Multi-scale modeling of triaxial braided composites for FE-based modal analysis of hybrid metal-composite gears

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Fiber-reinforced polymers represent a significant portion of the composites that are currently used in different industrial applications. When using composites instead of, for example, steel and aluminum alloys, significant reductions in weight can be achieved, while preserving high load-carrying capability. Thanks to the higher strength-to-density ratio, combined with other advantages over traditional materials, such as resistance to chemicals, thermal and electrical insulating properties, composites are gaining ground in different sectors. This trend is also confirmed for applications in mechanical structures. In this direction, with the aim of reducing weight while limiting noise and vibration, mechanical transmissions can be considered as ideal candidate application for composite materials. Recently, efforts have been spent to expand the use of composites to mechanical transmissions, bringing to a new gear concept defined as hybrid gear. From a functional viewpoint, a gear can be divided into three main parts: the hub, that allows the connection between gear and shaft; the rim, which is the toothed ring; and the web, which joins hub and rim. In hybrid gears, as proposed recently in [1], the web is made of composite material. The aim of the work presented here is to apply multi-scale composite modelling for material characterization and Finite Element (FE) based modal analysis of hybrid gears, where the web is made of a polymer matrix reinforced with two-dimensional (2D) braided fabrics. The first step of the proposed methodology is the characterization of the orthotropic web material, for which a multi-scale approach ([2]) is used to take into account the anisotropic properties. In detail, at the macro level the geometry of the composite part, which can be seen as translated copies of several Repetitive Unit Cells (RUCs), is defined. The material properties can be then derived by analyzing the mechanical behavior of the single RUC at meso level. For this purpose, a meso-macro scale FE procedure was used to estimate the orthotropic properties of the web material, which has a quasi-isotropic in-plane behavior. Specifically, the CAD model of the RUC geometry was built and processed in Siemens PLM software's Simcenter. The interweaving as well as the cross-section geometry of the yarn, its volume fraction and local fiber orientation were considered. Afterwards, contacts between yarns and matrix were defined and periodic boundary conditions were implemented. Finally, NX Nastran software was used to analyze the meso model subject to different static load-cases. The final step of this automated workflow brought to the homogenized macro elastic properties of the composite. Once estimated, the orthotropic material properties were included in the macro model of the web, as to create the FE model of the entire hybrid gear for subsequent modal analysis. By comparing the achieved numerical results with the measured eigenfrequencies reported in [1], the predictive accuracy of the proposed multi-scale modelling approach proved significantly superior than the one achievable by considering the quasi-isotropic web material as perfectly isotropic.

Acknowledgements: The authors gratefully acknowledge SIM (Strategic Initiative Materials in Flanders) and VLAIO (Flemish government agency Flanders Innovation & Entrepreneurship) for their support of the IBO M3Strength project, which is part of the research program MacroModelMat (M3).

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439 | Feasibility tests on the carbon felt reinforced thermoplastic composite plate for PEMFC bipolar plates

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Polymer electrolyte membrane fuel cells (PEMFCs) have high efficiency, low operating temperature and nearly zero environmental emissions. The bipolar plate is one of the main components in the PEMFC because it accounts for a great part in weight, volume and cost. Recently, carbon fiber reinforced thermoplastic composite bipolar plates for PEMFCs have been attracted owing to their simple fabrication method, high flexibility, excellent corrosion resistance, and damage resistance. The efficiency of the PEMFCs predominantly depends on the performances of the bipolar plates, however, the composite bipolar plates have high surface electrical contact resistance because of their resin-rich area. In this study, a carbon felt was used to fabricate the bipolar plate for PEMFCs. Also, sol-gel method and the double percolation concept were introduced to improve the impregnation state of the thermoplastic polymer and electrical conductivity of the composite plates respectively. The areal specific resistance, double percolation morphology, and impregnation state of the newly developed composite bipolar plates were measured by using four-point probe method, transmission electron microscopy analysis and scanning electron microscopy analysis respectively. The results of the experiments were compared with the Department of Energy's (DOE's) technical target value.

191 | Multi-physics modeling of composite materials for magnetic pulse welding tools

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Composites materials, in general, are widely used in different industrial applications. Additionally, to their strength-to-weight high indicators, composite materials are very attractive to multi-physics applications where not only structural but electrical insulation performances are required. In the present work, the structural composite materials as a part of tools for magnetic pulse welding (MPW) have been investigated. MPW process is the object of JOIN'EM project which is funded by the European Union within the frame of the Horizon 2020 research and innovation program (Grant Agreement No. 677660). MPW is an innovative technology for producing metallic bonds of similar and dissimilar metals. The setup of the process, which is based on the electromagnetic forming technique, consists of the inductor (i.e. the tool), the pulsed power generator, the flyer, the target and additional elements ensuring that flyer and target are positioned with a defined small gap in-between them. There are several typical technological process variants, which can be performed by MPW. In this work, the main focus will be on sheet welding for which the tool consists of a copper winding embedded into insulating housing material. This housing is made of composites. Sometimes a lack of process understanding and underestimation of the loading conditions of components can lead to failures in tools. In order to ensure all requirements and long operational life of the tools, a multi-physics modeling of MPW must be performed to investigate all particularities related to MPW process. Thus, at the design stage coupled electro-magneto-structural simulations are performed to calculate the loads acting on the tool elements. Knowing this, the material modeling of housing material can be done using two techniques. The first one is a macro-scale modeling where housing is considered as an anisotropic damageable material with predefined interfaces between the plies and the second one is a multi-scale technique which provides a methodology of the effective properties evaluation from the mesoscale structure. In actual design frequently plain weave glass fiber textile composites are used as housing. Detailed investigations related to material modeling can be divided into two groups: experimental observation and numerical model developments. There are few groups of tests that have been performed: a) static tensile tests in warp, weft and bias direction; b) three-point bending test; c) cyclic loading-unloading test in all directions in order to estimate damage accumulation in the materials and d) fatigue tests under sinusoidal tensile-tensile loading. All experiments were accompanied by digital image correlation techniques if it was relevant. Composite behavior has been modeled with 3D progressive damage model. In order to take into account fatigue damage effects in the material model, the macroscopic stiffness and strength degradation have been introduced based on the initiation and growth of damage on the meso- and microscale. All required material data have been obtained from experiments. Consequent application of the multi-scale and macro-scale simulations has revealed weaknesses in the design and

allowed improvements of the inductor systems. Moreover, this methodology allows considering potential improvements in the material design and application of advanced textile composites.

186 | Ballistic performance of hybrid nonwoven/woven polyethylene fabric shields

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In the last years, new lightweight composite materials have progressively replaced conventional metallic components in certain industries such as automotive, marine or aeronautical. In the particular case of ballistic protection, dry fabrics made up by high strength fibers represent the most outstanding solution. They can be divided into woven and nonwoven fabrics depending on the architecture of the fibers. In the former, fibers are bundled in yarns weaved following a regular pattern, while fibers form a disordered network consolidated by means of thermal, chemical or mechanical bonds in nonwoven fabrics. The combination of both woven and nonwoven fabrics in hybrid laminates is an innovative solution to arrest fragments within a wide range of calibers. In general nonwovens are stacked facing the projectile to enhance the load transmission into the woven fabric. In addition, there are reports of changes in the mechanical response of the nonwoven fabric due to the interaction with the woven layers at the rear of the laminate. This synergistic contribution to the impact resistance emerging from the nonwoven/woven laminate lay-up has not been studied in detail and this is the main objective of this research. To this end, the ballistic response against small projectiles of a hybrid laminate made up of a front layer of a needle-punched nonwoven fabric and several layers of a woven fabric was analysed from the experimental and numerical viewpoint to understand the peculiar deformation and fracture mechanisms of this system. Two commercial fabrics were used in this investigation. The first one was a needlepunched nonwoven fabric denominated Fraglight NW201 (DSM) manufactured by Dyneema SK75 fibers of approximately 60 mm in length. The second material was 4 harness satin polyethylene woven fabric made up with Dyneema SK65 fibers. The configuration of the hybrid shield for the impact tests included 1 nonwoven fabric layer (NW) supported by 4 woven layers (W) leading to a stacking sequence [NW/0W/90W/0W/90W]. Impact tests were carried out with a gas gun using a pneumatic launcher SABRE A1. The projectile was a steel sphere with 5.5 mm in diameter and the impact velocity was in the range 300 to 400 m/s. Additionally, the mechanisms responsible for the ballistic performance of the hybrid shield were ascertained by means of numerical simulations. Simulations were carried out using the finite element method in Abaqus/Explicit within the framework of large displacements and rotations with the initial unstressed state taken as reference. Different finite element approaches and constitutive equations were used to describe the woven and the nonwoven fabrics. On the one hand, the woven fabric was simulated at the mesoscale including every single yarn in the 4 harness weave. The polyethylene yarns were modelled as transversally isotropic linear elastic solids. On the other hand, the mechanical behavior of the nonwoven fabric was given by a multiscale constitutive model able to take into account the complex deformation and fracture mechanisms of this material under quasi-static in-plane deformation. Impact experiments showed that the energy absorbed by the woven fabrics was very low as the projectile penetrated easily in between the yarns due to yarn slippage. The polyethylene nonwoven fabric was able to absorb more energy during impact by the in-plane deformation of the fabric. Final penetration of the target was accomplished by tearing around the projectile as the fibers were pulled out from the entanglement. The deformation and failure mechanisms obtained in the numerical simulations were in agreement with the experimental results and they provide more details about the origin of the efficient behavior of the hybrid shield. Initially, the projectile could not penetrate in between the yarns of the woven fabric because it was stopped by the nonwoven fabric. On a first stage the energy was transmitted to the woven yarns through the nonwoven fabric, avoiding the local penetration observed in the woven shield. Second, the projectile surrounded by the nonwoven fabric slipped through the yarns of the woven fabric and the contribution to the energy dissipation of the latter was reduced. However, the energy absorbed by the nonwoven fabric increased rapidly from that instant due to the confined deformation of the nonwoven in front of the projectile until the final penetration, taking advantage of the energy dissipation capability of the nonwoven fabric.

175 | Anode/cathode integrated carbon composite bipolar plate for LT-PEMFC

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Even though carbon composite bipolar plates have high corrosion resistance and stiffness, they do not exhibit sufficient electrical conductivity and thus reducing the efficiency of PEM fuel cells. To increase the performance of the PEM fuel cell stack, an anode/cathode integrated carbon composite bipolar plate has been developed. The anode and cathode sides of the bipolar plate are co-cured to eliminate the interface contact resistance between the bipolar plates. During the co-curing process, in order to form a coolant channel, a thermoplastic channel frame is inserted between the anode and cathode bipolar plates. The channel frame is easily dissolved after the fabrication of the integrated bipolar plate. The stress distribution in the anode/cathode integrated bipolar plate relative to the curing condition is calculated using finite element method. The electrical resistance and mechanical properties of the developed bipolar plates are measured and compared with those of the conventional bipolar plate.

87 | On the mechanics of composite metamaterials based on confined pentamode lattices

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In the last few years, mechanical and acoustic metamaterials have attracted the attention from different areas of research because of their unique behavior. Such smart materials are artificial structured lattices whose mechanical properties are mainly derived by their geometrical structure rather than their chemical composition (refer, e.g., to papers [1][2]). The class of "extremal materials" has been introduced in [3] to define materials that behave as extremely stiff in some deformation modes while very soft in others. These are called uni-mode, bi-mode, tri-mode, quadra-mode and penta-mode materials, from the number of small deformation modes they can achieve. This definition applies to a special class of mechanical metamaterials - composite materials, structural foams, cellular materials, etc. - which feature special mechanical properties. A specific category of extremal materials, called pentamode metamaterials, have received particular attention in the literature. In particular, 3D printing techniques have been employed to manufacture such materials both at the macroscale [4][5] and microscale [6]. We examine in the present study metamaterials that use pentamode lattices whose unit cell consists of one half of the face-centered-cubic (fcc) unit cell usually analyzed in the literature on pentamode lattices (sfcc systems). Considering the infinitesimal incremental motions from the reference configuration of an elementary sfcc module, we show that the examined systems, when equipped with perfectly hinged connections, feature only three zero-energy modes, as opposed to the five zero-energy modes of unconfined pentamode lattices, and exhibit positive elastic rigidity against both vertical and bending loads. We conclude that single- and multi-layer composite structures alternating sfcc pentamode lattices and confinement plates are able to carry vertical and bending loads also in the presence of zero bending rigidity of nodes and rods, as opposed to confined and unconfined fcc systems. As a result, we note that such metamaterials can be effectively employed as novel impact protection gears and seismic isolation devices, by suitably designing the lattice geometry, the stiffness properties of the joints, and the lamination scheme, as a function of the operating conditions. We also study the mechanical response of layered pentamode metamaterials in the large elastic strain regime, observing a stiffening effect in terms of the lateral force vs. lateral displacement response with increasing amplitude of lateral displacements. Such a geometrically nonlinear effect is accompanied by a softening response in vertical direction under mixed force-displacement loading, and becomes less effective by layering multiple pentamode layers, one over the other. It is worth noting that a similar hardening response is a desirable performance for seismic isolators potentially experiencing large displacements [7]-[10]. Using a multi-layer design strategy, we are able to design laminated sfcc systems made of steel, which exhibit effective lateral stiffness comparable to that of a commercial seismic isolator made of soft rubber-pads and thin steel shims. In addition, the analyzed sfcc pentamode bearings are tension-capable, i.e., can bear both compression and tension vertical loads during seismic excitations, due to the nonzero tensile strength of the rods forming the pentamode lattices.

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68 | Assembly and performance evaluation of the structural battery cell using a load-bearing separator

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Load-Bearing Energy Storage Structure and Structural Battery: The initial structural requirements of conventional transportation vehicles such as aircrafts and automobiles were fuel saving through weight reduction and structural safety using high stiffness and strength properties. Composite materials with high specific strength satisfy such requirements and recently composite materials are increasingly used in the structures of aircrafts and cars. Composites have been studied for their high mechanical properties as well as multifunctionality. Among such researches are that of the load-bearing energy storage structure which focuses on multifunctional composite materials where a part of the load-bearing structure simultaneously performs energy storage functionality. These studies were carried out according to the energy storage method. The device that performs energy storage by redox reactions is a battery while the structural batteries are batteries with load-bearing capacities. Assembly of a Load-Bearing Separator Applied Structural Battery: A new structural battery structure with a load-bearing separator is proposed in order to resolve the fundamental problems of structural batteries. The structural battery with load-bearing separator used the cathode and anode materials which are widely used in commercial batteries and used a solid polymer electrolyte as the separator pore filler and ion conductor between the electrodes. A unit cell was prepared using a portion of one layer of the composite structure to create a battery. First, the cathode of the battery was selected based on low material cost and environmental compatibility compared to other cathode materials while having the advantage of a flat voltage profile. Due to the properties of the lithium salt included in the electrolyte used in this study, the low voltage cathode material, LFP, was used. For the anode, graphite was used since it is generally used for commercial electrodes. For the two electrodes, a slurry was prepared with a binder(PVDF) or conductive material (Carbon Super P) to secure conductivity then cast on the aluminum and copper foils to be used as the current collectors and dried. Finally, they were cut to 2mm×2mm, and aluminum and copper tapes cut longer than the width of the composite to be fabricated were adhered to the current collector for connection with the external circuit. The electrolyte was fabricated by stirring together a polymer of outstanding mechanical strength and electrical conductivity(SBS-g-POEM), plasticizer(PC), lithium salt(LiTFSI), and solvent(THF) in a glove box. The electrolyte in liquid form was first casted and dried to become solid at the center of the glass fiber over an area of 2mm×2mm using a mold, and a cell was composed by casting the liquid electrolyte on the manufactured electrodes then pressed on each side of the electrolyte application area on the glass fiber followed by drying. Next, glass fabrics were laminated on either side of the cell to form a casing and a permeation barrier and cured using epoxy. Due to the vulnerability of batteries to moisture, the final processes were also carried out in a glove box. Structural Battery Performance Evaluation: The electrochemical properties of the prepared structural battery were measured using a Galvanostat and the mechanical properties were measured using a UTM. In this paper, 2 new practical performance indexes were proposed for the structural battery. For the electrochemical property of the structural battery, the electrochemical performance of the structural battery divided by the electrochemical performance obtained through coin cell testing was proposed, and for the mechanical property of the structural battery, the mechanical performance of the structural battery divided by the mechanical performance of a composite material fabricated with only reinforcement and epoxy and without the structural battery applied was proposed. The first index was named “Strattery Electrical Efficiency” and the second index was named “Strattery Mechanical Efficiency”. Here, “Strattery” is a newly defined term compounding the words structure and battery. The sum of the two proposed efficiency values exceed 100% and this result reveals the high potential and usefulness of the structural battery.

59 | Mg-Al-hydroxysilicate composite: novel insights into nanomechanics, surface potential and interaction with organic compounds

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Phyllosilicates are an important group of minerals with applications in composite materials, involving for instance inorganic-organic interactions such as organic containing geopolymers for structural applications. The physico-chemical properties of their extensive surfaces take part in the interaction processes with the surrounding environment. It is thus of paramount importance to study morphology, chemical composition, defective sites, layer charge and mechanical stability. Among phyllosilicates, chlorite group has an interesting composite structure made up of two structurally and chemically different layers of sub-nm thickness. In the present work we report on the investigation of clinochlore, a Mg-Al-hydroxysilicate of the chlorite group. This phyllosilicate exhibits very interesting physico-chemical surface properties that can actively drive the interactions with organic molecules and be a model to derive innovative applications in geopolymer science and biotechnology. A cross-correlated AFM-based and ab-initio theoretical investigation has been used for the characterization of this material. As mentioned above, the investigated material consists of a mica-like and a Mg-Al-hydroxide layers. The mica-like layer, 1 nm thick, is made of two tetrahedral sheets bound together by magnesium cations in octahedral coordination. Both silicon atoms of the tetrahedral sheets and magnesium cations can be partially substituted by aluminium atoms. The Mg-Al-hydroxide layer, 0.4 nm thick, is made up of magnesium cations in octahedral coordination with hydroxyl groups. Magnesium can be partially substituted by aluminium atoms. At the interface between the two layers the surface of monoclinic crystal system of the mica-like layer deforms to match the trigonal crystal system of the hydroxide one. The two layers present very different physico-chemical properties in terms of nanomechanics, surface electric potential and hydrophilicity/hydrophobicity, which need to be investigated in detail in the composite material. Atomic force microscopy (AFM) based methods were used to investigate the nanomorphology and nanomechanical properties of the composite material. Both the mica-like and the hydroxide layer were observed to be typically present at the surface, thus determining a general anisotropy of the physico-chemical properties of the whole composite surface. Terraces were extended from tens of nm to hundreds of micrometres, whereas surface steps typically from the single layer to tens of nanometres. The mechanical properties at the nanometre level were characterized by using an AFM-based method that simultaneously performs the surface mapping of the elastic modulus and the morphological characterization without shear forces. A feedback circuit controls the maximum force of interaction with the sample which can range down to the pico-newton, thus remaining in the elastic deformation regime. The elastic modulus is calculated by fitting the first linear part of the unloading curve in a force versus separation experiment with the Derjaguin–Muller–Toporov (DMT) model. The contribute of the two layer to the surface elastic modulus was found to be of the order of tens of GPa. The surface electrostatic potential difference dV between the two layers was studied by Kelvin probe microscopy, measuring dV figures ranging from tens to hundreds of mV. The composite stability, surface potential and interactions with organic molecules were also investigated by quantum mechanics (QM) simulations. Experimental and theoretical data were found in very good agreement, complementing each other. The electrostatic surface maps and interaction with organic compounds are comparable with those obtained by AFM. The knowledge of this nanoscale properties anisotropy is very promising to develop novel geopolymers and biotech applications.

DAMAGE IN COMPOSITES STRUCTURES

468 | Phenomenological approach to the study of hierarchical damage mechanisms in composite materials subjected to fatigue loadings

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In this paper, it is shown that the strength degradation can be described by three distinct functions associated to the sequence of damage mechanisms. Each function is calculated using a recently developed two-parameter phenomenological model based on residual strength, Despite the phenomenological prerogative of the model, from the analytical approach it results that the multiple damage mechanisms develop simultaneously even with different kinetics and manifest their effectiveness at different time scales, accordingly. This highlights the hierarchical nature of damage accumulation in composites, from diffuse matrix cracking, to fiber/matrix interface failure to fiber and ply rupture and delamination.

231 | Validation of a Continuum Damage Model for predicting the axial-crush response of CFRP composite material

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In this work, the validation of the Finite Element (FE) analysis code PAM-Crash for the simulation of crashworthy composite structures is proposed. The investigation follows the principles of the Building Block Approach (BBA): FE analyses are supported at an increasing level of geometrical complexity by experimental campaigns. The investigation starts with multiple sets of coupon level testing on carbon fiber-epoxy UD material, followed by the quasi-static axial crushing of a self-supporting specimen. Tests performed include: tension, compression, in-plane shear and delamination modes I and II. A continuum damage mechanics (CDM) model is implemented starting from elementary load cases, then scaling up to the self-supporting specimens. The phenomenological meso-model for the intra-ply post-failure behaviour is based on the studies of Ladevèze, as later revised by Johnson and Pickett. In addition, a cohesive zone model is used to account for the delamination phenomena. Influence of different simulation strategies and simulation settings are discussed within the body of this work: a model comprising a single multilayered shell element, a staked set of shells representing the single constituent ply connected by inter-ply cohesive elements, and lastly, an intermediate solution using sub laminate groups. Influence of mesh size, friction coefficients and crushing velocity are also discussed. Results show that the CDM model alone is not able to correctly simulate the complex load cases, but calibration strategies of the material card are necessary to fit the experimental data. The required manual tuning limits the predictive quality of the model, as the characterisation effort alone is unable to describe the energy absorption characteristic of the different physical phenomena occurring during crushing. In addition, due to the different features of the proposed numerical approach, the contribution on Specific Energy Absorption (SEA) of the different crushing modes is discussed. A sensitivity analysis of different card parameters on simulation results is finally discussed in order to propose a framework for future investigation.

269 | An assessment of the damage induced by drilling operations in composite laminates

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The connection among different structural components may be promoted by several means. Among these, if one considers mechanical connections, it becomes often necessary to drill the components. When the materials that constitute these components are fibre reinforced composite laminates, the consequences of the drilling operation may induce a relevant area of damage, namely related to delamination or fibre pulling-out that should not be neglected. Under these circumstances, not only the stiffness and strength of the material will be reduced in the drilled region neighbourhood, but ultimately a more worrying situation may arise if specific conditions exist to enable propagation and subsequent failure. It is therefore important to typify the influence of drilling and material parameters on the drilling areas neighbourhood, as well as the thermally affected area, which this study aims to obtain. The experimental methodology behind this work is based on the use of digital images obtained through thermographic cameras. A set of illustrative cases is presented and conclusions are drawn.

198 | Evaluation of damage outcome in carbon fibre reinforced laminates

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Carbon fibre reinforced laminates have been assuming a growing importance in engineering and their use is becoming more common even in structural parts. Important characteristics of these materials, such as high mechanical properties along with low specific weight, have allowed a wide application in distinct areas like medicine, sports, aeronautics, defense or automotive industry. Most of the parts produced in these materials are in a near-net shape form, close to the desired final functional design. However, their use does not exclude, in most of the cases, the need of additional machining processes, particularly drilling. Therefore, the drilling of carbon fibre reinforced laminates remains a very common process and, despite several advances in this area in recent years, it still can cause damage to the laminates whose effects must be taken into consideration. Among the main problems resulting from drilling, delamination is one of the most important, due to the particular nature of these materials, as it causes concerns about mechanical and fatigue resistance of the parts. The objective of this study was to evaluate the magnitude of the area damaged by drilling in carbon fibre reinforced laminates with an epoxy matrix and how does the resulting damage caused by the drilling process affected the mechanical properties of the laminates. With this purpose, thirty five test coupons in carbon fibre reinforced epoxy laminate were manufactured and drilled with four different drill geometries – Carbide Twist drill, Carbide Dagger Drill, Carbide Brad drill and High Speed Steel Twist drill - to obtain uneven damage areas. When using the carbide twist drill geometry, two different machining strategies were combined, one with pilot drilling strategy and other without it. All the drills had a 6 mm diameter and to avoid a large diversity of cutting parameters and evaluation factors, the spindle speed was always 1120 rpm whereas the feed rate had two levels: 0.12 and 0.30 mm/rev. These cutting parameters were selected according to tool manufacturer's recommendation and former experience of the authors. After the drilling process, the delaminated area around the drilled hole was evaluated using enhanced digital radiography. In order to generate a contrast, the laminates were first immersed in di-iodomethane for some minutes. Then the radiographic images were acquired using a 60 kV, 300 kHz Kodak 2100 X-ray system associated with a Kodak RVG 5100 digital acquisition system. From the resulting images it was possible to calculate the damaged area, using an image editing software. Finally, the test coupons went under two mechanical test - Three point flexural and Pin-Bearing test – to assess the mechanical properties and consequences of the machining of holes in the laminates. The determined damaged areas were related to the loss of mechanical properties verified during the tests, with the help of statistical tools. The achieved results allowed to establish and model the relations between the damaged area during drilling and the material's mechanical resistance. The bending resistance does not vary greatly with the damage area. On the other hand, the bearing resistance decreases with the increase of the damaged area. The results demonstrate the importance of an adequate assessment of damaged area and proper selection of machining parameters to extend the reliability and life cycle of these laminates.

97 | Modeling intralaminar damage progression and delamination in layered composites

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Carbon fiber reinforced composites are typically composed of either unidirectional carbon fibers or textiles, in which the reinforcing fibers are woven or braided, embedded in an epoxy matrix material. These composites are advantageous due to their ease of manufacture, damage tolerance, and relatively low cost. However, physics-based modeling of their mechanical behavior is challenging. While in the unidirectional case all fibers are considered as perfectly aligned in one particular direction, textile composites introduce additional geometric

complexities, which cause significant local stress and strain concentrations. Since these internal concentrations are primary drivers of nonlinearity, damage, and failure within textile composites, they must be taken into account in order for the models to be predictive. In this work, a thermodynamically consistent continuum damage model is proposed. The model is anisotropic and allows taking into account the interaction of damage evolution in different directions by introducing six independent damage variables. Furthermore, it is mesh independent due to the use of an energy based regularization scheme. It is shown that the model can be successfully applied on different scales: on the micro-scale of unidirectional composites it is applied in an isotropic manner for the matrix material, whereas on the meso-scale of textile composites the same model can be used to describe the orthotropic damage behavior of the yarns. Finally, on the macro-scale the model allows the prediction of delamination in layered composites.

321 | Influence of drilling parameters in aramid composites

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Nowadays, the rise in terrorism, civil and international conflicts has led to the terrorism, civil and international conflicts, the number of people afflicted with war-related traumatic brain injuries (TBI) is increasing. The role of personal protective equipment is crucial in order to minimize the morbidity and mortality resulting from ballistic head injuries. The combat helmet is often used since it offers a good penetration resistance against incident high energy projectiles. However, TBI is most often related to their exposure to blast and ballistic threats and it is necessary to get auxiliary protective equipment such as visor or mandible guard. The mechanical joining of this auxiliary protective equipment with combat helmet is a common and critical activity for manufacturers since it may be carried out a significant reduction of penetration resistance is the join zone. The most common machining operation required for further mechanical joining of the components is drilling. The combat helmets are usually made on aramid composites due they present excellent mechanical properties, mainly high strength, high modulus, and high strength-to-weight ratio. However, aramid composite may delaminate easily and causes difficulty during machining. Among damage caused by drilling, the delamination, fibrillation, burning, clogging of the drill, and patches of material still attached to the hole exit can be highlighted. In this work, the influence of the main process parameters (feed rate, cutting speed and drill tip) has been deepened.

38 | Failure model of composite plates after low-energy impact subjected to the Compression-After-Impact (CAI) test

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The study presents a simplified model of damage of composite plate elements subjected to impact tests using low impact energies. The research enabled development of an original model of damage based on reduction in thickness of the laminate layers as a function of impact energy. A procedure enabling the mapping of a real extent of damage to the laminate structure causing a significant weakening of the plate's stiffness was established. The modeling of the actual region of damage due to the low-energy impact tests was based on the literature-reported results of experimental tests conducted on multi-layered rectangular plates made of the CFRP composite. Reduced strength of the laminate structure was measured in compression-after-impact (CAI) tests. A numerical analysis by the finite element method was performed for composite panels with mapped regions of damage caused by the different energy impact tests, subjected to uniform compression. The numerical results describe the behavior of the laminate structure during compression, taking into account the damage process. The damage is assessed using the progressive damage criterion. The initiation of damage of the composite material was performed using the Hashin criterion, whereas damage progression is described by means of the energy criterion. The numerical investigation of compression of damaged composite structures was treated as a geometrically non-linear problem solved using the incrementally-iterative Newton-Raphson method. The numerical computations were performed with the commercial software ABAQUS®. The employed simplified model of laminate damage due to low-energy impacts accurately reflects the decrease in stiffness of the plate observed in the CAI tests. The numerical results show a very high agreement with those of experimental studies performed on real structures and reported in the literature.

Acknowledgements: The study was conducted under the project UMO-2015/17/B/ST8/00033 financed by the National Science Centre Poland.

37 | A multiscale damage analysis of notched and unnotched laminates using the parametric HFGMC micromechanical method

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A multi-scale nonlinear static analysis based on the parametric High Fidelity Generalized Method of Cells (HFGMC) micro-mechanical method is extended to predict the mechanical progressive damage response of laminated composite structures, with and without notches, subjected to tensile and compressive static loading. The HFGMC linear, nonlinear, and damage parameters are calibrated from tested axial, transverse, and in-plane shear responses of unnotched laminates. Verification of the implemented multi-scale analysis is performed for open-hole multi-directional layups under both tensile and compressive static loading. A ply-by-ply modeling approach integrated within shell-based finite-element (FE) is used to analyze thin-section laminates. The thickness material and orientation of each layer is explicitly modeled with one integration point under plane stress conditions. Constant transverse-shear cross-sectional stiffness is assumed for the shell elements. The material model is implemented as user subroutine (UMAT) within Abaqus FE code. The material behaviors of the fiber and matrix constituents, are directly prescribed at the micron level. The matrix is assumed to have a nonlinear elastic behavior using classical J2-deformation plasticity. The micro-mechanical HFGMC method is used to generate the global mechanical response of a material/integration point. Failure criteria, such as the Tsai-Wu, can be applied at the layer level with simple strain softening technique for post-failure behavior.

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DELAMINATION AND FRACTURE

434 | Experimental study of the interlaminar fracture of composite materials in mode III using the Modified Split Cantilever Beam (MSCB) test

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The purpose of this study was to identify the behavior of composite materials in mode III interlaminar fracture using the Modified Split Cantilever Beam (MSCB) test. A MSCB fixture was designed to provide the corresponding load configuration and to get a pure mode III effect on the crack tip. Load versus displacement curves were given by the UTM (Universal Test Machine) and were used in the calculation of the mode III critical energy release rate (GIIIc). Studies were performed for 3 different composite materials: carbon fabrics, glass fabrics, and unidirectional glass. A delamination was introduced at the mid-plane of the tested specimens. The specimen length and width with the values of 160mm and 12mm respectively, were kept constant for all specimens. A total of 54 experiments were performed. The same crack behavior was seen for the 40 experiments with a smooth propagation. For the other 14 experiments damage of the specimens were obtained before any delamination propagation. Different thicknesses, different initial crack lengths and different stacking sequence were studied to investigate the effect of the specimen's on the test results. Results showed that the energy release rate was not entirely accurate as the values were unstable. The second evaluation consisted of a comparison between two glass UD materials with different thicknesses. It turns out that the thickness was playing an important role on the value of GIIIc. The stacking degree sequences of fiber did not however alter the result of the energy release rate but it prevented the specimen from failing. A pure mode III was not achieved even though

some changes were made to reduce the effects of modes I and II. In Further studies, we could consider reducing the specimens' friction and changing the stacking sequence for better-improved results.

470 | Observation of damage evolution and delamination in a thermal barrier coating system using digital image correlation

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Yttria-stabilized zirconia composite coating is normally used for thermal barrier applications. The low thermal conductivity of the coating decreases the substrate temperature and consequently longer life can be expected for the substrate. Hence, it have been applied extensively to many key engine components. On the other hand, TBC systems are subjected to both mechanical and thermal loads in service which progressively alter their physical and mechanical properties. Hence, damage formation gradually occur which finally fractures the TBCs. Porosity existed in the ceramic top coat along with the thermally grown oxide layer generated as a result of thermal exposure generate the multiple failure mechanisms in a TBC system. In the current research, Acoustic Emission (AE) and Digital Image Correlation (DIC) techniques were simultaneously employed to identify the damage initiation and propagation within the TBC system coated on the rectangular super alloy specimens. Two different damage mechanisms were observed and the critical strains associated with onset of the delamination were reported.

472 | Effects of aerofoil curvature on the delamination of thermal barrier coatings; a numerical study

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Composite thermal barrier systems such as air plasma sprayed yttria (8 wt %) stabilized tetragonal zirconia (ZrO_2) (YSZ) are used widely on a range of components that operate at high temperatures. Hence, substantial temperature drop on the component can be achieved as a result of application of thermal barrier coatings. Turbine blades are one of those critical components that are benefits from application of these coating to respond the growing engine temperature requirements. On the other hand, failure of these composite coatings can significantly reduce the blades life. Therefore, besides many research conducted to understand the failure mechanism of TBCs, it is required to investigate the role of curvature of the aerofoil geometry in TBC delaminations. In the current research, an aerofoil geometry features were modeled and the process of the air plasma spray was simulated to generate an aerofoil shaped specimens with TBC composite layers. Residual stresses were therefore generated altering with curvature. Cohesive properties were assigned to the layers to simulate the behavior of the layers more realistically. Surface roughness were also simulated to investigate details delamination mechanism at the different points of microstructure. Comparisons between model predictions and experimentally measured stresses in the literature were made. The results increase the understanding of initiation and propagation of TBC cracks that can be employed in design and assessments.

55 | A thrust and feed prediction model for drilling of composite materials

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This paper presents a mechanistic model for use in predicting critical thrust and feed at the onset of delamination during composite materials drilling. Oblique cutting force model was used to obtain the elementary cutting force distribution along the drill radius. The cutting force distribution was simplified by an equivalent distribution of the thrust force along the drill radius. Based on classical plate bending theory and linear elastic fracture mechanics, a delamination onset model for drilling was proposed to predict the critical thrust force over which delamination occurs at drill exit. Using this model together with oblique cutting force model, to relate cutting force to machining parameters, critical feed rate model was obtained. An advantage of this model over other proposed models is that to avoid delamination via thrust monitoring, the thrust force will need to be sensed and used in adaptive control, while optimal feed rate can be used directly in CNC command generation to maximize productivity.

265 | Influence of cutting parameters on tool wear and hole quality in composite aerospace components drilling

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The employment of composite fiber reinforced plastics (CFRP) by aerospace industry has stood out in the last decade due to their outstanding specific mechanical properties and fatigue and corrosion resistance, until today when they shape over 50% of the structure of some aircraft. Composite materials are also characterized by its manufacturing process which allows to produce near net shape. Nevertheless, machining is unavoidable, being drilling the most common procedure for the assembly of different components, which are stacked together to perform the operation in single shot, usually including countersinking to maintain the aerodynamic shape. This minimizes positional errors, enhance tight tolerances and reduce process time. Composites are inhomogeneous and anisotropic materials constituted by different phases: the reinforcements which used to be brittle and the matrix which tends to be more ductile. Hence their machining is based on intermittent fractures and bouncing of cutting forces. Furthermore, rapid cutting edge rounding is promoted, by abrasiveness of fibers, and machining induced damage or thermal degradation may affect structural integrity of the component. Because of these, strict requirements are imposed on the material and geometry of the cutting tool, as well as specific cutting parameters. At the end, these considerations turn into expensive and short useful life tools. Due to the large number of holes required for the assembly of aeronautical components, improving cost efficiency and/or reducing production time are crucial for achieving manufacturing operations with competitive costs. For this purpose, countersink drill bits were tested on CFRP test specimens representative of aircraft components with the objective of looking for extended tool life and more productive cutting parameters. In order to position the test specimen and vacuum the chips and dust generated, a made on purpose tooling was designed. Initially, cutting tools were tested employing cutting parameters currently used in industry. Along this process, tool wear is monitored, by means of an optical microscopy, in order to track its evolution and determine the dominant wear mechanism limiting useful life. In this case, tool life criterion is based on the assessment of machined surface quality (roughness, overheating, burring and delamination) and dimensional tolerances of hole geometry (diameter, transition radius and countersink angle). So, the inspection procedure of test specimens was carried out with a contact profilometer to analyze hole and countersink geometries and roughness. On the other hand, machined induced damage was evaluated by visual inspection and delamination was quantified by comparing the maximum damaged diameter and the nominal diameter. Then, different cutting parameters were tested to evaluate its influence on tool wear and hole quality. Delamination was found to be the criteria defining tool end of life, besides, the transition radius was decreased from the nominal value as the useful life progresses. Regarding tool wear, chipping was identify to be the predominant wear mechanism. At the end, all the information gathered from monitoring tool wear and inspecting hole quality can be used for the enhancement of CFRP drilling and the improvement of the manufacturing process competitiveness, in terms of production cost and time.

233 | Evaluation of flexural rigidity and shear stiffness of curved sandwich composite beams

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The application of composite sandwich materials is becoming more popular. Different areas of industry prefer to use composites due to their high stiffness and strength properties. Composite materials are now the most preferred materials in aircraft and marine automotive structures. Most of structural components in aircraft and marine structures could contain curved beam regions or could be in the form of curved panels. To investigate the laminate stresses in a curved laminated beam subjected to a pure bending moment is an important characteristic. It is seen that the effects of curvatures and delamination have been dealt with separately therefore, to determine the effects

of both debonding and curvature on composite sandwich structures are very significant. In this study, a curved composite sandwich beam was built using polyvinyl chloride (PVC) foam as the core with two different thicknesses of upper and lower laminates. Glass fibre was used as a reinforced material for laminates. The resin used in this study was comprised of epoxy resin and hardener for a resin-hardener ratio of a 100:25 by weight. Due to the increasing use of composite sandwich beams in different engineering applications, the failure criteria need to be well understood. Standard 4-point bending loading configuration and 4-point quarter span loading configuration have been applied to determine longitudinal modulus. Compressive and tensile stresses occur in the cross-section of the samples subjected to bending. Two different lengths of 300 mm and 400 mm specimens have been prepared and tested. Results of flexural and shear properties determined using the experimental method are shown to correlate well with the results from the finite element modelling.

239 | Calculation of stress intensity factors in cracked shafts under coupled bending, axial and torsion

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For cracked structures, the knowledge of the stress intensity factors (SIFs) plays a fundamental role in linear elastic fracture mechanics. There is an important class of crack problems, involving surface damage in the form of part-through cracks in round bars or beams under coupling bending, axial and torsion, where a three-dimensional analysis becomes necessary. In this chapter, two simple engineering methods for a fast and close approximation of stress intensity factors of cracked or notched beams are presented. The first method is based on an elementary beam theory assuming that the strain energy release rate for crack extension is equal to that for crack widening so that the well-known Irwin's relation can be used to determine the stress intensity factors. Another one named section method and based on equilibrium condition for internal forces evaluated in the cross-section passing through the crack tip, the stress singularity at the tip of an elastic crack into account. The analytical results are straight forwardly compared with the theoretical predictions from the handbooks and agreed well with the theoretical results already proposed in the literature.

Keywords: Crack propagation, Cracked shafts, Stress intensity factors, Coupling loading.

209 | Repair delaminations in composite laminates by screws

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In recent years, there has been a rapid growth in the use of fibre-reinforced composite materials in engineering applications. However, the strength and stiffness of those materials are affected significantly by geometrical and material defects that may result from imperfect manufacturing process or from external loads during the operational life. Delaminations between different oriented layers are the most typical damage, which affects considerably the residual mechanical properties. Independently of the existing solutions, the damage repair remains a great challenge. According to the literature, the main techniques are: resin injection [1], application of bonded repairs [2] and by through-thickness reinforcement repair (TTRR) technique [3]. Therefore, the aim of this work is to study the repair of composite laminates containing delaminations by application of screws. For this purpose, compressive tests were performed using an Instron 4206 universal testing machine and an optical extensometer with digital image correlation. The repair technique studied showed to be a good option for delaminations higher than the diameter of the screw, within a specific range of values, but the compressive strength decreases significantly for smaller delaminations.

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179 | Size-effect experiments for characterization of fracture properties of composites

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Size-effect is a salient feature of composite materials, which are quasi-brittle in nature, and is essential to understand the scaling of their mechanical properties for the design of large composite structures. This presentation discusses size-effect tests conducted recently at Northwestern University on textile composite samples to characterize their fracture properties. Test results of intra-laminar as well as mode I and II inter-laminar size-effect are presented. The size effect tests were conducted on geometrically similar Single Edge Notched (SEN), Double Cantilever Beam (DCB), and End Notch Flexure (ENF) specimens made of epoxy/carbon twill 2x2 laminates. Results show that the nominal strength decreases significantly with increasing specimen size and that the experimental data can be fitted well by Bažant's Size Effect Law (SEL) while deviating from classical predictions of Linear Elastic Fracture Mechanics (LEFM). The analysis of the data obtained through the SEL allows accurately identifying intra-laminar and inter-laminar fracture energies of the material. While the intra-laminar fracture energy deduced from the size effect tests is shown to agree well with the fracture energy obtained by direct testing of post-peak softening of compact-tension fracture specimens, the size effect tests require only the knowledge of the peak load, which makes the testing methodology more appealing and easier to perform in practice.

255 | Fractographic assessment of delamination in carbon/epoxy composites manufactured with plain weave fabric prepreg

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Delamination is the most significant failure mechanism in limiting the useful life of polymer composites with continuous fiber reinforcements. Influenced by the polymer matrix, this type of mechanism is characterized by the physical separation between layers due to the absence of fibers through the thickness of the laminate. Generally, its propagation contributes to the degradation of stiffness and subsequent failure of a composite structure. It can be initiated from fabrication defects, impact damage and three-dimensional interlaminar stresses distributed at the free edges of adjacent layers or in discontinuity of surfaces, for example, holes. The development of this type of failure can occur under static and dynamic loading of the laminate in three different pure modes of fracture known as; Mode I, Mode II and Mode III. Mode I is related to separation between layers by the action of the dominant normal stress in the transverse direction along the thickness of the laminate. Modes II and III are associated with transverse shear stresses, mutually orthogonal to the direction normal to the plane of the laminate. Resistance to the delamination growth is characterized by the interlaminar fracture toughness by means of standardized tests, with a pre-cracked specimen with an insert placed in the laminate midplane. In the present work, the laminates were processed with prepreg of plain weave fabric made of carbon fibers IM7/epoxy matrix M21 with bidirectional orientation (0°, 90°), followed by the autoclave consolidation. Specimens were prepared in accordance with the test configurations; Double Cantilever Beam (DCB) for Mode I and Four Point Bend End-Notched Flexure (4ENF) for Mode II. All specimens were tested under static loading at room temperature. Fractographic evaluation of the delamination was performed by scanning electron microscopy (SEM) to identify the fracture aspects on the fractured surfaces of the specimens. The analysis of the captured images provided the determination of the differences between the two pure modes of fracture considered, indicating that the predominant fractographic aspects are the marks of river lines, scarps, feather marks and shear cusps. Furthermore, it can be observed that the interlaminar fracture of the polymer matrix was influenced by the

waviness of the fibers between the warp and weft directions, as well as by the interstitial sites located in the interlacing of the fiber strands.

256 | Failure analysis of carbon fiber/epoxy laminates submitted to high strain rates in compression

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The requirement of aerospace industry for light structures has stimulated greater application of composite materials, mainly fiber reinforced polymer composites. Nevertheless, composite materials undergo intricate damage processes, which difficult the development of models to predict the mechanical behavior of these materials. This difficulty is particularly true when composite is exposed to impact loads, as in the case of structures submitted to ballistic impact or meteorite collision. In this context, this work aims to study the fracture behavior of fiber reinforced polymer composites submitted to high strain rate in compression. A composite laminate plate was obtained via Resin Transfer Molding process using a plain weave carbon fiber fabric and an epoxy resin as matrix. A Split Hopkinson Pressure Bar was used to apply the compressive loads in three different strain rates. To assess the influence of the fiber orientation the composite plate was trimmed in six different directions (0°, 15°, 30°, 45°, 60°, 75°) relating to the warp orientation. The fracture behavior of the composites was studied using a high speed camera to record the Split Hopkinson Pressure Bar test, allowing to identify the compressive failure modes. It was possible to see that there is a prevalence of the splitting failure when the lowest strain rate was applied. This probably happens due to the fiber waviness, which induce stress concentrations and can promote translaminar fractures. As for the specimens loaded with the highest strain rate, the delamination buckling failures were more likely to occur, possibly due to viscoelastic effects which end up in a higher resistance of the carbon fibers to compressive loads.

171 | Variational formulations for multilayered rectangular plates with circular delaminations

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Interlaminar delamination is one of the most commonly seen failure phenomena in composite laminates, and such failure may significantly reduce the residual strength and the critical load-carrying capacity of laminated structures. Specifically, the existence of the delamination may cause growth of the delamination under in-plane loads, which could lead to ultimate failure of the composite laminates. In tension load cases the delamination will not grow and will result in a small stiffness degradation to the structure. In compression, delaminations can allow a sublaminate to buckle which further drives to the delamination growrh. This mechanism of failure, if not accounted for properly, can lead to uncontrolled delamination growth and premature failure of the structure. Therefore, predicting the delamination growth can be critical to determining the structural integrity. There are mainly two approaches available for studying interlaminar delamination growth of composite laminates. The first approach is related to damage mechanics, in which the interface enclosing the delamination is modeled with a damageable material and delamination occurs when a damage variable reaches its maximum value. The second approach, perhaps the most important and popular approach, is based on the methodology of fracture mechanics. The aim of this work is two-fold: - to compare the finite element results in order to discuss the advantages and disadvantages for the modeling of fracture behaviour and to provide suggestions for reliable prediction of consequences of delaminations in multilayered composite panels, - to analyse buckling and postbuckling behaviour of plates with embedded circular delaminations. The description of fracture, buckling and post-buckling behaviour of composite structures with delaminations can be carried out in two general ways: (1) 3-D approach – usually the finite element methods (2) 2-D approximations. In the latter case the form and the correctness of the

analysis depends mainly on the form of the prescribed 2-D approximations of 3-D displacements. In both commonly used 2-D formulations four parameters are identical, i,e. the normal transverse displacement u3(x,y) (in the plate mid-surface) and the displacement components, of the jump discontinuities between the separated layers of the laminate. The above problems are studied with the use of different variational formulations based on the Lagrange, Reissner and mixed Reissner approaches. The effectiveness and accuracy of solutions are discussed in details.

53 | Fracture toughness of concrete reinforced by metallic fibres

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The value of Mode I plane-strain fracture toughness of plain concrete is generally determined by employing RILEM recommendations and measuring fracture energy. An alternative method to evaluate fracture toughness is the Two-Parameter Model (TPM). Both procedures assume that the non-linear slow crack growth, experimentally observed in quasi-brittle materials before the peak load, occurs under pure Mode I loading. Such a behaviour is observed in plain concrete specimens, but it cannot be noticed in concrete reinforced by fibres. As a matter of fact, in the latter case cracks under far-field Mode I stresses tend to deflect during fracture extension as a result of microstructural inhomogeneities represented by fibres, and both Mode I SIF and Mode II SIF appear at the tip of the kinked crack. Therefore, to determine the critical stress-intensity factor for fibre-reinforced concrete, a modified TPM proposed by the authors [1,2] is here applied to concrete specimens reinforced by randomly-distributed metallic short-fibres produced by the NV Bekaert SA in Belgium [3], for different values of the fibre aspect ratio (fibre length to fibre diameter).

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DURABILITY OF COMPOSITE MATERIALS

438 | Cyclic responses of polymeric fiber reinforced composites

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Fiber reinforced polymer (FRP) composites are preferred materials used for high performance load bearing applications. During service, FRP composites are often subjected to cyclic loading at various frequency, amplitude, and duration. Experimental investigation on cyclic response in FRP composites indicates enormous amount of heat being generated from the energy dissipation which softens the polymer matrix and accelerates failure (Laferie-Frenot et al. [1] and Bellenger et al. [2]). Higher frequency loading leads to ductile failure due to softening of the polymeric matrix from heating. Extensive research efforts on cyclic response in FRP composites focus on understanding the macroscopic performance of composites, i.e., number of cycle to failure for a given frequency and loading amplitude. However, understanding how softening in the polymeric matrix is being formed during cyclic loading and its effect on the overall (macroscopic) performance of composites is still lacking. This study presents micro-macro mechanics analyses on FRP composites under cyclic loading, 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. We examine the effect of loading direction and existence of voids, which often cause stress concentrations, on the matrix softening and macroscopic hysteretic response of the FRP composites. Strain increases are quite

pronounced at the matrix-to-fiber interface and near the voids, which could lead to damage initiation and failure of composites.

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251 | Fast prediction of fatigue limit for woven composite materials using a visco-elastoplastic damage model and fractional derivative approach

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The extensive use of composite materials in the industrial applications requires a careful study of their mechanical properties. The examination of the fatigue limit is an essential part in the structural certification. The classical S-N fatigue test requires significant materials and time resources due to the anisotropy and heterogeneity of composite materials. In order to provide the fast fatigue limit identification, an alternative method based on the self-heating test has been developed for the composite materials [1]. The self-heating method consists of applying a cyclic loading of constant amplitude. The stabilized temperature of the composite specimen is measured during each cycle. When the value of the stabilized temperature increases significantly, it is considered that the fatigue limit is attainted. The experimental results of the self-heating method are in good agreement with the conventional fatigue tests (Wöhler curve). Indeed, the self-heating method allows us to achieve the state of material damage equivalent to one's under the fatigue loading. The development of the material damage leads to increase in the energy dissipation and material heat. The numerical simulation of self-heating test can significantly simplify the analysis and increase the potential of the experimental method. The collaborative model [2] provides a finest description of the intrinsic dissipation due to material damage, viscoelastic effects and plasticity and then the full thermo-mechanical material analysis is possible. The collaborative model is suitable to represent visco-elastoplastic damage behaviour of composite materials with thermosetting or thermoplastic matrices. The model is composed of two sub-models. The first one deals with the elastoplastic damage behaviour [3, 4] which is observed during loading path. The second sub-model represents the hysteresis loops using a fractional derivative law during unloading path. Moreover, the collaborative model takes into account the materials viscoelasticity and can be applied to describe the material strain-rate dependence. This paper deals with the finest estimation of the internal dissipated energy provided by the collaborative model. The fatigue limit is determined by using the representation of the self-heating experimental test. The obtained results are in good agreement with these of self-heating test and to the conventional S-N method. The methodology is validated for thermoset and thermoplastic composite material. Moreover, the implementation of fractional derivative in the finite element code is proposed. Thus, the collaborative model is a simple and powerful tool to predict fatigue limit using a finite element simulation of quasi-static test.

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249 | On the estimation and optimization capabilities of the fatigue life prediction models in composite laminates

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Laminated composite structures especially used in the applications such as airplanes and wind turbine rotor blades are subjected to significant cyclic fatigue loads throughout their service life, which may lead to catastrophic

failure. Accordingly, fatigue is an important parameter that must be considered in investigation and design processes. Fatigue life, thus structural performance of laminated composites can be identified by prediction models, and furthermore can be considerably increased through the optimum design of layers. In this study, the estimation and optimization capabilities of the fatigue life prediction models selected from the literature are investigated. The study includes two main parts. In the first part, the estimation capabilities of the models are tested by a correlation study using experimental data of different composite materials from the literature. The results indicate a comparison of the prediction capabilities of the models on multidirectional laminates and support the applicability of the models on design optimization. In the second part, the fatigue life prediction models are applied to the optimum stacking sequence design of glass/epoxy composite laminates under various in-plane cyclic loadings to obtain maximum fatigue life. A hybrid algorithm combining particle swarm and generalized pattern search algorithms is used in the optimization. It is found by test problems that the hybrid algorithm shows superior or at least comparable performance than the best-known results given in the literature. After assuring the performance of the proposed hybrid algorithm, a number of problems including different design cases are solved using the models, and the multidirectional laminate designs which give the maximum possible fatigue lives are determined for each model. The results show the changes in optimum designs when different models are used. In general, the study supports the necessity and importance of a fatigue design methodology for composite laminates.

328 | Selection of optimal components based on polyurethane resin for the production of tools used for dynamic sheets stamping

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The paper presents the results of the influence of fillings, reinforcements and of metallic particles on the static and dynamic properties of composite with polyurethane resins. Tensile strength, compression strength and Charpy impact test were specified for the different ingredients composition. Reinforcements were glass fibers and rovings cut, fillings were aluminum hydroxide and aluminum powders with different grain size and varying percentage share. The research was targeted on the selection of optimal components for the production of tools used for stamping processes of large shell elements with aluminum alloy sheets.

203 | Durability characteristics of structural nano-synthetic fibre reinforced cementitious composites under chemical environments

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In this study, we evaluated durability of cementitious composite which was reinforced by structural nano-synthetic fibres. The nano-synthetic fibres were used 0.26% of total volume of cementitious composite to evaluated durability of nano-synthetic fibre reinforced cementitious composites(NSFC). We were classified accelerated degradation environment as two categories; physical degradation environment which consists of resistance to repeated freezing/thawing and abrasion; chemical environment is immersed in solution like H2SO4, CaCl2, and Na2SO4. For durability under the chemical degradation environment, it's evaluated compressive and flexural strength of NSFC after immersing in each solution for 50 days. As results, NSFC obtained excellent resistance to repeat freezing/thawing and abrasion. In case of chemical resistance, it had different trend according to immersion environment and time. However, NSFC could be obtained durability as retain strength under the chemical degradation environment.

161 | Effect of drying on the behavior of fiberglass reinforced polyamide

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Short-glass-fibre reinforced polyamide has a hygroscopic behaviour, showing a water absorption capacity up to 4-8% by weight depending on the inorganic reinforcement content. The amorphous matrix area and the interphase between the polymer and fibre-glass are preferential zones where water can introduce. The thermo-mechanical behaviour of reinforced polyamide depends strongly on the humidity content. For this reason, some standards of high responsibility products, injected with this material, establish that their quality control must be done after being eliminated the water content at 100ºC. This work shows that polyamide 6.6 reinforced with 30% of short fibre glass, aging at 100 ºC, depends on the time used to eliminate the humidity content. In this study for drying

times of 0, 3, 7, 10 and 15 days, it has been found that: The considered aging times do not show any variation in the polymer glass transition temperature (which is set around 60 ºC). However, for the highest aging time the cristalinity degree tends to grow. Polyamide viscosity increases with drying times, due to a spontaneous polymer post-condensation. This fact provides to the material a higher fatigue resistance, increasing it up to 12% for the most extreme drying condition.

18 | Effect of accelerated aging of impregnated Carbon Fabric Cementitious Matrix (CFRCM) composites under uniaxial tensile tests

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Sound knowledge of composite durability is a key pre-factor for its successful application in engineering structures. In this paper, we discuss the effect of environmental exposure on the mechanical performance of impregnated Carbon Fabric Reinforced Cementitious Matrix (CFRCM) composite. Following the recently published IIC-ES AC434 guidelines, mechanical performance of prismatic composite specimens is determined on the basis of tensile uni-axial tests under deformation control. The tested environments comprise saltwater, distilled water, alkali and acid aqueous solutions. Freeze-thaw cycles are also considered. Specimens are exposed after a 28 or a 60-day curing period, to reveal the effect of curing time on performance degradation. Deformation is monitored via Digital Image Acquisition (DIC). Special emphasis is placed on analysing the crack pattern evolution during testing as a mean to gain a better insight into matrix and matrix/fabric bond performance. In particular, average crack spacing, crack saturation spacing and average crack width are determined as a function of strain for all test environments and curing times. It is found that average crack spacing provides a very reliable measure of matrix and matrix/fabric bond degradation at all test stages with strong statistical significance.

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DYNAMICS OF COMPOSITE MATERIALS

206 | Dynamics of composite thin-walled beams: uncertainty quantification due to randomly distributed thermal/hygroscopic aspects

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In this paper, we analyze the dynamic behavior of thin walled composite beams (TWCB) considering hygroscopic and thermal effects in the constitutive equations. A model of shear deformable TWCB is employed as the basis for deterministic calculation that are carried out in the context of the finite element method. This model is conceived in the frame of first order shear theories (FOST). The deterministic model incorporates the effect of hygro-thermal stresses and strains in the classical way however considering them as uncertain due to the randomness associated to the material of the matrix resin (in the absorption of humidity) while the composite beam is constructed or while the structure is under service. The variability of the stiffness and mass properties of the composite beam is

assumed as a random field taking into account the elastic coupling between bending, twisting, shear and axial motions together with the hygroscopic effect. The probabilistic model is constructed appealing to the Maximum Entropy Principle in order to derive the probability density functions, according to increasing levels of entropy (i.e. with less number of constraints or less information). The analysis is performed in the frequency domain by comparing the probabilistic models with different levels of information (i.e., given the mean and/or the bounds, etc.) with previously developed probabilistic approaches such as the ones with parametric uncertainty. Also, the Entropy of the response is evaluated in order to quantify the propagation of uncertainty in the information of the model. A number of different hygroscopic sensitive composites have been evaluated and the dynamic responses of TWCB constructed with them have been compared with the homonymous of a dry specimen of the same volumetric fraction of reinforcement. Preliminary comparisons have shown that the moisture affects highly the response TWCB with nylon matrices, in a range of nearly 20%-25% with respect to the perfectly dry case. TWCB constructed with other matrices such as epoxy or polyester resins have shown much lower discrepancies.

455 | Experimental study on dynamic behavior of steel-concrete composite small box girder models with accelerated construction

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Aiming at existing problems on bridges replacement maintenance or newly-built bridges for small and medium span in the construction of urban infrastructure facilities, this paper proposed a oriented-prefabrication production, low beam depth and large rigidity, high performance steel-concrete composite small box girder bridges, which can give full play to the strength of the steel and concrete material, and adapt to the accelerated construction of medium and short span bridges. Considering the requirements of the static and dynamic behaviour analysis and experimental study, the three high-performance accelerated construction steel-concrete composite small box girder models with different parameters of the group stud arrangement and a cast-in-place traditional high performance steel-concrete composite small box girder model with uniform arrangement shear studs along the beam length were designed and manufactured. The different design parameters of steel-concrete composite box girder models were described. The main content and measuring method of the dynamic test were discussed. The effect of the different parameters of group stud arrangement and bond-slip on the dynamic performance of this kind of model boxes was explored by the experimental study. The results showed that the stud quantity of welding group stud in the accelerated construction steel-concrete composite small box girder has greater influence than the spacing of group stud on natural vibration frequencies.

286 | Vibration damping of cantilever beam by means piezoelectric actuator

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The present work is a study of active vibration control of a smart beam. In this regard, piezoelectric patches are using as sensor and actuators. Based on Euler-Bernoulli theory a sate space equation is adopt and extend to the case of cantilever beam, moreover, LQR and LQG controller are using. The analysis studies are carried out using Ansys and Matlab.

306 | A Strain rate and temperature dependent yield stress criterion for CFRP composite materials

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Composites materials are increasingly used today in transport industry and in particular in the aeronautical one. These materials permit to reduce the aircraft weight, to avoid corrosion and to build complex parts more easily. One major issue in this industry is to ensure safety. For that purpose, it is important to understand the mechanical behavior of the used materials for all aircraft operational conditions. During the aircraft exploitation, it can be exposed to extreme loadings, from quasi-static to dynamic strain rates, and large variations of temperature [-50°C, +50°C}. Therefore, all of these conditions must be studied in order to model and numerically predict the mechanical behavior of composite materials, and to be able to perform structural analysis under representative flight conditions. The material studied here is the carbon fiber reinforced polymer (CFRP) T700/M21 composite. One main concern of the paper deals with its dynamic behavior characterization. Indeed, there is no standard or clearly defined methodology to study the fast dynamic mechanical behavior of materials, incl. composites. Moreover, dynamic tests and their analysis are quite tricky to perform because of the experimental noise some dynamic test means can produce. The mechanical behavior of CFRP can be split into three domains: an elastic or viscoelastic reversible behavior, a nonlinear irreversible behavior and the final rupture of the material. The reversible behavior has already been studied by Berthe et al. with the influence of the strain rate and temperature being considered. In his works Berthe proposed to use a viscoelastic spectral model to describe this behavior from creep to fast dynamic loadings. Then, in other previous works, an experimental method was proposed to characterize the transition between the linear reversible and nonlinear irreversible behavior (under constant strain rates test conditions) of T700/M21 material. This method permitted to measure the stress or strain transition value for a large range of strain rates [10-5 s-1,10+3 s-1] and temperatures [-100°C, 20°C], and to highlight the influence of the strain rate and temperature on this criterion. The present works focus on the modeling of this transition criterion according to the strain rate and temperature. For this purpose, different models are considered. The literature concerning the influence of the strain rate and temperature on composite materials yield stress or failure criteria is quite poor. Consequently, the polymer literature is preferred and in particular the Goldberg's model used by Gerlach to model the influence of the strain rate on the ultimate strain for RTM6 resin. The second studied model is Richeton's one which was used to model the influence of the temperature on the yield stress of different polymers like PMMA. These models - once separately applied to the test results obtained with the T700/M21 composite material – do not seem to accurately describe all the encountered phenomena. Therefore, it is proposed in the present paper to adapt them first by superimposing two Goldberg's type models to describe the bimodal influence of the strain rate from quasi-static to dynamic loadings. Then, Richeton's model is adapted and mixed with the previous one to introduce the influence of the temperature on the proposed transition criterion. The final model is finally compared with the set of available T700/M21 tests results for a large range of strain rates and temperatures, which turns to give quite a satisfying agreement.

253 | On the damping behaviour of single and multi-layer coatings

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Mechanical components with high stiffness, resistance and vibration damping specifications are tipically required in most aerospace and industrial mechanical applications. Composite materials such as multi layer materials can be properly designed and optimized to this aim. Most coating layer deposition technologies can be effectively used to increase the component dissipative behaviour, as it is also shown by some experimental results reported in this work. This result can be obtained by applying coating layers with high internal hysteresis or by maximizing frictional actions between the different layer interfaces. Different deposition techniques, such as the reactive plasma vapor deposition and the anodizing process, are considered in this work. Single-layer and multi-layer coatings are applied on metallic substrates. A theoretical model for multi-layered beams is proposed and critically discussed. Conventional beam theories, like the Timoshenko-Bernoulli beam theory, can not be employed to accurately describe the complex behavior of multi-layer beams and even higher order theories show some shortcomings when dealing with nonlinear contributions such as interface slipping and friction. A third order zig-zag layer-wise model approach is considered in this work, where the number of kinematic variables is not dependent on the number of layers considered in the model. The contribution of the frictional actions at the layer interfaces and of the viscoelastic behavior of the coating layer materials is considered. The increase of the damping behaviour of coated specimens can be obtained by properly designing the interface frictional actions at the modeling stage, by adopting a consistent coating deposition technology and then by experimentally validating it. Different material solutions are tested for both the substrate and the coating technology, i.e. aluminum alloy, structural steel and stainless steel for the substrate and metal, metal oxide and metal nitride for the coating layers. Dynamical measurement data in a wide range of excitation frequency are obtained from slender beam specimens

by means of a dynamic mechanical analyzer, in a flexural forced excitation experimental set-up, with clamped-sliding boundary conditions. Homogeneous, uncoated specimens are also tested and experimental measurements are used to compare the effectiveness of the different coating solutions. The complex material modulus is estimated from force and displacement experimental data taking into account of the contribution of the inertial actions. The material constitutive relationship is modeled by means of a high order generalized Kelvin model, and this results in non-trivial constitutive material equations. A robust identification procedure resulting from previous work of the authors of this paper is used to identify the optimal material model and its parameters, and to eliminate the non-physical model components.
The ratio of imaginary and real part of the estimated complex modulus is considered as a measure estimate of the material dissipative behaviour. Results related to different technologies are presented and compared. Some engineering test cases are considered and critically discussed in this work.

185 | Strain rate dependent constitutive model for textile composites subjected to impact

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Composite structures used in aerospace applications are frequently subjected to impact loads during in-service conditions. In order to reduce the extension of delamination in aeronautical components, textile composites are progressively replacing the traditional unidirectional laminates, however, the lack of constitutive models able to account for their complex failure mechanisms and the interaction among them increases the cost of integrating these materials in aeronautical components. The aim of this work was to develop a mesoscale constitutive model able to predict the damage evolution of textile composites subjected to impact loads at low and high energy levels, with emphasis on the strain rate dependency. The constitutive model was formulated at lamina level in which the finite element size implemented was at least ten times bigger than the representative volume element. To obtain a good prediction of the damage evolution, a continuum damage mechanics approach was used to account separately for the response of the warp and weft yarns. Failure modes included yarn tensile failure by fibre breakage, yarn compressive failure by fiber kinking, and transverse failure of the yarns, under tension or compression, accounting for matrix cracking and fibre debonding. Evolution of damage was implemented by a phenomenological softening function controlled by the fracture toughness of the material at each particular direction and the element size. Strain rate dependency was implemented in the ply properties together with a damping algorithm for stability purposes. Validation of the constitutive model was carried out for a quasi-isotropic 8 harness satin S2 glass woven laminate subjected to low and high velocity impact, covering a wide range of impact events. Low velocity impact was carried out by drop weight test in square plates of 145 x 145 mm2 with a free surface of 127 x 127 mm2 and a hemispherical tup of Ø12.7mm. High velocity impact was accomplished by means of ballistic tests. Square plates of 100 x 100 mm2 were impacted with spherical steel projectiles of Ø5.5 mm at velocities ranging from 300 m/s to 700 m/s. A set of finite element models was generated to replicate the experiments in Abaqus/Explicit. The constitutive model described before was implemented as a user subroutine to account for the lamina response. Interply delamination was controlled by cohesive elements included in the interface between layers. Good correlation was obtained in terms of mechanical response and delamination for both, low and high velocity impacts. Impact performance of the laminate was highly dependent on the ply strength and had a very strong influence on the prediction of the force-displacement curves of drop weight test and ballistic limit velocity for impact test. Furthermore, strain rate dependency was a critical parameter to obtain a correct prediction of the ballistic limit of the material and lower sensitivity was found for drop weight test, due to the lower deformation rate. Delamination patterns were correctly predicted as well. In the particular case of drop weight test, delamination was located under the tup and coupled with matrix cracking decreasing the extension of damage along the plate. In ballistic tests, the delamination propagated over a wider area 5 times larger than the projectile diameter and the model was capable of predicting the delamination extension and the crack path through plies with different orientation leading to a characteristic delamination pattern. The constitutive model helped to understand the role played by the different failure mechanisms during impact and was sensitive enough to predict a different performance when impacting at different energy regimes.

92 | Damping mathematical modelling and dynamic responses for FRP laminated composite plates with polymer matrix

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This paper proposes an assumption that the fibre is elastic material and polymer matrix is viscoelastic material, therefore the energy dissipation only depends on the polymer matrix in dynamic response process. The damping force vectors in frequency and time domains, of FRP (Fibre-Reinforced Polymer matrix) laminated composite plates, are derived based on the assumption. The governing equations of FRP laminated composite plates are formulated in both frequency and time domains. The direct inversion method and direct time integration method for nonviscously damped systems are employed to solve the governing equations to achieve the dynamic responses in frequency and time domains, respectively. The computational procedure is given in detail. Finally, dynamic responses (frequency responses with nonzero and zero initial conditions, free vibration, forced vibrations with nonzero and zero initial conditions) of a FRP laminated composite plate are computed using the proposed methods. The assumption, based on the theory of material mechanics, needs to be further proved by experiment technique in the future. Dynamics of Composite Materials

360 | Flapwise vibration of a rotating composite cantilever plate
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The free vibration analysis of a rotating laminated composite cantilever plate using Ritz method is investigated. Simply polynomial satisfying geometrical boundary conditions are chosen for displacement field. Classical plate theory is used in formulation. The effects of fiber orientation angles, rotation speed, hub ratio and orthotropy ratio on the vibration frequencies are examined.

359 | Effects of an attached mass on the vibration analysis of rotating composite beams
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The free vibration of rotating laminated composite beams with attached point mass is investigated. Ritz method with algebric polynomials are used in the formulation. The boundary conditions are considered as clamped-free. Different shear deformation theories and classical beam theories are used in the formulation. Cross-ply lamination configurations are considered. Effects of ratio of attached mass to the beam mass, rotation speed, hub ratio, orthotropy ratio and length to thickness ratio are analyzed in detail.

ELECTRO-THERMAL PROPERTIES OF COMPOSITE MATERIALS

194 | Electro-thermal properties by structural control in metal-hybrid composites
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Recent electronic devices, for the purpose of high performance through seeking high density of modules, thereby increasing the calorific value in the devices, in order to solve this problem, is in progress various researches. In particular, the high power LED modules, by improving the material property and structural design of LED frame, heat spreader and heat sink parts, which aim to release heat efficiently. Representative materials used for the heat-managing parts is aluminum and copper, most research, involving controlling these materials conductive properties and microstructure attempt to improve the thermal conductivity, is continuously performed. In this study, after cladding only two kind metals of aluminum and copper, the laminating of the clad structure, which is called metal-hybrid composite(MHC) having a convincing thermal conductivity with lightweight, was developed through plastic deformation processes such as extrusion, rolling and drawing. The developed material has a very uniform macro- and microscopic structure, through fraction and interfacial properties control of consisting metals, the MHC was confirmed that high potential as a thermal managing material. Production method, properties change depending on the macro/microscopic structure of the MHC and case studies, for application, will be introduced.

EXPERIMENTAL ANALYSIS OF LAMINATED PLATE AND SHELL STRUCTURES

234 | Research the crashworthy capability of composite conical shell with different factors
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Carbon Fiber Reinforced Plastics (CFRP) has been the most popular raw material for crashworthy structure. On account of it has many advantages over traditional material in crashworthiness and density. The crashworthy capability is different with the change of structure, however, the most studies focus on the circular pipe, the research about other shapes are little, such as conical shell. In fact, the shape of crashworthy structure is complex in practical application, so it is necessary to research the crashworthiness of other basic geometries. This paper aims at the composite conical shell to research the energy absorption property with different influence factors. There are four factors will be researched, semi-angle, thickness, weaving method and composite core. The experimental results show that the semi-angle is one of the most important factors for energy absorption. The total energy absorption and stability will increase with the increasing of thickness, but their relationship is nonlinear. The weaving method is a key factor for conical shell failure mode. And the test data shows that the composite core has little help for improving crashworthiness.

222 | Experimental investigation and theoretical analysis of tear propagation of GQ-6 airship envelope

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This paper reports the central tearing properties of a new airship envelope fabric, GQ-6, from experimental investigation and theoretical analysis. First, the effects of the load ratio, the initial crack length, and the crack orientation on the tearing mechanical properties of such material were evaluated. The experimental results revealed that the mechanical properties of GQ-6 decrease with the increase of initial crack length. Two fracture modes were observed, e.g. either along the warp or the weft yarns directions, which depend on crack orientation and load ratio. Oriented crack can be represented by non-oriented crack with crack equivalent length under biaxial condition. The toughness KIC for the fabric was determined based on experimental results, as well as critical energy release rate GIC. A comparison of the mechanical behaviors of this textile under uniaxial and biaxial tensile condition is also presented. The allowable crack length for GQ-6 envelope fabric during working condition is estimated.

219 | Selected mechanical properties of composites with foam core Herex

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Sandwich composites are used in the construction of aircraft and ships, where the important parameter is low weight and high rigidity. Depending on the application, components modifications of such composites can be made in order to achieve particular properties. The aim of the research presented in this paper was to determine selected mechanical properties of sandwich composites with HEREX foam core. In order to carry out the research we made composite panels, which the matrix was epoxy resin Havel HL 145, cured at room temperature with the hardener H 147. The support (external) layers of the composite were made of carbon fabric with a density of 160 g/m2 and as the sandwiched core was used HEREX C70.75ET material of a 3 mm thickness and a density of 80 kg/m3. The composite plates were cut by "water jet" method on samples used to determine impact strength, puncture strength, bending strength and tensile strength. The same mechanical properties were also tested for the samples made solely of HEREX, which as was expected showed in all the tests significantly worse properties. Made as a reference material, two layer composite reinforced with carbon fabric of a weight of 160 g/m2 proved to be useless in impact tests and other properties of its composite were lower than properties of the sandwich composite.

180 | Numerical and experimental investigation of curved sandwich panels and plates

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In this study, curved sandwich panels and plates composed of carbon fiber laminate facesheets and honeycomb core are investigated by using numerical and experimental methods. They are tested by using a gas gun test machine at 100-150 m/s impact velocities. 10 mm diameter of spherical projectile is impacted at the center of the test samples in axial direction. Three strain gauges are bound to the back surface of the samples to measure strains on different points. Besides an accelerometer is bound the back surface of the sandwich panels. The numerical studies are conducted by using LS-DYNA software, which is based on explicit time integration method and desirable program especially for dynamic impact analysis. Composite laminates are considered orthotropic and based on Chang Chang failure criterion. The nodes along the edge of the sandwich panel are clamped. Fine meshes are created in the impacted zone because of the localized effects. In the section of results and discussion, the penetration of the projectile and the failure mechanisms of the panels are simulated, strain variations in time and the specific absorbed energy for each panel are denoted. The results of experiments and analyses are compared with regard to the absorbed energy, contact force, reaction force on the boundaries, displacement at the center of the backplane surface and residual velocity of the impacting object.

EXPERIMENTAL METHODS

277 | PvT-HADDOC: a stress-controlled analyser for the simultaneous characterization of curing and anisotropic dimensional variations of thermoset composites under processing conditions

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In several industry sectors such as aeronautics and automotive, composite materials have known a growing interest during the last decades, owing to their outstanding specific mechanical properties. One particular feature of those materials is that the material and the part are often creaed at the same time, so that fabrication processes involve mechanical, thermal and chemical evolutions, as it is the case for thermoset composites. The mechanical state of any produced part is therefore strongly dependent on the thermal history that systematically results in residual stresses and possibly in shape distorsions with respect to the initially expected design. In order to succeed in optimization of the process, it is thus necessary to know as perfectly as possible the material behaviour and its properties during curing. In particular, the composite undergoes thermal expansion and chemical shrinkage. These two properties have a high importance in the obtained final shape and possible residual stresses but as commonly used composite materials are composed of fibres and organic resin, their properties are often anisotropic. This requires a multiaxial measurement of its dimensional variations, which in practice is very difficult to achieve. Several techniques based on volumetric dilatometers or through the thickness measurements allow determining dimensional variations of a sample during cure but are limited by their lack of multi-axial investigation. Furthermore, thermoset composite materials are subjected to a phase change as the resin goes from a liquid to a solid state, which is difficult to handle when an external pressure needs to be applied. In order to overcome those limitations, a new homemade apparatus was developed, on which temperature cycle and hydrostatic pressure are applied to the sample while interfacial heat fluxes and transverse and in-plain deformations are recorded. These last deformations allow determining thermal expansion and cure shrinkage tensors during cure when applied on a composite material. Several tests were carried out in order to validate the measurements and first results on two thermosetting prepreg composite are presented, one on an automotive high performance SMC and the other one on an aeronautic unidirectional carbon/epoxy prepreg. Anisotropic dilatation and shrinkage tensors are shown to be obtained with a reasonable precision, which opens the way for a better characterization and understanding of the residual stress development under processing conditions. Lastly, by a comparison to a periodic homogenization method, this new experimental apparatus is also shown to be a sound comparison basis for multiscale models using the local thermo-physical properties of the constitutive materials of the composite prepregs.

442 | The experiment of real scale fire by the fire load

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In this study, real scale fire experiments were conducted based on the fire loads in order to use the result as guidelines and fundamental data for performance-based designs. In the real scale fire experiments conducted in a 10 MW calorimeter, wood cribs were placed in a 2.4(L)×3.6(W)×2.4(H) m mock-up of a compartment which had one 0.8(L) x 2.0(H) opening for different fire loads and heating was continued until all of the wood cribs were burned down. Heat release rates started to increase rapidly 90 seconds after the wood cribs caught fire. In the test with fire load level 1, a maximum heat release rate of 4743.4 kW was reached at 244 second. In the test with fire load level 2, a maximum heat release rate of 5050.9 kW was reached at 497 second.

399 | Effect of mould vibration on the mechanical properties of aluminum alloy castings

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This paper presents the effects of mould vibration on the mechanical properties and microstructure of LM6 and LM26 aluminum alloy castings at different vibration frequencies. The vibration frequencies used during the solidification process were 0, 5 and 9 Hz. The mechanical tests conducted were hardness test, tensile test and fatigue test while microstructure analysis was performed using scanning electron microscope (SEM) and energy dispersive X-ray (EDX). The experimental results show that the mechanical properties of LM6 and LM26 alloys can be improved by vibration. It was observed that increase in vibration frequency up to 9Hz led to an increase in ultimate tensile strength from 89.11 MPa to 100.17 MPa (12.41%) for LM6 and from 102.42 MPa to 117.65MPa (14.87%) for LM26 aluminum alloys. It was also found that hardness and fatigue life improved significantly with the increase in vibration frequency. The microstructural studies reveal finer grains, fragmented microstructure, better distribution and low porosity with the increased application of vibration. This leads to less defects and improved mechanical properties in castings products.

299 | Experimental study of composite T-joints subjected to hydrodynamic ram pressure

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The hydrodynamic ram (HRAM) phenomenon occurs in aircraft wing structures with internal fuel tanks. It causes significant damage to the wing fuel tank, which contains the fluid, and the connection structure of the wing fuel tank. Therefore, the HRAM phenomenon is one of the main threats for ballistic battle damages of military aircrafts and has great importance to airframe survivability design. However, it is very difficult to accurately predict the structural damage due to HRAM pressure, because the HRAM effect occurs by the interaction between the fluid and structure. It is needed to perform the experimental study for understanding failure behavior of composite structures under the HRAM phenomenon, particularly of the interaction between the fluid and composite structures. In this paper, a static test and an HRAM test of the composite T-Joints were performed. The composite T-Joints were designed to represent the skin and spar joint structures of an aircraft wing box structures. Considering the dimension of the small sized ram simulator, the flange and web of laminated skin T-Joint were designed as length of 100mm. A Sandwich skin T-Joint was designed by inserting honeycomb core to flange structure, flange of sandwich skin T-joint was designed as length of 140mm and web of sandwich skin T-Joint was designed as length of 100mm. The web of T-Joints was laminated in 3 layers of [0/45/-45/90]s, The skin of T-Joints was laminated in 2 layers of [0/45/-45/90]s and the flange was laminated with 1 layer of [0/45/-45/90]s. The composite T-Joints were made of UD prepreg (USN-150b, SK Chemical). The composite T-Joints failure test was performed using a ram simulator that can simulate the HRAM effect. The HRAM test setup consists of a gas gun to launch a high speed projectile; magnetic sensors for measuring the speed of the projectile; the ram simulator, which can generate HRAM pressure; and a signal acquisition system for storing the signals of the sensors in real time. The composite T-Joints were installed in the ram simulator. When a high speed projectile which was made of a 64 gr cylindrical brass puck was fired to the ram simulator filled with water, the HRAM pressure was generated. Two pressure sensors were installed inside of ram simulator to measure the pressure of the fluid ahead of specimen flange. Strain gauges and PVDF sensors were also attached to the surface of the composite T-Joints to measure their dynamic strains subjected to HRAM pressure. The hydrodynamic test for examining the failure behavior of composite T-Joints were successful in accurately recording the pressure time histories and strain time histories. The dynamic strains on the web during the static tests and the HRAM tests were compared. The higher

frequency dynamic strains on the web were observed during the HRAM test compared to those during the static test. It was found that the failure behavior of a composite T-Joint due to HRAM pressure were mainly cause by not only the magnitude of static pressure but also the frequency response of the T-Joints due to the dynamic characteristics of HRAM pressure.

282 | Assessment of the residual strength of marine laminate panels

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Marine grade laminates are subjected to a wide variety of impacts from objects of all shapes and sizes and to different impact energy levels. The impacts considered here may be simulated by quasi-static indentation. The impact may range from between barely visible impact damage (BVID) to complete laminate penetration. The damage sustained will influence the residual properties of the composite material. The laminate panel configuration is designed in accordance to the Small Craft Standard BS EN ISO 12215-5 for CE certification, fabricated by the hand lay-up technique following ASTM D5687. Tensile, compressive and flexural properties characterisation in accordance with ISO 527-4, ASTM D3410 and ASTM D790 respectively were conducted. Impacted by quasi-static indentation, ASTM D7766M-11 and ASTM D6264M-04, when the load is applied slowly pressing an indentor on the 152 mm square laminate specimen surface. Two support configurations for QSI are possible - procedure A, rigid support and procedure B, simply supported on a 127 mm diameter circular opening, by two different shaped indentors. The indentors are the standard hemisphere of 12.7 mm diameter, a pyramid, having a 30o apex angle and 52.8 mm maximum dent depth and a 15 mm diameter cylinder. Following which, the damaged laminate is tested in a compressive after impact (CAI) apparatus, ASTM D7137M, for determining the compressive residual strength. The tensile and flexural residual strength were also assessed by testing the damaged specimens using the tensile and flexural standard testing procedures to obtain the strength-retention factor (SRF) of the laminate panel. A new concept of the modulus retention factor (MRF) is also introduced. Composite materials designer will benefit greatly from a means of predicting the post impact behaviour of the composite laminates.

366 | Multi-material sandwich panel produced with Desktop 3D printer

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Fused Deposition Modelling (FDM) has gained important segment in the market of consumer goods in recent years. With the expiration of the existing patents more and more producers have started constructing their own 3D printer with different qualities and different capabilities. For example, ASTRA (Additive manufacturing for Systems and_sTRuctures in Aerospace) group at Politecnico di Torino uses a Desktop 3D printer with FDM technology to construct structural part of a multifunctional UAV in order to have an easy to access platform open to researchers and consumers. The advantage of the patented solution is that it is possible to reconfigure the aerial vehicle printing just 8 different components in more than twelve versions. In this manner, not only the spare part logistics is dramatically simplified but also the overall cost of the drone itself is reduced. Constructing a part with FDM means to add several filaments of semi-melted material that glues each other layer after layer. This technology obviously introduces anisotropy due to the technique of fabrication itself: different properties have been found along the fibres respect to the crossing direction; moreover, along the construction direction there are again other mechanical properties. This anisotropy seems to suggest a design approach similar to the one already validated for composites for the ply orientation. Technologically this is quite easy to apply using open FDM machines where the strategy of deposition (raster orientation) can be changed easily. Another problem that will be faced in this work is related to solve a disadvantage of this constructing technique: after the deposition that is at high temperature (245 °C for the ABS (Acrylonitrile Butadiene Styrene)) the fibre cool down rapidly and the thermal deformation introduced between different layers a traction tension. This inconvenience can lead to separation from the building platform of the component or, also, the delamination of the part itself. Different materials, with different melting temperatures and different thermal expansion coefficients give different

responses to this bad phenomenon. For example, PLA (PolyLactic Acid), a natural fibre derived from Corn, gives less distortion respect to ABS or Nylon but has got lower mechanical properties. In this work, this technical disadvantage will be overcome introducing multi-material structures: complex part made with an internal core of PLA (easy to manufacture) and strong external skin in ABS or Nylon. this strategy opens the design scenario to multiple possibilities: in fact, is not only possible to change the internal core material but also the shape of the core from honeycombs to square etcetera. Also, the raster orientation explained above and the density of the fibres deposited for the skins will be investigated. In this manner, it will be possible for the designed application (e.g., the proposed multifunctional UAV called Polidrone) to have stiffener and lighter structures easy to be manufactured with a low-cost 3D printer.

252 | Characterization and analysis of homogeneous and sandwich PLA/ABS specimens produced via the FDM printing process for UAV structural elements

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The present new work focuses on the use of the Fused Deposition Modelling (FDM) technique and the desktop 3D printers for the production of structural elements of small Unmanned Aerial Vehicles (UAVs). The considered UAV is a multirotor and multipurpose modular drone which has been patented by the first author in collaboration with the Politecnico di Torino. The proposed drone, called PoliDrone, has only 8 basic elements which can be combined in different ways and numbers in order to obtain 12 different configurations. Each basic element can be produced by means of desktop 3D printers based on the FDM technology. The possible choices can be 3, 4, 6 and 8 arm configurations with the possibility of a single rotor per arm, double rotors per arm and a combination rotor/inflatable element per arm. The inflatable elements can be positioned at the bottom of each arm to allow the protection in the case of landings in the water or forced landings. The payload is always protected and it can be changed in accordance with the chosen mission. A large number of arms and rotors allows a great stability connected with a reduced endurance. On the contrary, a reduced number of arms and rotors allows a long endurance connected with a reduced stability. Desktop 3D FDM printers are usually employed for the production of non-structural objects. The innovative idea of the present work is the use of this technology to produce structural elements employed in the construction of small UAVs. Mechanical stresses are not excessive for small multirotor UAVs. Therefore, the FDM technique combined with polymers, such as the ABS (Acrylonitrile Butadiene Styrene) and the PLA (PolyLactic Acid), can be successfully employed to produce structural components. In order to achieve this target, this work is devoted to the statistical study of the performance of a desktop 3D printer to understand the process development and its boundary limits of acceptance. Mechanical and geometrical properties of ABS and PLA specimens are evaluated by means of a capability analysis which allows both mechanical and dimensional performance identifications. Experimental collected data are used to determine statistically stable limits. The ABS and PLA specimens are produced using appropriate geometries for tensile and compression experimental tests. Moreover, such tests are conducted for several specimens produced using different directions for the deposition of the material via the FDM technology. In the preliminary project of PoliDrone, ABS has been chosen as the structural material because of its high mechanical properties combined with a reduced weight. However, a first drone prototype has been produced using the PLA because this material is easier to be printed even if its mechanical properties are lower than those of the ABS. The first prototype of PoliDrone produced in PLA has made its first flight on 4th of July 2015. In order to use the FDM technology and the ABS and PLA materials, it is necessary to know the mechanical properties and the dimensional accuracy of specimens obtained via FDM. The mechanical properties are fundamental for a correct structural analysis and optimization of the drone for the actual loads and employed materials. This study is necessary because the filling percentage of ABS or PLA and the manufacturing process influence the mechanical properties of the finished pieces. The dimensional accuracy is necessary to provide essential information on the tolerances to use in the project. The dimensional behaviour is strictly dependent on the specific used 3D printer. Furthermore, a capability study is proposed to understand the statistical behaviour of 3D printers. Therefore, this work is focused on both the mechanical and dimensional characterization and on the capability analysis based on the Six Sigma process. For both tensile and compressive tests, Young Modulus, maximum stress at rupture and stress at proportional limit are determined. These values can be used with confidence as inputs in the UAV project. Future studies will also consider bending tests combined with different directions of deposition for the construction of ABS and PLA specimens via the FDM printing. A novelty of the proposed work is the realization of 3D printed sandwich specimens with external skins in PLA and an internal core in ABS or external skins in ABS and an internal core in

PLA. Sandwich configurations could give an important weight reduction without significant decreases of mechanical properties.

158 | Effect of low and high temperature on the mechanocal properties of short glass fibre reinforced polyamide

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The properties of thermoplastics are temperature dependent owing to the fact that they are soft when heated and hard when cooled. An increase in temperature reduces the Young's modulus and tensile strength but increases the failure strain, leading to a material more ductile and less stiff. The influence of temperature on the polyamides PA66-GF30 in a structure illustrates their impact resistance and their temperature dependency. The increase in temperature softened the material, which absorbed more impact energy in deformation. The brittleness of PA66-GF30 at −30°C contributed to reduced peak load and stiffness in the range of temperature studied (−30 to 120°C). Also, it is proposed a one-dimensional viscoelastic phenomenological model able to yield a physically realistic description of the temperature sensitivity and damage observed in tensile tests that can be used in engineering problems. The material parameters that appear in the model can be easily identified from just two tests performed at different isothermal temperatures. The results of tensile tests conducted at different isothermal temperatures are presented and compared to model estimates of damage progression, and show good agreement.

166 | Dynamic response of the laminated box-beam with damages taking into account the effects of bending-twisting coupling

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In the present study, the numerical and experimental modal analyses of the thin-walled laminated box-beams with damages were performed. This paper was financially supported by the Ministerial Research Project No. 2013/11/B/ST8/04358 financed by the Polish National Science Centre. The cantilever beams with thin-walled, rectangular cross-section were examined. The arrangement of the laminate layers were: [90/15/15/15/90/15/15/15/90]T. In these cases, the strongest effects of bending-twisting coupling took place. Likewise, the strong interactions between vibration mode shapes were observed. Many configurations of laminated layers were examined. The circumferentially asymmetric stiffness (CAS) and circumferentially uniform stiffness (CUS) composite beams were analysed. In first configuration (i.e. CAS) a coupling between bending in flexible direction and torsion was observed. Bending in two perpendicular (flexible and stiff) directions were coupled in the second configuration (i.e CUS). The damage of the beams as an intersection along the fiber direction were introduced. The influence of damage location taking into account the bending–twisting coupling effects were considered. The position and size of the damage have a significant impact on the dynamic response of the system. The numerical and experimental studies were performed. The numerical simulations were made using the finite element method. The Abaqus software package was used. The FE models of the box-beam were made of S8R shell elements. Individual layers of the laminate were made according to the Layup-ply technique. The mechanical boundary conditions of the numerical models were realized by restraining the nodes located on the one end of the box-beam all the translational and rotational degrees of freedom. A number of simulations for different location, size and plies configurations of structure were performed. The eigenvalue problem was solve using Lanczos method. The natural frequencies and the modes of free vibrations were determined. The selected cases were examined using the experimental setup. The experiments were performed on a test stand installed at a Structures Dynamics Laboratory at the Lublin University of Technology. The carbon-epoxy, unidirectional

prepreg was used to prepare the specimens. An autoclaving technique was adopted. The walls of specimen were plane and perpendicular to each other. The rounding of the corners was small. They were cut to a definite dimension using laboratory circular saw. Experimental tests were conducted using the non-contact laser vibrometer, Polytec PSV 3D. The laser vibrometer consists of a scanning head and a data acquisition-visualization unit. The vibrometer provides the non-contact measurement of vibration, thus eliminating the distortion caused by sensors (inertia), temperature fluctuations of the object, method of the sensor placement. The experimental modal analyses were performed. All results were compared with the results of the modal analyses for the specimens without damage. The numerical and the experimental results show a very good agreement.

167 | The influence of defect localization to the local and global dynamic response of a thin walled composite cantilever beam

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Structural health monitoring and defect localization is intensively studied in recent years where the different methods and original algorithms were applied. They are strongly dependent on analyzed structures and a type of the damage. In this paper, a composite thin-walled cantilever beam with a box cross-section has been taken into account. The external dimensions of the beam are 80x20x870 mm and each composite wall consists of several unidirectional carbon-epoxy layers oriented in the following order: [λm/θn/λ/θn/λm]T with respect to the beam axis where λ is an angle equal 0 or 90 degrees. The layers defined by angle λ are necessary from technological point of view. The angle θ is optimized in order to perform the strongest coupling between bendings in two perpendicular directions, having highest and lowest stiffness, respectively. Two n/m ratios have been tested: 3/1 or 4/2. In such structures three types of defects can be found – classical delamination, delamination parallel to the fiber orientation or a hole in the beam surface. This work has been focused on a detection of the third type of the mentioned damage. The effect of the size and localization of the hole on the structure's dynamic behavior has been studied in numerically and by experimental tests. Using Abaqus software the numerical model of the structure has been created. Then natural frequencies and shape modes for different layers orientation for the healthy and damaged beams have been extracted and then the size and localization of damage have been tested. For selected cases, numerical prediction has been verified experimentally for three manufactured composite beams with especially simulated defects. The experimental modal analysis based on the impact testing has been used. Two kinds of shape modes can be specified. First, with a rectangular shape of cross-section maintained along the beam's length – called global. Second, a shape of cross-section changing while system vibrates – surfaces of the beam reveal plate-like vibrations. Then local effects are observed.

Acknowledgements: This paper was financially supported by the Ministerial Research Project No. 2013/11/B/ST8/04358 financed by the Polish National Science Centre.

9 | Flow control in resin transfer molding using model predictive control

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Resin transfer molding (RTM) is an efficient manufacturing process for fabricating high-strength and lightweight polymer composites, which injects liquid thermosetting resin into a closed mold to saturate a fiber preform placed between the mold halves. In RTM, effective flow control is necessary to direct the resin flowing in the desired manner and avoid the formation of defects like dry spot and air entrapment. Most previous methods are based on numerical flow simulations whose accuracy is tied directly to the fidelity of the physics and material models in the codes. Consequently, the performance of flow control largely depends on the quality of the models. The traditional proportional-integral-differential (PID) controller is unsuitable either, because of the nonlinear and time-varying characteristics of the RTM system. In this research, a model predictive control (MPC) strategy is proposed for adjusting the flow behavior of the resin inside the mold, which does not rely on process simulators. In the proposed strategy, the recursive least squares (RLS) method with an adaptive directional forgetting factor is adopted to identify the input-output relationship of the process under control. Based on the identification results, both the flow velocity and the flow front profile can be controlled simultaneously. The applicability and effectiveness of the proposed strategy are illustrated with experimental results.

FAILURE OF COMPOSITES

426 | Stochastic modeling of polymer matrix composite using N-body tree algorithm

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Composites in which individual fiber strength shows high variability, fail due to formation of large clusters of fiber breaks. The simulation of such a failure process in composites requires prohibitively large computational resources. This restricts the understanding of failure behavior in such composites. An N-body tree algorithm based numerical scheme is developed to computationally expedite the solution for the multiple fiber break problem required during the simulation for shear lag based composite fiber model. This scheme is used to perform Monte Carlo simulations on different realizations of composite containing as large as 2^{16} fibers. These simulations show the absence of brittle-ductile transition, establishing that a weak-link character indeed exists for high variability fiber strength composites. A probability model is proposed based on stochastic modeling of sequential breaks of equal load sharing bundles which captures this weak-link strength distribution character for all fiber strength variability regimes. The lower tail behavior of the proposed model for realistic composite dimensions is compared with the other established models in literature.

427 | Series-parallel shear lag model for hybrid composites

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A shear lag model is developed to model an infinite uni-directional hybrid composite with uniformaly spaced high extension hard fibers and low extension soft fibers embedded in a matrix. Hard fibers and soft fibers are placed alternatively in a periodic patch and have different elastic moduli subjected to tensile load at far field. Model allows arbitrary array of fiber breaks and matrix tears that depicts fiber/matrix debonding or fiber pullouts. The resulting differential equations form an eigenvalue problem and solved exactly in the linear elastic framework for displacements and stresses. The model has shown that the fracture toughness of the composite increases with hard and soft fibers and predicts a range in terms of moduli ratio that maximizes the fracture toughness of the composite. The results emphasize that allowing the fiber/matrix debonding may enhance the fracture toughness of the composite.

138 | Tensile failure analysis of glass/epoxy composites: Effect of through-thickness compression

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The effect of through-thickness compression on in-plane tensile strength of glass/epoxy composites with random microstructure was investigated numerically and experimentally. The studied composite laminates were manufactured with a self-regulating Resin Transfer Moulding device. Their mechanical behaviour was assessed in pure in-plane tensile and through-thickness compressive tests, followed by biaxial simulations and tests combining both loading modes; indenters with a radius ranging from 5 to 25 mm were used to impose a compressive mode. Several classical polynomial failure criteria were analysed comparatively to predict the tensile failure strengths of the composites under effect of through-thickness compression based on numerical stress

analysis. The obtained results demonstrate a nonlinear decreasing trend for the in-plane tensile strength under the growing through-thickness compressive stress. The predicted results agree well with the experimental data.

168 | A comparison between the failure modes observed in biological and synthetic polymer nanocomposites

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Polymer nanocomposites display improved mechanical properties with regard to unreinforced polymeric materials. Synthetic polymer nanocomposites have enhanced toughness and energy absorption, which allow for a wide range of engineering applications. The improvement of the mechanical properties in polymer nanocomposites is related to the interaction between the polymeric matrix and the reinforcements. This interaction triggers different failure mechanisms including crack pinning, crack deflection, micro-cracking, fiber pull-out and fiber fracture. On the other hand, biological nanocomposites including bone, abalone shell, fish scales, dermal plates, among others, sometimes display higher toughness than synthetic nanocomposites due to their self-assembly characteristics and hierarchical organization starting at the nanolevel. Moreover, biological nanocomposites exhibit failure modes that seek to prevent catastrophic failure using mechanisms that are related to the absorption of energy during deformation. These failure mechanisms include mineral bridges, delamination, crack propagation, crack deflection, fiber breakage, brittle fracture and plate pull-out. In this work, the failure modes of synthetic polymer nanocomposites reinforced with carbon nanotubes, graphene, silica nanoparticles, nanoclays and metal nanoparticles, are compared with the failure modes of hard and soft biological nanocomposites. The aim of this work is to summarize and report in a systematic way the failure mechanisms that occur in both, synthetic and biological polymer composites. This will allow for rationalizing new design criteria for the development of novel bioinspired polymer nanocomposites with enhanced mechanical properties.

325 | Dominant Fatigue Failure Mechanisms in Bolted Composite Laminates under Flexural Bending

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High specific stiffness and strength enable composites to have large field of applications especially in the areas of aerospace, automobile and marine structures. Because of the intrinsic behavior of these structures, cyclic loadings come into consideration which cause fatigue failure of structures. In contrast to the case of metals Fatigue damage mechanisms in composites are more diverse and complicated. Furthermore, composites are flexible in design and manufacturing. Different lay-up sequences are used to have desirable mechanical properties in desirable directions. Because of this diversity, the damage mechanisms are different for different design styles. For example, fatigue damage mechanisms of n-layer unidirectional laminate under a specific cyclic loading is completely different than that of damage mechanisms for the n-layer angle-ply laminate under the same loading condition. As another structural parameter, which is investigated in this study as well, is the effect of thickness in the change of the failure mechanisms of laminated composites. For the thin laminates the dominant stress components are in-plane stresses. The failure mechanisms that are being affected by these stresses are dominant. In the case of the thick laminate, however, out-of plane stresses are considerable. Therefore, the failure mechanisms that are happening because of these stress components are more involved. There are many fatigue damage modeling techniques available in the literature. Fatigue life models, similar to the fatigue failure theories of metals, are one of the major categories of fatigue failure criteria for composites. One of the earliest fatigue failure theories is Hashin Fatigue Failure Criteria (HFFC). HFFC have the advantage of distinguishing between different failure modes; Fiber failure in tension or compression, matrix failure in tension or compression, fiber-matrix pull-out and delamination in tension or compression. In this paper HFFC are implemented to investigate the fatigue failure behavior of thick composite laminate to see the effect of thickness change in the failure mechanisms. For implementing the failure equations, a progressive damage model is developed. In the available progressive damage models in the literature, mostly the material degradation schemes are discussed. However, the structural behavior could change the dominant damage mechanisms. Progressive Fatigue Damage Model (PFDM). A finite element model has been developed using ANSYS Parametric Design Language (APDL). The model is able to capture the fatigue damage progression based on Hashin equations. At the beginning, because in the composite materials the material properties could be slightly different in different locations of the laminate, a normal distribution has been implemented based on the mean values and standard deviations coming from coupon test experiments for both stiffness and strength of all elements. This helps to simulate the material behavior as precise as possible. In each load step, the failure cases of the elements are examined for all failure mechanisms

based on Hashin equations and obtained stress state. In case that failure happens, the material of the element is degraded and the next loading step is applied. Results and Discussion. The progressive fatigue damage model is validated based on both coupon level and laminate test results. For example, for the case of laminate test, the reduction of load ratio for different deflection levels are compared with the same parameter coming from experiment and there is a good agreement between results of experiments and PFDM. Furthermore, there is a correspondence observed between two phenomena, i.e. decreasing of load bearing capacity and decreasing of the number of undamaged elements. This shows that the number of undamaged elements could be taken as an indication of fatigue damage progression in the laminate which is directly related to the stiffness degradation of the whole laminate.

39 | Research on low-energy impact damage location effect on stability and post-critical states of compressed composite profiles

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The study investigates the effect of the region of damage due to a specified energy impact on the buckling and postbuckling of compressed thin-walled structures with channel section. The profiles were made of the GFRP composite, with a symmetrical arrangement of layers relative to the central plane of the laminate. The region of damage (size and shape) was adopted on the basis of literature-reported experimental findings of tests conducted on composite plates. The mapping of damage of the composite structure was done using a simplified damage model based on reducing thickness of individual layers of the laminate depending on impact energy value. The numerical modelling by the finite element method led to development of a number of numerical models of a thin-walled profile with a channel-section profile. The profile was implemented with the developed damage model by placing the damaged area at different points in the walls and the channel-section profile's web. The aim of the investigation of critical states using linear analysis of the eigenvalue problem was to assess the effect of the damage region on the buckling mode and critical force value. The next stage of the numerical simulation involved solving the problem of nonlinear stability of the structure with initiated lowest buckling mode and to determine the effect of damage location on the postbuckling equilibrium path. The geometrically non-linear problem was solved by the incremental-iterative Newton-Raphson method using the ABAQUS® program. The determination of damage of the composite structure in the postbuckling state was performed using the progressive damage criterion, wherein the initiation of damage of the composite material was done based on the Hashin criterion while the progression of damage was described with the energy criterion. The conducted simulations are the first stage in the investigation of the effect of location of composite damage resulting from low-energy impact tests conducted under the project UMO-2015/17/B/ST8/00033, financed by the National Science Centre Poland.

FRP AND HISTORIC MASONRY STRUCTURES

225 | FE investigation on PFRP-to-masonry adhesive joints

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The paper explores the perspectives of strengthening techniques for traditional masonry structures based on applications of pultruded FRP (PFRP) profiles. Such techniques, not yet specifically investigated in theory nor in practice, would offer sustainable solutions for quick, reversible and durable works of retrofit, e.g. moment or truss frames and local strengthening/substitution of parts e.g. beams. The aim of the research is to clarify the possibility and feasibility of PFRP profiles as an alternative to traditional materials like steel or aluminium profiles in such kinds of structural retrofit. The focus is on interfaces between masonry materials and PFRPs, especially adhesive joints. Currently, this subject needs experimental and numerical research. A programme of experimental tests will be carried on at IUAV University of Venice to investigate the mechanical behaviour of such joints. The tests are based on the EN 1052-3 standard procedure, i.e. sliding test on a brick-mortar triplet under different level of compression, to assess the basic shear properties of a masonry joint, i.e. shear strength and friction coefficient. The main parameters of interest will be the transfer length/surface of the joint, which depends on the type of pultruded FRP profile to be connected, and the type and thickness of the adhesive. A FE analysis with DIANA9.6 software has been set up before the experimental programme, to facilitate the test design and execution and to pre-evaluate the linear and nonlinear behaviour of the sample. The FE analysis will also allow to assess the level of

stress in the different parts of the PFRP-joint-masonry ensemble, to assess the effectiveness of load transfer, throughout the selected parameters. The numerical simulation of the nonlinear behaviour will rely on different options of interface models, i.e. bond-slip and Coulomb friction, to identify the most suitable one in view of model calibration after tests. Finally, the paper overviews the available analytical approaches to optimize the design of PFRP-to-masonry joints.

76 | Analytical study of the bond behavior of PBO FRCM materials for the strengthening of masonry or concrete structural elements

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Fiber reinforced cementitious matrix (FRCM) composites represent a promising alternative to fiber reinforced polymers (FRP) for strengthening and retrofitting existing concrete or masonry structural elements. Dry fabric is embedded in two layers of inorganic matrix to form the reinforcing system. Due to the vapor permeability, durability and reversibility, FRCM systems are compatible with historical buildings. The failure mode of FRCM-concrete or FRCM-masonry joints comprising one layer of FRCM strengthening was reported to be debonding of the fiber from the embedding matrix. In this paper the debonding process at the matrix-fiber interface is studied by means of a cohesive analytical model. The analytical model employs different trilinear simplified cohesive material laws that were obtained based on the results of an experimental campaign conducted on polyparaphenylene benzobisoxazole (PBO) FRCM-concrete joints tested using a push-pull single-lap direct-shear test set-up. The influence of the different cohesive material laws on the FRCM-concrete joint load response is studied. Comparison between experimental and analytical load responses showed that the analytical approach proposed can be effectively used to reproduce the bond behavior of FRCM-concrete joints.

FRP REINFORCED CONCRETE STRUCTURES (CHAIRED BY MANTAS ATUTIS)

450 | Finite element based vibration analysis of pretensioned concrete beam strengthened with CFRP laminates

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Finite element based free vibration analysis of prestressed concrete (PSC) beam with carbon fiber reinforced polymer (CFRP) laminate is conducted. Reinforced concrete (RC) and PSC beams are calibrated with experimental results and theoretical computations respectively to correctly establish the concrete, prestressing steel constitutive material properties and the concrete-prestressing steel interface model. RC beam with CFRP laminate is validated with experimental results to accurately model the CFRP laminate and the concrete-CFRP interface. The established modeling techniques from validations are used to model the PSC beam with CFRP laminate. Cohesive interface elements capable of showing debonding failure are used to model the adhesive between the concrete beam and CFRP laminate at its soffit. Effect of prestressing force, location and profile of prestressing tendons on the frequency of the un-strengthened and strengthened system is then studied. Strengthened system has higher fundamental frequency due to increased stiffness. Fundamental frequency is independent of the prestressing force but varies with the location and profile of the tendons.

41 | Active confinement of concrete columns using dry fibers bundles

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An experimental program is developed in which dry carbon and glass fiber wires bundles were spirally wrapped around concrete cylinders as an active confinement. Stub columns were manufactured using 150 x 300 mm cylinders with a different number of fiber wires as transverse reinforcement. It was concluded that bundling 20 wires of CFRP fiber yarns and bundling 30 wires of GFRP yarns gave ductile response. However, the use of 20 bundled wires of CFRP out-performed the 30 bundled wires of GFRP.

1009 | Environment-assisted degradation of FRP composites for advanced civil engineering applications

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Common concretes use considerable amounts of fresh water and river sand, and their excessive use has serious implications on environment. In this respect, seawater and sea sand concrete (SWSSC) is a very attractive alternative, since it addresses the increasing shortage of fresh water and dredging of river sand. A major concern with reinforced SWSSC is the severe corrosion of the steel reinforcements by sea water (that has a very high content of chloride which is very corrosive), thereby seriously impairing the strength of such concrete. Fibre reinforced polymer (FRP) can be a suitable alternative to replace steels as reinforcement. However, there has been little systematic work to understand the degradation kinetics and mechanisms of FRP in the chloride-containing alkaline SWSSC environment. This presentation will provide an overview of the degradation of FRP composites in chloride-containing alkaline SWSSC environment, as well as provide a pathway to systematic experimental approach to understanding such degradation, particularly by using scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR).

218 | Prestress losses due to relaxation of basalt fiber reinforced polymers

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In general, fiber reinforced polymer (hereinafter - FRP) have a high resistance to creep, but for a prestressing tendon, cable or bar relaxation is more important than creep, since relaxation reduces the available prestressing force. Estimation of the prestress losses over time requires that stress relaxation of the tensile element shall be known. Matrix resins are viscoelastic materials and thus exhibit relaxation. The creep laws both of concrete and of FRP bars are known, whereas their relaxation functions are unknown, in particular to FRP. Moreover, none of the codes provide significant information to determine the prestress losses due relaxation neither numerical method nor approximate solution and only empirical prognosis for limited types of FRP (glass, carbon, aramid) is available. This research consists of theoretical analysis and experimental program considering a degree of the prestressing (40, 45 and 55 percent of ultimate tensile strength) in order determine relaxation of basalt FRP and to propose a solution suitable for common practice.

254 | Experimental study of effect of arrangement of GFRP bars on tensile behaviour of concrete elements

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Despite simplicity of test layout of tensile concrete prism reinforced with a centre bar, interpretation of the experimental results may not be adequate. Typically, a tie-test provides measurements of average deformations of the reinforcing bar and the concrete surface. However, the experimental output might contradict to the general assumption of equivalence of mean strains of the reinforcement and concrete. This contradiction increases with decreasing stiffness of the reinforcement, which is characteristic of the specimens with GFRP reinforcement. Moreover, the tie specimens do not allow to investigate the diameter-to-reinforcement ratio (Ø/p) effect due to correlation of these parameters. To solve these problems, specific equipment for anchorage of multiple bars has been designed and produced. The present experimental study deals with the effect of arrangement of GFRP bars on the deformation behaviour of concrete ties. The analysis is based on the average strains of reinforcement and concrete surface. The study presents experimental and numerical simulation results of 16 concrete prisms with

different arrangement of GFRP bars. The number and diameter of the bars are varying from 4 to 16 and from 6 mm to 16 mm, respectively. Bond properties of the bars were varied as well.

363 | Crack-based computational model for reinforced concrete elements subjected to tensile loading

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When a reinforced concrete element is subjected to tension loading, two main stages can be distinguished: (1) un-cracked stage and (2) cracked stage. In the first stage, the overall behavior is almost linear elastic, until the concrete reaches its tensile strength limit. This stage exhibits a much higher stiffness by comparison to the stiffness of the individual steel bar. In the second stage, as loading of the reinforced concrete element continues cracks take place progressively in the concrete section. The cracked stage is characterized by the number of the cracks developed and their opening widths. This stage is accompanied with a gradually decrease in the global stiffness of the loaded reinforced concrete element, until it reaches the stiffness of the individual steel bars. Nowadays, the study of the cracked stage has gained more and more interest and becoming very popular. Developing nonlinear methods taking into account the contribution of the tensile zone of the concrete in the cracked stage, is one way to describe more closely the real behavior of reinforced concrete structures and so to increase the robustness and capabilities of the computational methods. During the last decade, extensive experimental investigations have been carried out on reinforced concrete prisms under tension with the aim to increase the knowledge and to understand the basic mechanisms involved in the cracked concrete section and the tension stiffening effect of the un-cracked region. Thus, several theoretical models have been proposed to assess the relationship between the tension stiffening effect of the un-cracked concrete section and the steel stress. Based on the literature review, we use the shape of the slip-adhesion curve between steel and concrete proposed by the European Committee for Concrete to estimate the crack openings. Relationships covering the cracked stage, up to the yield strength 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 computational efficiency of the developed model has been verified through some academic examples gathered from the literature using the commercial ABAQUS finite element software.

100 | Structural retrofit of reinforced concrete circular columns using CFRP

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Fiber reinforced polymer (FRP) composite external wrapping have found numerous applications in the field of Civil Engineering, mostly because of their beneficial properties like high strength-to-weight ratio and corrosion resistance. This study presents an easy and expedient finite element approach (FEA) using the software ABAQUS to accurately estimate the axial load capacity of reinforced concrete circular columns confined with externally bonded carbon FRP CFRP sheets. The load carrying capacities of representative confined columns were compared with experimental results, and also with predictions from the American Concrete Institute (ACI) design guidelines. Different orientation and layer numbers of the CFRP wrapping were considered. The developed FEA models simulated well experimental data from published literature. It was found that an optimum value of the CFRP confining strength can be recommended to optimize the concrete confined compressive strength. The strain efficiency factor from ACI, which accounts for premature failure of the CFRP jacket, does not take into account the FRP contributions.

FUNCTIONALLY GRADED MATERIALS AND STRUCTURES

462 | Layerwise fabrication of refractory NiCrBSi composite with gradient grow of nano WiC additives by selective laser melting

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The nickel based superalloys is applied in gas turbines of air, sea or road transport and industrial turbines for electro- or gas-pumping stations, rocket motors, automatic spacecrafts, and nuclear reactors. The basic units of the

turbines where nickel-based superalloys could be used are combustion chambers, guide blades in nozzles, rotor blades, and turbine disks. It is known that with the temperature rise by every 100° at the turbine inlet, the increase in efficiency is about 3–4%. The turbine blade's materials are required to be creep resistive to possess lasting plasticity, resistance to gas corrosion and oxidation, high strength, fluidity, and viscosity. However, machining of Ni superalloys by conventional methods is difficult due to rapid work hardening. Therefore, powder metallurgy methods, such as conventional casting, powder sintering, and/or self-propagating high-temperature synthesis are not allowed to fabricate Ni superalloy-based functional parts directly. So recently, additive manufacturing has been applied to produce Ni superalloy-based parts from corresponded powders. In the present study, we the experimentally determined regimes of selective laser melting (SLM) for multilayered 3D parts of metal matrix composites (MMC) based on nickel heat resistance alloy with WC nano ceramic reinforced additive. Via combinatorial method of design it was shown the possibility of layer-by-layer SLM of functional grade (FG) 3D parts from these MMC for account of increasing the alloying element concentration - (5 %-10 %-15%vol) for nano WC in NiCrSiB matrix. Methods of optical and scanning electronic microscopy, X-ray and EDX microanalysis, microhardness measurement have been used to estimate the structure formation features in the fabricated gradient layers. In certain cases we recommend additional thermal heating of the initial mixture and/or substrate for temperature gradient reduction in the volume of the 3D part to decrease residual stresses and propensity to delamination. Phase analysis of the fabricated MMC showed that the initial WC particles are dissolved after the laser remelting with different velocities depending of the layer height concerning substrate. It was shown the control capability by the mechanical properties (microhardness) within such FG cladded layers. By our opinion, the proposed by us combinatorial approach is an effictive high-throughput tool for detection and design of new alloys for additive manufacturing, studying of phase-structural transformations in nonequilibrium conditions of 3D laser synthesis, and prediction of perspective aircraft MMC and heat resisting alloys, studying phase-structural transformations in nonequilibrium conditions of 3D laser synthesis.

444 | Evaluation on the fire propagation characteristics of thermoplastics

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Since the plastic is mostly composed of organic substances such as carbon, hydrogen and oxygen, it is easy to combust, its ignition and combustion speeds are fast and it generates massive toxic gases on combustion. When heated, its volume decreases as its surface melts. Inflammable fluid of low viscosity generated while being decomposed accelerates its combustion. Radiant heat generated at this moment propagates the fire, which is likely to lead to a great fire and cause great property and human losses and damages. related studies are required but in Korea, related efforts are limited to flame retard classification on plastic. Interior finish materials used for buildings in Korea are classified into incombustible material, semi-incombustible material and flame retardant material and the flame retardant property is determined based on KS F ISO 5660-1 (cone calorimeter method). However, since it is determined by the heat release rate of material only, it is considered that it is limited in identification of fire propagation of a material.

394 | Effect of warm peening on fatigue performance of coil spring

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The application of shot peening as a mechanical surface treatment to significantly improving the fatigue life of most mechanical parts is by no means new. As the possible increase in the fatigue resistance by using conventional shot peening treatments is limited, warm shot peening is being introduced as an alternative way. In this study, the effect of shot peening at elevated temperatures on fatigue performance of coil spring composed of quenched and tempered SAE 9254 steel, was investigated. An industrial, heat circulated oven was used to allow shot peening being done at elevated temperature. Specimens are peened at different peened temperatures, range from 200°C to 350°C, and then were tested on fatigue test machine. The fatigue life results between different warm peened specimens, and between conventional shot peening, were compared in this paper. The results show that the warm peening improved significantly the fatigue life of spring. Moreover, based on the residual stress results, the increase in magnitude of compressive residual stress are affected by the shot peening temperature, and hence would influence the fatigue life of spring.

266 | Analysis of vibrations in beams constructed with FGM: propagation of uncertainty due to parameters

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Functionally Graded Materials (FGM) have been studied for several years due to their useful constructive features. Unlike laminated composite materials, FGM can be designed by mixing the constitutive components smoothly and continuously from one surface to the other following a particular law of distribution or a given proportion between ceramics and/or metals or piezoelectric and piezomagnetic/magnetostrictive materials. This type of materials has a lot of crucial uses in engineering designs, products and high technology devices with a growing importance in control of deformations and vibrations, gathering energy; and commonly they are used as actuators and sensors. The study of such structures, in a context with uncertainties in several parameters of the models, is limited and necessary in order to improve the applications of engineering systems. In the present article, the linear vibratory response of slender beams (straight or curved) constructed with FGM is studied. The governing equations of the structure are derived by the Hamilton's principle and implemented in the context of the finite element method. Moreover, the propagation of uncertainty associated to several parameters of the model is evaluated, in order to characterize their effective influence in the dynamics of smart structures with newer materials. This is done by appealing to the so called parametric probabilistic approach according to which, some parameters of the model are associated to random variables whose probability density functions are derived, depending on the available information, by employing the Maximum Entropy Principle. The probabilistic model is then constructed using the finite element equations previously proposed and the Monte Carlo Method is used to perform the simulation of the dynamics. The influence of prescribed uncertainty in the parameters of the model, such as material properties, type and form of FGM distribution, is evaluated in order to characterize the propagation of uncertainty in the vibratory response in the spectral domain.

415 | Vibration of fluid conveying functionally graded beam considering thermal effects

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Vibration of fluid conveying functionally graded beams with thermal effects is investigated. Euler-Bernoulli beam theory is used in the formulation of the problem. The temperature is considered to vary in the thickness direction. Temperature dependent material properties are obtained considering volume fractions of metal and ceramic material. Equations of motion are solved using finite difference method. Frequencies and damping effects are obtained for different boundary conditions.

106 | Effect of change in position of neutral axis on the bending of functionally graded plates

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Analytical solution for the static analysis of the simply supported anisotropic functionally graded plates based on higher order theory is presented. Analytical model presented herein incorporates shear deformation as well as transverse normal strains which eliminate the need of shear correction factor to rectify the unrealistic variation of shear stress through thickness. Primary displacement field is expanded in the thickness direction using eleven degrees of freedom. Equilibrium equations in the present higher order shear and normal deformation theory (HOSNT11) are variationally consistent and obtained using principle of virtual work. Numerical results of displacements and stresses are compared with three dimensional (3D) elasticity solution and other two dimensional (2D) models. Effect of change in position of neutral axis on the bending of plate is studied and presented.

425 | Active-passive damping in functionally graded sandwich plate/shell structures

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In this work, a simple and efficient finite element model is developed for vibration analysis of active-passive damped multilayer sandwich plates/shells, with a viscoelastic core sandwiched between functionally graded materials (FGM) layers, including piezoelectric layers. The FGM/piezoelectric layers are modelled using the classical plate theory and the core is modelled using Reddy's third-order shear deformation theory. The finite element is obtained by assembly of N "elements" through the thickness, using specific assumptions on the displacement continuity at the interfaces between layers. To achieve a mechanism for the active control of the structural dynamics response, a feedback control algorithm is used, coupling the sensor and active piezoelectric layers. The dynamic analysis of these types of plate/shell structures is conducted in frequency domain to obtain the natural frequencies and, for the case of viscoelastic core, the respective loss factors, and in time domain for steady state harmonic motion. For both analyses, a finite element code is implemented. The model is applied in the solution of some illustrative examples and the results are presented and discussed.

Keywords: Finite Elements, Piezoelectric Actuators, Velocity feedback. Viscoelastic material.
Acknowledgements: This work was supported by FCT, Fundação para a Ciência e Tecnologia, through IDMEC, under LAETA, project UID/EMS/50022/2013, and also CNPq, CAPES and FAPERJ, from Brazil.

395 | Characterization of functionally graded particulate composites using micro-CT

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Glass particulate polymer based composite materials can be an option for applications require increased wear resistivity such as brakes and clutches. Using various techniques (e.g. centrifugal casting), glass particles can be densely distributed over outer surfaces of cylindrical parts. These kinds of materials may be categorized as functionally graded materials (FGMs). In order to characterize these materials, optical microscopy or electron microscopy are regularly used, which are limited to 2D, time consuming, and may be destructive. In this study, x-ray micro-CT technique is used to evaluate the variation of mechanical properties through the thickness direction of glass filled epoxy resin. Flake shaped glass fillers were dispersed into a mixture of low-viscosity epoxy resin and its hardener. Three-dimensional distributions of glass fillers in epoxy resin were reconstructed using micro-CT. The scanned volumes were approximately 7 mm x 7 mm x 5 mm. It was observed from micro-CT images that fillers were well settled. The originally grayscale image was converted into a binary image through adjustment of a grayscale threshold value that decides the split between fillers and the matrix. The micro-CT data is then exported for further numerical analysis. A stack of black and white (B/W) bitmap images were exported with each image corresponding to a specific z-coordinate. Each bitmap image, representing a single layer of voxels, contain white and black pixels corresponding to glass fillers and epoxy resin, respectively. An in-house Python 2.7 code was written to convert the bitmap images voxel data to be used in statistical analysis and subsequent simulations. Finite element (FE) models were developed to calculate the effective mechanical properties of the material. The voxels created from a stack of binary images are simply converted to brick elements of cubic shape. Five representative volume elements (RVEs) were constructed by randomly selecting sub-volumes from a larger cubic volume of 3 mm x 3 mm x 3 mm represented by a stack of black and white (B/W) bitmap images. Each RVE was divided through thickness direction. Effective properties of each division were calculated leading to a functional representation of the variation of mechanical properties through thickness. The distribution of fillers and the variation of mechanical properties through thickness will be presented.

396 | Wear study of glass particulate reinforced polymer composites using micro-CT data

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Glass fiber reinforced epoxy composites were extensively used for wear resisted applications with superior tribological performance of short glass fibers [1]. Functionally graded formed composites are prefered because of the smooth variation of material properties across the thickness unlike to step increase in laminated composites where weak interface problems occured [2]. In this research, wear behaviour of glass particulate reinforced composites was studied. The particulate reinforced epoxy composites were prepared using MGS L285 epoxy resin, hardened by H285 curing agent. The glass fillers added to the polymer mixture were prepared using grinding machine. After grinding, glass particles were sifted to get the particles between 75 um and 150 um. The average dimension of the particles is 100 um. The glass fillers then were added to mixture of resin and hardener and mixed. The whole mixture was hold under vacuum to eliminate the air bubbles. The mixture was cured at

room temperature for a day. Compression tests were done to determine the elastic properties of the neat epoxy. Measured elastic properties were used in the Finite Element Model (FEM). The fillers were obtained at functionally graded form along the thickness. Dynamic wear coefficient of composites was studied using block on disc friction and block on disc wear test specimens were prepared according to ASTM G77-98. Dynamic friction coefficient of neat epoxy and glass fiber reinforced composites were found using the test setup. It was found that neat epoxy gives higher dynamic friction coefficient as compared to glass filled epoxy. It gradually increases from bottom to top as the filler volume fraction decreases in the case of glass filled epoxy. The effect of sliding distance, wear speed and normal load on wearing was considered. The wear depth obtained by experiments according to Holm modified wear equation [3]. The effect of sliding wear on composites were studying by using real image based material model obtained by Micro-CT. Contact pressure was found by finite element model which depends on the volume fraction of the filler through the thickness.

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174 | A high order theory for functionally graded beams, plates and shells

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A new high order theory for functionally graded (FG) beams, rods, plates and shells based on the expansion of the 2-D beams and rods, and 3-D plates and shells correspondently equations of elasticity for functionally graded materials (FGMs) into Fourier series in terms of Legendre's polynomials is presented. Starting from the equations of elasticity, the stress and strain tensors, the displacement, traction and body force vectors are expanded into Fourier series in terms of Legendre's polynomials in the thickness coordinate. In the same way, the material parameters that describe the functionally graded material properties are also expanded into Fourier series. All equations of the linear elasticity including Hooke's law are transformed into the corresponding equations for the Fourier series expansion coefficients. Then a system of differential equations in terms of the displacements and the boundary conditions for the Fourier series expansion coefficients are obtained. In particular, the first and second order approximations of the exact shell theory are considered in more details. The obtained boundary value problems are solved by the finite element method (FEM) with Mathematica and MATLAB software. Numerical results are presented and discussed.

339 | Virtual testing and homogenization of pin-reinforced foam core FRP sandwich structures using parametric nonlinear numerical analysis

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Sandwich structures with face sheets made of fibre-reinforced plastics (FRP) are well known for their high bending stiffness yielding a low susceptibility to buckling at yet a minimal weight. Typical core materials in aerospace applications are honeycomb and foam core materials. In contrast to the FRP face sheets being tailorable in their layup according to the local and global requirements of the structure, these core materials must be chosen to bear the highest occurring stresses within the whole structure. This introduces in many cases a weight penalty which may even flip the scale with respect to overall competitiveness. Pin-reinforced foam core sandwich structures provide an additional dimension in the design space. Stitching a narrow grid of FRP pins into the foam core, and these pins being intrinsically linked with the face sheets, each pin may be oriented in an angle and distance as local stress requirements dictate, ideally yielding a weight optimal solution everywhere in the structure. Together with the opportunity to machine and thermoform the foam core material prior to stitching, the overall manufacturing complexity is significantly reduced and still fully automatable. However, the emerging challenge of handling this vastly increased design flexibility lies within the stress engineer's responsibility; and, since an empirical approach of testing each possible material and pinning configuration is out of the question, numerical simulation must bridge the gap. The presented approach builds and extends on a multi-purpose parametric finite element model of a unit cell of the sandwich structure. Both linear and nonlinear elastic, as well as buckling analysis are available for many principal and specific design load cases, i.e. in- and out-of-plane compression, shear, and bending, but also impact and indentation load cases, each at in general arbitrary levels of detail and specimen sizes. Fully automatic model generation, analysis and post-processing of a multitude of

configurations in parallel enables the rapid determination of key material characteristics, including the verification of expected and unexpected trends from data of accompanying physical tests. The various models are explicitly developed to represent the actual physical tests, but also allow the virtual characterisation of homogenised material properties and material nonlinearity for example due to pin buckling. This combined approach allows the rapid selection of the most promising candidates of material and pinning configurations. The numerically determined and homogenized material properties enable a much higher level of technology readyness in the early phases of product development. Most importantly, this combined approach enables the development of improved material models and sizing criteria, to better understand individual phenomena, or to simplify product development and industrialisation. Present paper addresses the structural mechanical requirements and criteria, the design of the parametric model and its objective to reduce product development time. The close link to physical tests is demonstrated, and practical examples are given where this approach indeed led to the understanding of otherwise undetected structural mechanical phenomena.

Acknowledgements: Parts of the presented work are performed in the frame of the LuFo V project SCHACH, publicly funded by the German Federal Ministry of Economic Affairs and Energy, BMWi.

385 | Vibration and buckling behaviours of functionally graded microbeams based on the state space approach

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In this study, the free vibration and buckling behaviours of functionally graded microbeams are examined using various shear deformation models. The variational principle is applied to achieve the governing equations and the boundary conditions based on the modified couple stress theory. The solutions of natural frequency and critical buckling load are obtained from the state space approach for arbitrary boundary conditions. In addition, the effects of boundary conditions, material distribution, slenderness and material length scale ratios on the vibration and buckling behaviours of microbeams are investigated.

386 | Levy-type solution for the vibration and buckling behaviours of functionally graded sandwich plates

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This paper presents the vibration and buckling behaviours of functionally graded sandwich plates. The governing equations of motion are obtained in the framework of Hamilton's principle using different refined shear deformation models. Considering the plates with simple supports at two opposite edges, Levy-type method provides the analytical solution for various combinations of boundary conditions at other edges. The effects of the geometric and material parameters and various layer schemes on the natural frequency and the critical buckling load of microplates are investigated.

398 | Isogeometric analysis of functionally gradded microplates based on the modified strain gradient theory

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In this paper, a novel numerical model for analysing bending and buckling behaviour of functionally graded microplates is developed based on the Modified Strain gradient Theory (MST) and Isogeometric Analysis (IGA). The MST captures the size effect with three different length scale parameters. Material properties vary through the plates thickness in accordance with the mixture rule, while the displacement filed of the present plate model is based on the third-order shear deformation theory. Principle of virtual work is utilized to develop governing equations, which are then discretised using Non-Uniform Rational B-Splines (NURBS) basis function to satisfy C2-continuity requirement. Numerical examples are carried out to verify the accuracy of the present model. Also, parametric studies are also conducted to investigate the size effect on the responses of microplates.

268 | A Bayesian assessment of FGM plates' static response variability

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Composite materials are known by their ability to be tailored to meet specific performance pre-requisites, constituting thus important candidates to replace in a partial or total manner other often used materials. With this ability, a greater number of variability sources arise, namely due to the manipulation of geometric properties, the selection of material's phases, as well as the spatial disposition of the reinforcement particles within the continuous material phase. All these quantities are affected by uncertainty, being thus important to characterize the relations among the different parameters and some relevant structural responses. Characterizing this uncertainty may be crucial from the structural design perspective, as it will enable to understand and identify the parameters with a greater influence on the uncertainty associated to the simulation models considered. In the present work, we study the influence that the multiple input material and geometric parameters, have on the static response of a functionally graded plate. This study will be carried out using a robust approach based on a Bayesian linear regression model.

250 | A 3D linear elastic static analysis of functionally graded structures subjected to transverse shear loads

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This work proposes an exact three-dimensional shell model for the linear elastic static analysis of plates and shells embedding Functionally Graded Material (FGM) layers. This general shell model allows static analysis of plates, cylinders, cylindrical and spherical shell panels subjected to transverse normal and transverse shear loads applied at the external surfaces. The application of transverse shear loads is the main novelty introduced by the present work. Exact solutions are possible because simply supported boundary conditions are considered and harmonic forms for mechanical loads are applied. The 3D shell model is based on a layer-wise approach which allows the zigzag form of displacements through the thickness direction. Displacements and transverse stresses will be considered as continuous through the thickness direction of the structures by means of the direct imposition of compatibility and equilibrium conditions in the proposed model, respectively. Such conditions can be included in the considered 3D layer-wise model without any difficulty. The equilibrium equations are written in general orthogonal curvilinear coordinates valid for spherical shells. These equations automatically degenerate in those for plates, cylinders and cylindrical shell panels by means of opportune considerations made on the radii of curvature. The proposed 3D equilibrium equations are a system of second order differential equations in z. These equations can be reduced to a system of first order differential equations in z simply redoubling the number of variables. After this reduction, the obtained system can be solved using the exponential matrix method. An opportune number of mathematical layers is used for the correct evaluation of curvature terms and for the appropriate determination of functionally graded material laws through the thickness direction of the structure. Results proposed at the conference will show the preliminary study for the correct choice of the appropriate number M of mathematical layers for the curvature and FGM law evaluations, and for the appropriate choice of the order of expansion N for the correct calculation of the exponential matrix. Moreover, new results will be shown for the cases of loads applied at the top and/or bottom of the structure in the x, y and z directions. Results proposed in tabular and graphical forms will show the 3D capability of the proposed shell model for the determination of the accurate stress and displacement states of one-layered and multi layered structures embedding functionally graded layers. The proposed stress and displacement states will confirm the zigzag behaviour of multi-layered structures and the continuity of displacements and transverse stresses through the thickness direction as given by the correct imposition of compatibility and equilibrium conditions. In general, in-plane stresses can be discontinuous through the thickness direction of typical multi-layered structures. The presence of FGM layers in multi-layered structures guarantees the continuous variation of elastic properties through the thickness direction. Therefore, this feature allows in-plane stresses which are continuous through the thickness direction of the FGM structures. The proposed results can be considered as reference benchmarks for the validation of new refined 2D numerical shell/plate models developed for the analysis of composite and sandwich structures embedding FGM layers. Future developments will consider the application of concentrated or distributed loads obtained using the appropriate Fourier series analytical solutions. Moreover, opportune failure analyses can be carried out by means of the implementation of the most known failure parameters for classical and advanced materials.

151 | Sandwich pipes with graded interlayers for deepwater applications

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Sandwich pipes that combine structural performance with thermal insulation in their design are viewed as a light-weight alternative to pipe-in-pipe systems, in which the core material is used only for thermal insulation purposes. Incorporating functionally graded material (FGM) interlayers into the sandwich pipe design may help improve adhesion at the interfaces between the core layer and inner and outer pipes which has been identified as one of the major factors affecting sandwich pipe performance. In this paper, we investigate sandwich pipes used in deepwater oil and gas applications in which the inter-layer adhesion properties between the core and inner/outer pipes have significant influence on the collapse pressure [1, 2]. In particular, sandwich pipes subjected to internal and/or external pressure with two thin functionally graded interlayers between the core layer and inner/outer pipes are studied in the context of elasticity theory and, the beneficial effect of FGM interlayers on pipe response highlighted [3]. The sandwich pipe wall investigated consists of five layers: an inner and outer isotropic homogeneous layer with same thickness, an homogeneous core layer and two interlayers of the same thickness between the core layer and the homogeneous layers. The core layer is assumed to be a softer isotropic material with respect to the layer materials. The two interlayers are considered to be FGM, with Young's modulus that varies with the radial co-ordinate according to the power law and Poisson's ratio constant. All layers are assumed to be perfectly bonded to each other, with displacement and stress continuity conditions fulfilled at all interfaces. The pipe is subjected to a combination of internal and external pressure. By considering the problem as a plane strain axisymmetric one and using the displacement formulation, the governing equations can be reduced to Navier equation; the specific form of which for layers 1 to 5 depends on the function that describes variation of the Young's modulus with the radial co-ordinate within each layer. Closed-form analytical solutions to these equations are derived in terms of hypergeometric functions and expressions for radial and hoop stresses in each of the five layers are obtained. The response of the pipe wall for a range of external-to-internal pressure ratios is investigated and compared with conventional sandwich pipe. In sandwich pipes with FGM interlayers, the magnitude of radial stress in the vicinity of core/inner pipe and core/outer pipe interface is slightly increased by absolute magnitude. When FGM interlayers are present, hoop stress discontinuity is eliminated compared to the reference pipe without graded interlayers. Significant reduction of hoop stress is observed in the pipe to which pressure is applied (inner pipe in the case of internal pressure, outer pipe in the case of external pressure). The benefit of using FGM interlayers is increasing with the increasing the external-to-internal pressure ratio, with the biggest reduction observed for the ratio equal to 3. Comparative analysis of stress and displacement fields in sandwich pipes with and without FGM interlayers revealed beneficial effect of FGM interlayers on pipe response. Under external pressure, FGM interlayers contribute to significant reduction of hoop stress in the outer pipe. This effect becomes more pronounced as the external-to-internal pressure ratio increases.

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64 | Dynamic response of imperfect FG beams under nonlinear thermal gradient and partially resting on Winkler-Pasternak elastic foundation

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The present paper investigates the dynamic behaviour of FG beam structures featured by porosities, subjected to nonlinear thermal gradient and partially resting on Winkler-Pasternak elastic foundation. The analysis has been carried out by using unconventional beam theories developed by means of the method of series expansion of displacement components (MSEDC). Various polynomial, exponential and trigonometric functions have been employed in the expansion in order to describe accurately the beam cross-section kinematics. The weak-form of the governing equations has been derived by virtue of Hamilton's Principle. The solution is sought in approximate sense by using and advanced Ritz formulation. Orthogonalised algebraic Ritz functions are employed in the analysis. A thorough convergence analysis of the proposed formulation has been carried out. The effect of the slenderness ratio, volume fraction index, porosity type, elastic foundation parameters and boundary conditions on the natural frequencies and dynamic response of the beam structures under investigation, is discussed.

HEALTH MONITORING TECHNIQUES IN COMPOSITE STRUCTURES

464 | Electro-mechanical impedance modeling of thin cylinder subjected to temperature variation

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Amongst, Impedance based Structural Health Monitoring "ISHM" as continuous health monitoring method by using piezoelectric wafer active sensors "PWAS" becomes a powerful nondestructive evaluation technique during the last decades. In this paper, an analytical model of electromechanical impedance (EMI) for thin-walled cylindrical shell is developed by interaction between PWAS and structure considering temperature variation. Energy method is used to obtain vibration equation of structure and PWAS. Advantage of this method is structure and PWAS is modeled together, so the effect of mass and stiffness of PWAS is considered. Rayleigh-Ritz method is used to discretize system with mode shapes function. Natural frequency of structure is calculated by solving frequency equation, which is derived by employing the Rayleigh-Ritz method to vibration equation of shell. Natural frequencies of cylindrical shell with clamp-clamp boundary condition without temperature variation effect are compared with previous results given in literature. Then temperature variation is applied to this model. By solving vibration equation in frequency domain and by applying Gaussian equation, impedance of PWAS has been obtained.

454 | Monitoring of low cycle fatigue effect on composite beam by electro-mechanical impedance method

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In last decay, the researchers show that Electro-mechanical impedance (EMI) method can be used as an efficient method in structural health monitoring to detect damage. This method is based on comparison of electrical impedance of piezoelectric wafer active sensor (PWAS) attached to healthy structure with PWAS electrical impedance of same structure after damage generation. The impedance of attached piezoelectric is coupled with dynamic response of structure and will change by variation of mechanical properties and/or damage generation on structure. The aim of present work is to monitor structural behavior and damage diagnosis of composite beams under cyclic loading using electromechanical impedance method. The uni-directional glass-epoxy composite sheets are fabricated by Vacuum Infusion process (VIP). The beams are cut from fabricated composite sheets. Tension tests are carried out to obtain the mechanical behavior of test specimens under uni-axial loading. Two piezoelectrics are attached on each specimen. The specimens are subjected to low cycle and low load fatigue (compression-traction) with different loading intensifications. Impedance of piezoelectric is measured after different number of cycles in order to monitor fatigue effect on dynamic structure response. The results demonstrate that effect of low load fatigue on EMI spectrum can be detectable and its trend is traced well. Root Mean Square Deviation (RMSD) and Correlation Coefficient Deviation Metric (CCDM) are applied as damage index metrics; the results show that using CCDM index, a better trend du to material degradation is observed comparing to RMSD index.

122 | Evaluation of mode II delamination growth using a new acoustic emission Lamb-based technique

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In this paper, a very promising procedure is proposed to evaluate delamination using Acoustic Emission (AE) technique in composite laminates. First, the influence of attenuation of fundamental antisymmetric (A0) and

symmetric (S0) wave modes were obtained on AE propagated waves. A new procedure was then developed to decompose the fundamental Lamb wave modes in small size specimens. After that, experimental procedures were conducted to characterize the delamination using End Notched Flexure (ENF) tests in woven and unidirectional specimens. The results showed that it is possible to successfully decrease the effect of propagating media such as attenuation of AE signals using the new proposed methodology. Also, it is found that more accurate results can be achieved using a unique velocity of S0 mode in each frequency range instead of using an effective AE velocity in all frequency ranges. Finally, the results of this study could lead to efficiently distinguish the delamination in laminated composite using AE Lamb-based technique.

300 | Disbond detection in adhesively bonded joints in composite structures using electromechanical impedance technique

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Adhesively bonded composite joints may degrade over time causing significant loss of strength and stiffness. These bonds are also vulnerable to manufacturing defect, load line porosity, and high operational loads. A built in structural health monitoring system for detecting these disbonds is often desired. Vibration based technique, ultrasonic testing, strain motoring through fiber optic sensors, impedance based technique, acoustic emission technique etc. are among the most popular techniques for structural health monitoring. So far most of the researchers have proposed strain measurement through fiber optic sensors or the study of the propagation of ultrasonic waves for health monitoring of adhesive joints. This is work is a numerical investigation into the suitability of using the electromechanical impedance based technique for detecting disbonds in adhesively bonded composite joints. In the electromechanical impedance based method, piezoelectric patches fitted to the host structure serves as sensor and actuator. Lead Zirconate Titanate (PZT) is the most commonly used piezoelectric material for such applications. When a piezoelectric patch is excited by a time dependent electrical voltage mechanical vibration is generated in the host structure due to the electromechanical coupling in the piezoelectric materials. And because of this mechanical vibration an electrical output signal is obtained in the piezoelectric patch. Thus the nature of the electrical impedance measurement obtained from these piezoelectric patches depends on the mechanical properties of the host structure and piezoelectric patches and the electrical properties of the piezoelectric patches. Hence, it is called the electromechanical impedance. By analyzing this electromechanical impedance at a broad frequency range, damage assessment can be done for the host structure. The principal advantages of this method include suitability in monitoring complex structures with inaccessible locations because of the use of small non-intrusive sensors, sensitivity to local minor damages, easy interpretation of the data, better feasibility for online monitoring. In spite of its simplicity and successful implementation for metallic structures the electromechanical impedance method has not found its wide application for structural health monitoring of adhesively bonded joints, especially of the composite structures. The heterogeneity of material properties and greater loss due to energy dissipation caused by high damping are the two primary reasons behind the limited use of electromechanical impedance technique in composite structures. Use of optimally placed large number of piezoelectric patches can be a solution to this problem. For this study, a single and a double lap joint have been considered. At first a finite element model of the adhesively bonded structure with piezoelectric patches has been developed. The finite element model involves modeling of the bonded composite components, modeling of the adhesive layer, and modeling of the piezoelectric patches with consideration to their electromechanical coupling followed by an assembly of the models. Disbonds have been modeled as a discontinuity of displacements between adhesive and adherent. Using the above mentioned finite element model, electromechanical impedances at the different piezoelectric patch locations for disbonds of different lengths and different locations have been found out. Damage indices have been formed from the electromechanical impedance data for different damage cases at different sensor/actuator locations. The entire data set is divided into a training set and testing set. A feed forward neural network has been trained using the training set for detecting the disbonds from the damage indices. The efficiency of the network in detecting the disbonds were tested using the testing set. The future involves experimental validation of this technique.

469 | Self learning health monitoring algorithm in composite structures

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The paper describes a system that it is able of monitoring the health state of a composite structure in real time. The hardware of the system consists of a wire of strain sensors connected to a control unit. The software of the system elaborates the strain data and in real time is able to detect the presence of an eventual damage of the structures monitored with the strain sensors. The algorithm used to detect the presence of a damage on the structure is based on the Leonardo property concept (TO2012A000588 - Method for performing diagnostics of a structure subject to loads and system for implementing said method, filed 4/7/2012, patent pending). Specifically, it requires as input only the strains of the monitored structured measured on real time, i.e those strains coming from the deformations of the composite structure due the working loads. The health monitoring system does not require any additional device to interrogate the structure as often used in the literature, instead it is based on a self-learning procedure. The strain data acquired when the structure is healthy are used to set up the correlations between the strain in different positions of structure by means of neural network. Once the correlations between the strains in different position have been set up, these correlations act as a fingerprint of the healthy structure. In case of damage the correlation between the strains in the position of the structure near the damage will change due to the change of the stiffness of the structure caused by the damage. The developed software is able to recognize the change the transfer function between the strains and consequently to presently able to detect the damage.

368 | A study on the strength evaluation and defect detection capability of adhesive joints according to CNT content of electric resistance method

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Mechanical joint and adhesive bonding are two typical joining methods for composites. The adhesive joint method has excellent fatigue properties because the load is distributed over a large area compared to the bolt fastening method. However, the strength of the adhesive joint greatly depends on the environmental conditions and the skill of the operator. Therefore, there is a need for techniques to evaluate and continuously monitor the integrity of the adhesive joints. The electric resistance method is a very promising technique for detecting defects by measuring electrical characteristics by dispersing CNT in an adhesive. In this study, adhesive single lap joint specimens were fabricated by using the dispersion method optimized for electrical resistance method and the static strength and defect detection capability of the joints were evaluated according to the CNT content. In addition, a technique to monitor cracks in adhesive joints under dynamic load condition was studied.

351 | Impact localization on a composite plate based on error outliers with concept selection

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A low-velocity impact is detrimental to structural safety of composite structures because it can generate impact-induced damages, i.e., barely visible impact damages (BVID) including fiber breakage, matrix cracking, and delamination. Therefore, a detection of impact points is essential to guarantee a structural safety and reduce maintenance costs of composite structures. This study proposes a novel impact localization method on a composite plate based on error outliers with Pugh's concept selection. The impact localization on a carbon fiber reinforced polymer (CFRP) composite plate is implemented using two fiber Bragg grating (FBG) sensors by detecting arbitrary fifteen impact points. The wavelengths of reflected peaks of FBG sensors were recorded at a sampling rate of 100 kHz. The reference data set was constructed in advance by impacting the reference points on a CFRP composite plate, i.e., 121 node points. Arbitrary fifteen points on the plate were additionally impacted and the corresponding wavelength variations were simultaneously measured. Then the numbers of outlier were estimated by comparing the reference and arbitrary impact signals. The nodes having the number of outlier less than the threshold level were chosen for each FBG sensor, and the impact points can be estimated by averaging the geometries of the chosen node. In addition, we firstly adopt Pugh's concept selection to choose the point with a less absolute error between two impact points estimated by two FBG sensors. We found that all impact points with relatively small errors were successfully detected. Therefore, it is concluded that the proposed impact localization method with Pugh's concept selection is effective to localize the impact points on composite structures.

Acknowledgements: This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (2016R1C1B2010417).

IMPACT PROBLEMS

418 | Influence of manufacturing defects in mode I delamination failure of fiberglass composites under impact fatigue loading

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The present paper studies the influence of manufacturing defects in Mode I delamination under impact fatigue conditions in a fiberglass-Vinilester composite (GFRP). Two types of fiberglass were used for the composite manufacturing: mat plies (short random fibers) and woven roving plies. A quasi-static test was performed according to the ASTM D5528-13 standard and GIc values were obtained for the material. A dynamic test was carried out with an in-house Drop Weight Impact Testing Machine applying low energy repetitive impacts to simulate the impact fatigue. A Double Cantilever Beam (DCB) was used as samples configuration under both load conditions. In the dynamic test, samples with a single pre-crack positioned between mat plies and samples with a second defect located between mat and woven roving plies were tested in order to establish the influence of the defect in the crack growth rate. Results obtained from the quasi-static test showed two GIc values. Results from the impact fatigue test showed that the defect affected the delamination, decreasing the crack growth rate. Finally, in dynamic conditions a low Gth value of 23,68 J/m2 was obtained for samples with a single pre-crack

20 | Impact behavior and damage analysis of laminated composites glass fibres/nano-reinforced thermoplastic matrix

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A laminate composite based on the new Elium® acrylic matrix and glass fibres has been prepared by an infusion process at ambient temperature in order to replace thermoset-based laminated composites with equivalent recyclable thermoplastic based composites. In order to enhance the impact resistance of the composite, the acrylic resin has been toughened by adding different amounts of acrylic tri-block copolymers (Nanostrength®). The composite plates were subjected to low velocity impact tests, performed at different impact energies and temperatures. Tomographic observations have been performed on impacted samples, in order to show the effect of all-acrylic block copolymers concentrations, temperatures and incident energy on the damage extension in the composites. A numerical approach allowing to describe damage mechanisms at different scales of the material, was proposed. A mesoscopic scale is chosen in order to highlight the layer's behaviour (intralaminar failure and interlaminar delamination) with respect to the material geometry representation: homogenous yarns of fibres drowned in an elastic-viscoplastic matrix. A micromechanical model providing the behaviour of the yarns is used to simulate the initiation and the propagation of damage induced by the impact loading at the constituent's scale (fibre breakage, matrix cracks, fibre-matrix debonding).

465 | Study for the human movement by evacuation elevators in tall buildings based on the decision processes of during evacuation

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In the past, high-rise buildings were allowed to use stairwell only in the event of fire, however after the 911 attacks, elevators should be allowed to use as an evacuate systems. Therefore, the purpose of this study is to know for human behavior in using evacuation elevators in emergency situation so the impact of delay time in elevator evacuation time.

405 | High velocity impact response of 3D printed thermoplastic composites

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The complex behavior of 3D printed thermoplastic polymers results in a real challenge regarding the prediction of their mechanical response and performance in the design process of products made from this kind of materials. These polymers show a considerable loss in ductility and increase in stiffness and yield stress below their ductile-to-brittle temperature, and in case of overpassing the glass transition temperature, they show a mark reduction in stiffness and yield stress and also an increase in ductility. Specially, these aspects are relevant in applications such as impact problems where high strain rates are reached. In this regard, one of the critical aspects to consider when using 3D printed thermoplastics is their vulnerability to out-of-plane impulsive loading, as a result of the reduced thickness of the structural configurations. The impact behaviour of 3D printed polymers has not been deeply studied under extreme conditions in terms of high impact velocity and perforation tests are not available in scientific literature. This work deals with the mechanical impact behaviour of 3D printed polymeric composites of polylactic acid (PLA) and thermoplastic elastomer (TPE). The set-up used was a gas gun capable of shooting a rigid spherical projectile of steel and the perforation test covered impact kinetic energies from 20 J to 150 J and impact velocities from 100 to 400 m/s. The study focuses on the effects of configuration of different plates on energy absorption of this type of lightweight structures.

397 | Mechanical behavior of 3D printed polymeric matrix under dynamic loading

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3D printing technology has aroused an increasing interest in both scientific and industrial communities due to the wide flexibility in the design, reduced product development cycle and low fabrication costs provided. Many polymeric materials are suitable to be used by this manufacturing process. Among these polymers, Polylactic Acid (PLA) and Thermoplastic Elastomers (TPE) stand out as promising candidates for their use as matrix in lightweight composites. Due to the intrinsically limited mechanical properties and functionalities of pure polymeric parts manufactured by 3D printing, there is a critical need to study their mechanical properties and energy absorption capability. This work deals with the mechanical impact behaviour of 3D printed polymeric plates of PLA and TPE. A drop weight tower CEAST INSTRON 9350 incorporating a climatic chamber has been used to conduct energy tests covering a range of impact velocities from 3 m/s to 15 m/s and temperatures from 15ºC to 60ºC. For the 3D printed sandwich configurations tested, the amount of kinetic energy of the striker converted into plastic work has been found to strongly depend on the testing temperature. Experimental results provide relevant data for designing 3D printed composites with customized properties as deformation behaviour in deep-drawing process; which is widely used in prototype industries.

285 | Fracture analysis of functionally graded plates with elliptic surface cracks under low velocity impact

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The dynamic response and fracture characteristics of functionally graded plates with semi-elliptical surface cracks under low-velocity impact are investigated using three-dimensional finite element analysis. The impactor is a hemispherical tipped cylindrical steel projectile of small mass (about 163 gms) with an impact velocity of 5 m/ to ensure low-velocity impact conditions, while the plate has a mass of 1.588 kg and is simply supported on all the four edges. The interaction force between the projectile and the plate is modeled as an integral part of the solution algorithm. The contact force between the projectile and the plate is calculated through a contact law incorporating the Newton-Raphson method. The impact is assumed to be a transient elastodynamic problem and solved using Newmark implicit transient time integration. The dynamic energy release rates for the plate are extracted from the finite element solution using 3-D virtual crack closure technique for each time step and converted to dynamic stress intensity factors. The base materials for the FGM plate are alumina for the ceramic and aluminum for the metal. A power-law variation is assumed for the property variation through the thickness. Three different types of FGM with material profile composition varying from ceramic-rich to linear gradation and metal rich are modeled and compared with homogeneous ceramic and metal plates. The semi-elliptical surface crack in the plate is such that the crack depth is parallel to the material gradation. To perform the simulations in general purpose finite element programs, a material property to pseudo-temperature mapping approach is used. An initial uncoupled

thermal conduction analysis using the pseudo-temperature boundary conditions is performed and the corresponding material property distribution in the finite element mesh is obtained from the results. Subsequently the dynamic analysis is performed. The results of the parametric analysis to study the effect of material gradation and crack depth on the dynamic stress intensity factors are presented in terms of normalized stress intensity factors and contact force history. The study clearly brings out the quantitative differences in the variation of the dynamic stress intensity factors and the nature of the crack growth across the crack front in the width and thickness directions, depending on whether the impact occurs on the metal side or ceramic side.

407 | Repeated impact behaviour of fully thermoplastic laminates

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The use of laminated composites is spreading in engineering applications, respect to heavier metallic materials, thanks to their excellent advantages of weight/strength and weight/stiffness ratio. Even if up to now the attention was focused on fibers reinforced with thermosetting matrix, in the last years, composites made with thermoplastic matrix have gained consideration. This is mainly due to their advantages in terms of low density and, more important, recyclability. The use of thermoplastics composites is of interest not only for the replace of the non structural parts, but also for the structural components located in areas potentially subjected to impacts. Depending on the design geometry and the field of application, some composite components may be subjected to repeated impacts at localised sites either during fabrication, routine maintenance activities or during service conditions. Even though the impact damage associated to the single impact event maybe slight, the accumulation of the damage over time may seriously impair the mechanical performance of the structure. In this paper, experimental data of repeated impact tests performed on fully thermoplastic thick laminates are presented. Repeated impacts at different energy levels are considered. The experimental data are analyzed evaluting the damage index (DI). This parameter has been previously defined and used for thermosetting composites in order to overcome shortcomings of the damage degree (DD) in case of thick composite laminates. The rate of initial steady damage accumulation as well as the onset of severe damage modes are analyzed and discussed in the paper. When applied to repeated impact tests, the DI allows to distinguish between an initial steady phase of damage progression and the onset of severe damage mechanisms. For the initial damage, the damage index increases linearly with the impact number whereas the severe damage mechanisms lead to laminate performation in few impacts. In this work, the values of the DI at different stages are discussed: at first impact, in the steady phase and at the onset of the unsteady phase. Moreover, the total energy absorbed by the laminate in the steady phase is also computed for all the performed tests and compared with the results of other thermosetting composites previously tested by other researchers.

155 | Impact of a rigid sphere upon a Kirchhoff-Love plate made of viscoelastic auxetic

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The problem of impact of a rigid sphere upon a Kirchhoff-Love plate of finite dimensions made of viscoelastic auxetic with fractional viscosity. Poisson's ratio of auxetic changes with time from negative to positive magnitudes, and its damping features are described by the fractional derivative Kelvin-Voigt model. For the linear plate the solution out of the contact domain is constructed in terms of the Green function, while within the contact zone the solution constructed with help of the generalized Hertz contact theory. During construction of the Green function the bulk relaxation is neglected, since for the majority of materials the bulk relaxation is much smaller than the shear relaxation, i.e., the bulk operator could be assumed to be time-independent, and the shear operator is governed by the fractional derivative Kelvin-Voigt relationship. These assumptions allow one to define the time-dependent Poisson's ratio varying with time from the initial negative value to a certain positive value, in so doing showing the behavior characteristic for auxetic materials. Before utilizing the generalized Hertz law, the rigidity time-dependent operator should be found, in contract to the elastic case when the rigidity coefficient in the Hertz contact law is defined by constant magnitudes of the elastic moduli and Poisson's ratios of colliding bodies.

In the given problem, Poisson's and rigidity operators have been determined using algebra of dimensionless Rabotnov fractional operators. The integral equations are obtained for the contact force and local bearing of the plate material, and their approximate solutions have been found due to short duration of the impact process allowing one to trace the influence of the order of the fractional derivative (fractional parameter) on the key parameters of the impact interaction. The asymptotic relationships obtained for the contact force and local indentation enables one to consider two limiting cases: when the fractional parameter tends to zero, the plate exhibits pure elastic features, but with the fractional parameter tending to unit the damping features of the plate are described by the conventional Kelvin-Voigt model. The constructed approximate solutions could be used in the engineering practice for estimating the magnitudes of the contact force and contact duration for the cases when the target is made of auxetic materials.

Acknowledgements: This research was made possible in part by the Ministry of Education and Science of the Russian Federation.

389 | Low-velocity impact characterization of thin thickness laminates

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In the last decades, CFRP composite materials are widely used to replace traditional ones in aerospace thanks to their functional and structural properties. Potential use of these materials, combining different phases like matrix, reinforcement and interface, is influenced by many factors including manufacturing conditions and poor compatibility between base constituents, as well as the stacking sequence. Moreover, the latter has a great influence on the damage onset and propagation. Since their inhomogeneity and anisotropy, composite laminates suffer crucial damages under dynamic loading conditions: different kind of damages, starting from matrix cracks through fibre failures and delaminations, can be observed after an impact; also a low impact energy can cause a delamination that sensibly reduces the compression residual strength. Moreover, the above damages can interact with each other in different and complicated interaction mechanisms. A large number of research works has been devoted to the mechanisms of damage initiation and growth. Starting generally from matrix cracks, laminate generally develops more than one delamination along the thickness during the impact, depending on the impact energy and the stacking sequence. Important questions, not solved yet, are: how the damage starts, how it propagates, is there one of these delaminations more critical in the subsequent impact or transverse loading? Is there the possibility to predict it? Is there a relationship between internal and external damage? How the residual strength is influenced by the delamination? Give an answer to the above questions is fundamental, in order to supply useful tools able to drive right decisions about the necessity of repair, or not, the impacted part of a composite structure. For this scope, in the present research different laminates made with IMS fibers and 977-2 Cytec epoxy resin have been considered, in order to have different impact responses in terms of rigidity, due to different thicknesses, and different interactions between layers differently oriented and stacked. A large campaign of experimental tests was performed with the final aim to have a better understanding of the phenomena of damage onset and its propagation, to develop methodologies for the design in order to achieve more efficient structures and more easily maintainable. This methodology should suggest solutions through fast simulations starting from simple and few experimental tests with the help of semi empirical models, avoiding future large number of impact tests. Low velocity impact tests were carried out at different energy levels, also with penetration, to investigate the damage propagation as well as the residual compression strength. The influence of the different impact parameters was observed through the validation of existing semi empirical models. Some interesting differences from what present in literature were found because of the very thin thickness of the laminate and the rigidity of the matrix used. The first aspect, in fact, is out of the field of the small displacement, condition necessary to validate some semi empirical models.

343 | Finite element and experimental analysis of Low-speed impact response of a 12k filaments plain-woven CFRPs

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Plain-woven Continuous-Fiber-Reinforced-Polymers have been increasing widely used in aircraft, because of its high strength and high stiffness in the fiber fabric plane. But they show relatively weak property in the direction normal to the plane. When the composite structures receive impact from objects such as tools, sands, and hails, they can be damaged as delamination. Delamination is still a typical damage mode in the plain-woven composites. After delamination, the strength and stiffness of the structure will decrease significantly. In this paper, impact response of plain-woven composites was studied by finite element methods and drop-weight impact tests. In the FEM analysis, each lamina in the composite is modeled with shell elements, 3D cohesive elements were inserted between adjacent laminas. Delamination is modeled as the failure of cohesive elements between layers. Drop-weight impact tests with a variety of impact energy were conducted on plain-woven T700S/2510 composites. After the tests, the samples were examined with an Ultra-sonic C-scan machine to show delaminated region. Relationships between the delamination area and impact energy were studied.

204 | Advanced impact simulations of aerospace grade composites based on high-velocity impact experiments

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The advanced modelling and simulation of different aerospace grade composite materials under high-velocity impact is treated in this study. Characterisation of the materials, including thermosets (epoxy) and thermoplastics (PEEK) with carbon (unidirectional and woven fabric) and glass fibres, as well as conventional metals (Al2024-T3), was conducted using high-velocity impact experiments. The test results indicate the glass fibre composites' superiority in the domain of classical composites in terms of weight-specific impact performance. The different carbon fibre composites have very similar ballistic limits but differ in terms of delamination behaviour. Nevertheless, none of these fibre-reinforced materials can reach the penetration resistance of aluminium 2024-T3. The derived material models are subsequently applied to assess different simulation techniques. These are ranging from simplified finite element models over more detailed and advanced methods up to peridynamic simulations of the impact events. To conclude the study, the tested materials are evaluated for application in representative aircraft structures in terms of weight benefits and penetration prevention.

288 | Experimental study of bird strike response of sandwich structures: overall trends

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Nowadays sandwich structures are used as bird shields to protect aircraft nose bulkhead. They are usually made of aluminum honeycomb and sheets. In order to optimize mass, cost and efficiency of such bird shields, aircraft manufacturers want to explore new materials and designs. In this context, this work aims at exhibiting influences of material and design parameters on the bird strike response of sandwich structures. Based on previous finite element calculations that enabled to determine the most influential parameters, a design of experiment has been defined to span a parameter space in 4 dimensions, namely the thickness of the front skin, the thickness of the core, the yield stress of the front skin and the crushing stress of the core. 13 configurations of sandwich structures are then tested according to this design of experiment. These samples are 800 mm x 800 mm square sandwiches simply supported on a rigid square frame. The impactor is a 1.6 kg gelatin bird substitute, thrown at a speed of 160 m/s. Based on high speed camera image correlation, an original approach is developed to measure and quantify the responses of the samples. For each configuration, the full displacement field of the rear face of the sandwich is calculated during the impact event. The final shapes for both rear and front faces of the shield are also reconstructed, enabling to compare the behaviors of the different structures regarding bending, indentation and core crushing. The exhibited trends in terms of influences of material and design parameters open prospects for pre-selection of candidate materials and designs for bird shield applications which could lead to mass and cost reduction while satisfying aircraft design constraints (no failure, low rear face displacement…).

294 | Methodology for identification of impact behavior of materials: application to bird strike

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This work proposes a methodology for identification of material parameters in the case of bird strike tests. A measure of displacement field of the backside of samples is performed by stereo-correlation of high speed cameras images. Hundreds of images are taken during the impact event, leading to reconstruction of corresponding deformed surfaces. The proposed identification methodology supposes that enough data is collected to identify both material parameters of an aluminum target plate and the ones of gelatin projectile. An error function is computed by comparison of the measured and simulated deformed surfaces. Due to the non-linear dependence of the error function on material parameters, a global optimization approach based on meta-modelling is considered. This methodology enables the direct identification of material parameters at the effective rates of loadings, without the need for lower scale coupon testing which do not always involve the right material and structural behaviors. Once the numerical model of gelatin projectile is identified, this approach could be derived to identification of more complex target material models like composite plates and sandwich structures.

380 | Low-velocity impact characterization of water-backed marine composites

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Several naval structures are routinely subjected to mechanical shock. A particularly relevant class of marine composites is constituted by carbon fiber reinforcements dispersed in a vinylester matrix. Understanding the dynamic response of these composites poses a number of theoretical and methodological challenges due to their inhomogeneity and anisotropy, determining the mechanics of damage formation. These challenges are further exacerbated when considering deployment in marine vessels, where extreme temperatures and fluid-structure interaction must be examined. The aim of this work is to improve the comprehension of the dynamic response of this class of marine composites, through a focused experimental study that cogently simulates realistic operating conditions in marine vessels. Specifically, a novel experimental framework is presented to elucidate the impact response of water-backed marine laminates at varying temperatures. The setup is constituted by an instrumented water-filled box used as support, where panels are fully clamped and subjected to low-velocity impact in a drop tower. During the impact, the deformation of the panel, the motion of the impactor and the pressure field in the box were recorded to ascertain the severity of the impact and quantify fluid-structure interaction. First, a detailed calibration study on aluminum panels is presented to ascertain the validity of the experimental setup and mitigate experimental confounds due to the size and geometry of the water chamber. Specifically, three different heights for the chamber and three different diameters for the pipe which is used to proxy outflow conditions are examined. Once the setup is fully validated, its use in a large experimental campaign on carbon fiber laminates in vinylester resin is demonstrated by comparing water-backing with classical air-backing. A radically different behavior is shown between the two loading conditions, in terms of both load-displacement curves and internal damage. Load-displacement curves are reconstructed from measurements at the impactor, while internal damage is assessed through post-mortem microscopy and non destructive ultra sound inspections. Experimental results demonstrate the central role of fluid-structure interaction on the panel response, whereby a dramatic variation in the peak load, maximumum deformation, strain energy storage, and failure modality are observed. A previously established modeling scheme is adapted to assist in the interpretation of the results and help quantify the role of added mass phenomena during the impact. The model is based on potential flow theory and modal analysis toward a precise quantification of bidirectional interactions between the fluid flow and the structural deformation comprising bending and membrane stretching.

63 | Woven carbon-epoxi laminates subjected to low velocity impact: from elastic regime to perforation

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Composite material is increasingly being used in transport industry due to its high stiffness-to-weight and strength-to-weight ratios that allows reducing the structure weight obtaining important economic and environmental benefits. First introduced in the 70s by the aeronautic industry, the spread of composite materials has reached nowadays more than 50% of aircraft structures weight. In order to increase the use of these materials it is essential to understand its behavior when subjected to different types of loading, from elastic domain to extreme conditions such as impacts. Concerning to impacts, it has been shown that low velocity impacts of large masses could induce different failure mechanisms like matrix cracking, delamination and fiber failure. The complexity of these damages, and its dependence on the loading condition and material configuration, increases the number of tests needed to understand the non-elastic regime. In this work, the different failure mechanisms have been studied on 5HS woven composite laminates subjected to low velocity impacts. To analyze this non-elastic behavior, a large range of energies (5-80J) have been used to induce different failures: delamination, fiber failure, shear fiber failure and perforation. In addition, it has been manufactured different configurations of AGP 280-5HS woven coupons to analyze the influence of thickness ((0/90)4S, (0/90)6S and (0/90)8S) and ply sequence ((0/90)8S, (+-45)8S, [(+-45)/(0/90)]4S, [(+-45)2/(0/90)2]2S, and [(+-45)4/(0/90)4]S).This work uses a combined experimental and numerical methodology, in which experimental tests have been used for validating numerical model developed. Experimentally, laminates have been subjected to low velocity impact using an INSTRON-CEAST Fractovis 6875 drop weight tower according to ASTM standards (D7136 and D7137). Each test has been recorded with two high speed video-cameras (Photron SA-Z 2100K) configured at 20000 fps in order to analyze the plate behavior during the impact. In addition, a three dimensional high velocity digital image correlation (HV-DIC) analysis has been done with the VIC-3D 7 system to measure the out of plane displacement and strains evolution. Once impacted, composite laminates were subjected to a non-destructive damage analysis. The damaged area was evaluated in each coupon by ultrasonic inspections (C-Scan and B-Scan techniques), studying the spread and location of the damage inside the composite laminates. The analysis of the influence of the plate thickness and ply sequence have been made according to the Composite Structure Impact Performance Assessment Program (CSIPAP) proposed by Feraboli and Kedward using the peak force and the absorbed energy. In addition, to reproduce the experiment tests, the drop-weight impact has been modelled using a commercial explicit finite element software with a user subroutine. The material model for the woven laminate takes into account different intralaminar failure mechanism based on a Continuum Damage Approach, such as fiber failure or in-plane shear; finally, the use of cohesive interactions allows reproducing the interlaminar damage. Once validated, the use of the combined methodology, numerical and experimental, would help to understand the non-elastic behavior of woven laminates and to establish recommendations that optimize the resistance of laminate when subjected to impact.

Keywords: Low velocity impact test, FEM modelling, satin woven CFRP laminates, ply thickness, ply sequence.

26 | Identification and modeling of barely visible impact damage - Numerical and experimental investigation

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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 objects of the analysis are composite profiles made of eight-layer GFRP laminate. The purpose of this work is to analyze the behaviour 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.

JOINTS

369 | Strength evaluation of composite single-lap joint reinforced by new stitching and Z-pinning method

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Laminated composites have high stiffness and strength in the in-plane direction, but are very weak in the thickness direction. Therefore, Various reinforcement methods (eg. stitching, Z-Pining, weaving, tufting, knitting) have been studied to overcome these problems. In general, stitching and Z-pinning are most widely used, but it is difficult to apply the conventional stitching method to the prepreg due to process characteristics. Prior to this study, we developed the new stitching method and dedicated equipment applicable to the prepreg. The proposed stitching method is an effective method to prevent delamination of a composite by inserting a single discontinuous fiber in the thickness direction of the composite and bending the fiber end to 90 degrees to form a head on both sides of the composite. In this study, to verify the reinforcement effect of the new stitching method, a new stitching method and Z-pining were used to fabricate composite single-lap joint specimens and their fracture strengths were experimentally compared and evaluated.

370 | A Study on the fracture strength of composite structure stitched with single fiber

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Composite laminates have higher specific strength and modulus than other metal materials, but have low strength in the thickness direction and are very vulnerable to interlaminar fracture. Stitching and Z-pinning are known as methods for improving the interlaminar strength and preventing the interlaminar fracture, and the researches about these methods have been actively conducted. In this paper, the new stitching method was suggested and composite specimens stitched with a single fiber were manufactured and tested. The new stitching technique is a technique to prevent interlaminar fracture by stitching one yarn discontinuous fiber. Composite specimens stitched with single fibers were fabricated according to the types of fibers (carbon fiber, aramid fiber), length, and preliminary holes, and fracture strength and failure modes of each specimen were evaluated.

244 | Determination of the influences of various tool rotation speeds on the tensile properties of friction stir welded AA6061/SiCp composite

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The difficulty of subprocesses such as joining and machining of metal matrix composites (MMCs) impedes these materials to find wider application areas despite the various advantages they have. Considering their joining processes, the conventional welding methods may result in unfavourable effects such as chemical reactions between reinforcement-matrix material, presence of several inclusions and presence of undesirable phases in

matrix material. Friction stir welding (FSW) has been so far the only outstanding method that can be applied to MMCs for resolving these undesired cases owing to its advantages provided as a solid-state joining method. The primary objective of this study is to investigate the weldability of particulate reinforced aluminum matrix composite by FSW and evaluate the joint properties in terms of the tensile strength. The material considered is aluminum alloy matrix/SiC particle reinforced composite (AA6061/SiC/20p). The composite studied in this work is produced by Materion (UK) and joined using a FSW adapted vertical milling machine at three different rotational speeds of 1000 rpm (Joint-1), 1250 rpm (Joint-2), 1600 rpm (Joint-3), and a constant welding speed of 100 mm/min. Temperature distribution around the weld zone was measured during the processes by using the non-contact infrared thermometer (Fluke 576 CF) so as to provide sound weld. A conical unthreaded tool with a shoulder of 20 mm diameter was used for the FSW processes. The tensile strengths, percentage of elongations of the similar joints were measured and joint performances were also calculated within the study. FSW exhibited joint efficiencies over 90% for Joint-1 and Joint-2 and of more than 85% for Joint-3. However, the process significantly reduced the ductility of the joints.

245 | Evaluation of fabric reinforcement in the bonding surface on the load-carrying capacity of adhesively bonded aluminum joints

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This study presents a comprehensive experimental investigation on the single-lap joints between AA6082-T6 fabricated by epoxy adhesive reinforced with woven E-glass and woven carbon fibers. The major objective of the study is to enhance the failure response of adhesively bonded single-lap aluminum joints under transverse impact and different temperatures. In this context, carbon and E-glass fabrics having a density of 500 g/m2 were utilized in the bonding surfaces. Araldite LY 1564 epoxy resin and Aradur 3487 BD hardener were used as the adhesive materials. Within this research, the joints were experimentally investigated through the tensile tests at various ambient temperatures (25°C, 50°C and 75°C). In addition, impact tests of the joints at an impact energy level of 2.5 J were also performed at room temperature so as to evaluate the effects of transverse impact on the load-carrying capacity of the joints. The obtained results show that single-layered and double-layer E-glass fabric reinforcements in the bonding surface increase the failure load of the joints by 28 and 85% at 25°C, respectively. Similarly, single-layered and double-layer carbon fabric reinforcements improve the failure load of the joints by 41 and 63% at 25°C, respectively. Moreover, the failure responses of the joints decrease significantly at elevated temperatures (50°C and 75°C). When these joints were subjected to low velocity impact test at an energy level of 2.5 J, the joint strength dramatically decreases compared to non-impact specimens. Considering the overall results, it can be said that fabric reinforcements in the bonding surface resulted in a significant improvement on the failure responses of the single-lap aluminum joints in terms of maximum failure loads.

349 | Experimental investigation of fatigue behavior of 3D carbon woven composites single-bolt bearing joint

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The objective of this paper is to present an experimental investigation on the fatigue behavior of 3D woven composites single-bolt single-shear joints. Though some recent literature has emerged in the field of experimental characterization of 3D woven composite, the field of bolted joints is even further limited. This research extends previous work (Warren et al. 2015a, 2015b, 2016) on the quasi-static characterization of 3D woven composite material properties and behavior of these materials in single-bolt bearing through experimental characterization of fatigue behavior. The composite material is reinforced with a three-dimensional woven ply-to-ply interlock IM7 carbon fiber preform impregnated with toughened epoxy resin and manufactured using a resin transfer molding process. While the joint investigated is commonly found in many aerospace structures, the composite material represents a unique material currently used in select aerospace applications. The tension-tension fatigue behavior of 3D woven composite materials in single-bolt bearing in the warp and bias (45 degree) directions was investigated. S-N curves were developed for up to one million load cycles. The methods for instrumenting the bolted joints during fatigue loading are presented. Experimental techniques were developed to measure fastener rotation. Damage initiation and propagation in the 3D woven composite material and the bolt observed during the cyclic loading are discussed. Fatigue failure modes of the 3D woven composite bolted joint in fatigue for the warp and the bias directions were characterized.

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357 | Parametric study of stiffener influence on repaired composite structure

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When patch repairs are chosen for stiffened aircraft structures the presence of stiffeners largely influences the local in-plane and out-of-plane stiffness of the skin. This study focuses on the evolution of the stress distribution in the patch bonded region as a function of the distance between a patch and a stiffener. A parametric three-dimensional (3D) finite element model is developed to consider a variety of stiffeners' position. The repair efficiency is evaluated by comparing the failure criterion index in the adhesive film of a circular repair to that of an elliptical repair. The stiffener pitch and distance to patch center as well as local scarf angle are considered as study parameters. Numerical results show that the stiffener position begins to affect the stress state in the adhesive film when a critical distance is reached. When patch is sufficiently close to stiffener, the stress distribution in bondline is modified. The shear stress becomes lower in regions that are adjacent to the stiffener and higher in the central adhesive film region. Consequently, the stress distribution on the overall bonded surface is affected and high stress concentration appears. Numerical analysis also reveals that an appropriate patch can balance the stiffener effect by adapting its local scarf angle resulting in a non-circular shape. It happens than that depending on the stiffener position or pitch, circular repair or elliptical repair becomes the most suitable in terms of stress distribution. This paper will outline recommendations for bonded patch repairs for damages close to the stiffener and provide examples for situations when patch design makes it possible to compensate the stiffener influence on the adhesive's stress state.

140 | Pinned joints in quasi-undidirectional glass-fibre NCF/epoxy composite laminates

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In this study, six types (three cross-ply and three quasi-isotropic layups) of composite laminates reinforced with the quasi-unidirectional non-crimp (NCF) fabric textile preforms were manufactured by the vacuum assisted resin transfer moulding (VARTM). The pin-bearing tests of the glass NCF/epoxy composite specimens were completed according to ASTM D5961. The damage modes and bearing strength of the pinned joints were documented, and also compared with the bolted joints of current material system. Moreover, a three-dimensional (3-D) progressive damage model (PDM) was developed and experimental results were predicted.

279 | A robust numerical model for the pre-design of composite reinforcement by expanded bonded bushing (EB²)

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For many years now, composite materials have been used for aeronautical and space structures. In order to join composite parts together or with metallic parts, classical bolted assembly technologies are generally employed, after being slightly adapted to these new configurations. Thus, for composite bolted joints the load transfer is mainly performed through the contact between the fastener's pin and the composite hole. This type of contact generates high local stress concentration around the hole, which then requires to be reinforced. One solution consists in adding a metallic ring inside the hole, which allows reducing the load along a part of the composite hole. Different processes can be used: expansion, bonding or simple setting. Capaero developed EB² (expanded bonded bushing), an innovative technique for ring reinforcement by expansion and bonding. This process provides the advantage of not requiring any specific device for bonding, since the adhesive lies in its microencapsulated form and is already part of the semi-product. The expansion of the pre-coated ring, with a mandrel, mainly aims at crushing the capsules inside the adhesive and mixing the two components together, but also at setting up a light radial preload inside the composite. The combination of expansion and bonding gives the joint better stiffness and failure strength for bearing loads, since the presence of the adhesive allows the load reduction all around the hole, and not only along a part of it. For the metallic case, the ring design usually relies on hardening criteria but for composite joints, a damage initiation is not desirable. Consequently, the design rules are totally different. For now, no design tools dedicated to composite yet exist. A particular design method has then to be defined, and its application requires the control of the expansion rate applied. Indeed, a low expansion does not allow improving mechanical performance, but a too high expansion can lead to premature bearing damage in the composite. given the potential combination of manufacturing tolerances in stakes in the joint, only taking into consideration the nominal optimal geometry is not enough. The present study first introduces the development of an axisymmetric finite element model, for a robust predesign. this model is used to run a high number of simulations, which takes into account different manufacturing variabilities. According to specifications, the analysis of residual stresses and circumferential strains allows the choice of proper ring geometries. The finite element model is then numerically validated by a previously developed 3d finite element model which reproduces accurately the expansion process. Finally, the model predictions are compared to the results of experimental tests, for several values of expansion rate. The experimental test run has two objectives: the first one is to validate the numerical model, by measuring the expansion load and strains around the hole, for numerous geometries of specimens and for different variations of processes. The second one is to identify which expansion rate generates the best adhesive activation. thus, after expansion, push-out tests are run on specimens, in order to estimate the joint quality by comparison of push-out loads between all configurations. The study brings conclusions about the relevance of such a tool and its limitations, and also the perspectives for this work, which could ultimately allow the study of bolted structures.

262 | Optimization of process parameters for friction riveting between a short fiber composite and an aluminium alloy sheet

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Friction Riveting is a process utilized for making structures by spot joining materials with different mechanical properties. Joining between thermoplastic polymers and metals have been tested confirming its potentiality in the connection of lightweight materials especially where only one side working accessibility is allowed. The basic configuration of the process consists in rotating a cylindrical rivet and inserting it into clamped sheets. In the first process phase, the rotational speed and the applied axial force heat the material by friction plasticizing it. During the heating phase, the tip of the rivet becomes softer because of the temperature increment. After that, the spindle rotation is stopped and the axial force is increased passing to the called forging phase. At this time, the rivet, due to the strength of the joined materials, which are colder and more resistant plastically deforms assuming a wider diameter in comparison to the initial rivet size. Several working parameters have to be optimized for achieving sound connections, such as: the rotational speed, the friction and forging times, and the friction and forging pressure. In the proposed work, the attention was given to the joints between a thermoplastic matrix composite and an Aluminium sheet. In particular, the worked composite is a polyamide 6 containing 15 wt% short glass fibers, used to produce components for the mechanical engineering, as well as for aircraft and automobile construction. This material is characterized by high stiffness and strength, low specific weight, long-term application temperature and a good chemical resistance. Its mechanical properties permit to design and manufacture light components, for instance for the automotive sector where the weight reduction is one of the

main priority. The selected Aluminium alloy is the AA-2024. This choice is justified because the AA-2024 is used in applications requiring high strength to weight ratio, as well as good fatigue resistance. Therefore, this is suitable for aircraft and automobile application. Furthermore, the AA-2024 is weldable only through friction welding and, therefore, these properties allow its workability by friction rivecting. Finally, a cylindrical shape with flat tip characterizes the rivet, made of Titanium Grade 2. A suitable equipment was designed and located inside the working volume of a milling machine enriched by a high spindle speed multiplier. This was introduced to increase the available spindle speed to values more consistent for the investigated process. The equipment was placed on a dynamometer to monitor the loads during the process at different working conditions. Finally, a thermocouple and a thermo-camera were utilized to check the temperature trend during the process. The experimental campaign was carried out to optimize the friction riveting taking into account specific process parameters. In detail, the spindle speed, the rivet feed rate and the working time, divided between friction and forging phases, were monitored. The quality of the obtained results was investigated by tensile tests. The joined sheets were, in fact, blocked in a tensile test machine where the rivet, clamped to the movable crosspiece, was pulled out from the sheets. Due to the complex geometry of the deformed rivet, the determination of a real cross-sectional rivet area is very difficult and, consequently, tensile strength of joints is presented only in terms of tensile force. Moreover, microscopic analysis was performed revealing the anchoring of the deformed rivet tip inside the connection volume and the influence of the joining process on the composite integrity. For doing that, the specimen was cut along a plane, perpendicular to the sheets and passing through the revolution axis of the rivet. The influences of the monitored process parameters on the above highlighted outputs were reported providing a guideline for the process optimization.

230 | Dynamic behaviour of adhesive joints between tubular composite profiles

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The incremental equilibrium equations for co-axial adhesive joints between tubular composite profiles are presented. With this in mind, the classical cohesive interface models usually applied for the static analysis [1-2] are extended towards a rate dependent formulation, according to recent works [3]. Many considerations are concerned. The first consideration deals with the relevance of the interplay between the mode II interfacial behaviour and the local shear deformations which occur over the bonding length within the thickness of the composite member, due to the usually low values of shear moduli for FRP [4-6]. The second one concerns the need for an enhanced cohesive law with a rate-dependent fracture energy, which is able to match the experimental results discussed in literature indicating that the debonding energy is an upperbounded function of the displacement jump rate, with the upper bound reached for very high-speed dynamic processes [7]. The previous considerations led the authors to formulate a mechanical model where appropriate kinematical assumptions [5] are combined with a dynamic mixed mode cohesive failure criterion [3]. The aim is to predict both the structural response at the service conditions and the ultimate strength of the joint, via a refined numerical analysis, which accounts for the local shear strains and the rate of the loading condition. A finite element discretization accompanied by a relaxed explicit-Newmark integration scheme in time is proposed. Keywords: Tubular profiles, GFRP, Adhesive bonding, Dynamics.

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MICROMECHANICS

401 | Calculation of effective properties of porous heterogeneous media using solutions of stochastic

boundary value problems

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Prediction of macroscopic properties of heterogeneous materials is related to the problem of reliable characterization of their microstructural behavior, including multicomponent interaction. A number of various analytical and numerical methods for effective properties estimation were developed to date, however, none of them is able to calculate the properties with absolute accuracy. One of the main general limitations is connected with possibility of precise consideration of microstructural features of materials such as orientation, size, form and distribution of constituents. This leads to necessity for further development of the effective properties estimation techniques. The existing approaches for determination of macroscopic response of heterogeneous materials are based on variational principles [1, 2], mean field methods [3, 4], direct finite element modelling [5] and statistical models [6]. According to the latter, deformation process in inhomogeneous media is described with multipoint statistics for stress and strain fields. Such statistics can be obtained via stochastic boundary value problems (SBVPs). Solution of such problems can be found in a form of integral-differential equation containing Green's function. The correlation functions of various orders are used for assessment of spatial interaction between microstructural constituents [6]. Most of the developed instruments in the frameworks of the statistical models employ second-order correlation functions. This works offers a new computational tool for calculation of effective properties based on application of multipoint approximated solutions of SBVPs and correlation functions of higher orders, which make possible to take into account microstructural peculiarities more precisely. Multiscale hierarchy of heterogeneous media is studied via representative volume element (RVE) concept. Mechanical models are built using structurally-phenomenological approach when homogeneous physical properties of each constituents are being determined with common phenomenological equations. The example calculations were performed for the case study of porous heterogeneous media, which RVEs contained spherical and ellipsoidal inclusions. Effect of microstructural characteristics on macroscopic properties was analyzed. Obtained results were compared with the estimates based on the traditional methods.

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474 | Influence of crack distribution on the responses of the homogenized unidirectional composites

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Accurate prediction of composites failure strength is crucial for structure designs. Due to highly inhomogeneous constituents and processing procedures, the micro-cracks and voids inside the composites are inevitable inside composites. To take into account of influence of micro-cracks and voids on the responses of composites, one can use cohesive zone methods or use a smeared scheme to homogenized the effects of micro cracks. Cohesive zone methods require prior known crack propagation path, which may be applicable only to simple configuration for coupon tests as one already knows what the crack propagation path is. It would be difficult to use cohesive zone methods to analyze microstructure with multi-cracks exist. Smeared crack method also has the disadvantage to take into account the interaction among cracks, particularly these cracks in the vicinity. In this research, the influence crack distribution on the homogenized responses is studied by Extended-finite element method. Influence of orientation of the initial cracks, number of initial crack in the representative unit cells on the crack propagation and homogenized responses will be studied. The results show crack distribution, number of cracks, and orientation of the crack have significant influence on the crack propagation and homogenized response.

342 | Comparison of scale effects in the frame of simplified gradient theories of piezoelectric composites with spherical inclusions

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The problem of the effective properties estimation of the piezoelectric filled composites taking into account the influence of scale effects is considered. Gradient models of piezoelectric materials based on SSGET and Gusev-Lurie theories [1] are involved. These theories contain additional material constants that allow to take into account not only the volume fraction of inclusions, but also the influence of the inclusions size. Analytical solutions for the effective properties determination of piezoelectric composites are derived using Eshelby's integral representations for spherical inclusion problem in the case of gradient theories [2, 3]. Numerical simulations for the cubic representative volume elements with different number of inclusions are also realized and compared to analytical one. For the considered theories, the effects of non-classical gradient parameters and size of inclusions on the elastic and piezoelectric modules and dielectric permittivity of composites are studied and compared. The possibility of identification of additional models parameters based on the measurements of the macroscopic effective properties of composites are investigated. Identification of scale parameters of gradient models on the basis of the direct measurements of interphase zones thickness surround the inclusions is also discussed. The comparison of obtained solutions in the frame of gradient theories and similar solutions in the frame of the three-phase models of composites with spherical coated inclusions is presented. Obtained results may allow to get the refined estimations of the effective electromechanical properties of filled piezoelectric nanocomposites.

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410 | Stress analysis of woven composites using heirarchical application of Variational Asymptotic Method

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When variational asymptotic method (VAM) is used for the homogenization of a periodic heterogenous material, it not only provides the effective properties but also the capability to relate macro-fields with micro-fields through recovery relations. Recovery relations can be used to determine the stress on the constituent phases in a hierarchical framework. In this paper variational asymptotic method is used in two stages/steps to carry out the stress analysis of woven composite till failure. The analysis is carried out to predict the strength of woven composites. The first stage is the determination of homogenized properties for the resin impregnated yarn bundle using VAM in 2D. This stage also provides with recovery relations between yarn bundle and its constituents - fibre and matrix. In the second stage VAM is used in 3D to homogenize the woven composite representative unil cell (RUC), where the homogenized properties for the yarn bundle from the first stage is used. Here again the recovery relation is obtained between the woven RUC and its constituents yarn bundle and pure matrix. Once the constituent stress is available, a micro-mechanics based damage model is used to determine the extent of damage in the constituent phases which is expressed by a damage factor. This damage factor in the constituent phases is volume averaged to arrive at the homogenized damage factor for higher level in the heirarchy. The analysis is carried out in multiple load steps increasing from zero to higher loads till the complete failure of RUC occurs. At each load steps the stiffness of the constituent phases are factored based on the damage factor. The analysis results in a non-linear stress strain curve indicating the failure behavior of woven composite. In this paper stress analysis procedure mentioned above is carried out on woven composite problems available in literature. The results obtained from the analysis validate the effectiveness of heirarchical application of VAM to predict the strength of woven composites. Parametric study on the composite is carried out to understand the failure behavior of woven composite.

335 | Computer homogenization of active micro and nanoscale composites with local inhomogeneities

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Electrically active materials are widely used in the manufacture of ultrasonic transducers for medical diagnostics and therapy, underwater acoustics, nondestructive testing, level and flow measurement, transducers and devices (sensors, actuators, ultrasonic motors, gyroscope, MEMS, "smart" devices, etc.) for household, automotive, biomedical, and aerospace industries. Rapidly growing requirement for reliability and cost efficiency constantly stimulates the development of new and improved materials and devices. The analysis shows that the properties of the electrically active material remain the limiting factor in the development of more effective piezoelectric transducers and devices. New nanostructured electrically active composite materials have a range of important advantages, such as the possibilities of controllable variation of the functional characteristics within a wide range, ultra-low mechanical quality factor, and large electromechanical anisotropy. The simulation of electrically active materials at various scale levels helps to enhance the technologies of directed change of the properties of these materials and provide a qualitative improvement of the transducers and devices characteristics. Furthermore, it should be noted that modeling of micro- and nanomaterials and devices has some specific features. It is known that a range of nanomaterials have abnormal mechanical properties. Thus, the experimentally observed fact is the stiffness increases with reducing the sizes of nanoobjects. One of the factors that are responsible for this behavior of nanomaterials can be the surface effect. In connection to this, the main difficulty can consist in the extension of this approach to the nanoscale elements of electrically active composites. Therefore, here it is logical to consider not only the mechanical surface effects, but also the surface effects of electric fields. The present research concerns direct finite element modeling of such active composites as piezoelectric and magnetoelectric mixture two-phase composites. The proposed technique is based on the models of micro- and nanoscale materials with surface effects, the effective moduli method, the modeling of representative volumes, and the use of finite element technology. As an example, we investigate the porous piezoelectric ceramics with closed and open porosities. For these materials, we use special models of representative volume for porous material with different types of connectivity, take into account for the heterogeneity of piezoceramic polarization near the pores and the surface effects on the boundary of pores.

Acknowledgements: Different parts of this work were supported by the Ministry of Education and Science of Russia, competitive part of state assignment, No. 9.1001.2017/PCh, and by RFBR, the project No. 16-01-00785.

367 | Doublet mechanics formulation for flexural waves in double nano beam systems

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In the present study, wave propagation in double Euler-Bernoulli nanobeams is examined by using a length scale dependent theory called as Doublet Mechanics. Two beams are coupled by Winkler foundation. Governing differential equations for double nanobeam systems is derived by using Hamilton principle. Dispersion relations are obtained for Doublet Mechanics theory and the results are compared with the classical elasticity solution. Explicit expressions are derived for cut-off frequency and escape frequency of nanobeams. Obtained results can be used in the modelling of nano-mechanical systems.

51 | A numerical micro-mechanical study on damage induced by the curing process in carbon/epoxy unidirectional material

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In the last few decades, aerospace industry has seen a considerable increase in the use of composite materials and structures. While ensuring a large number of advantages in terms of specific mechanical properties, only a little part of their true potential can be exploited since some of their degradation and failure mechanisms have not been yet completely understood. In order to deeply comprehend the physical nature of some composite behaviors, micro-scale analyses may be advantageously used. Many authors have studied this problem at such scale but only few of them have focused their attention on damage induced during the curing process, a phenomenon that involves both matrix-cracking and fiber-matrix debonding. On this point, the authors propose to study the effect of the polymerization process on the mechanical properties of unidirectional carbon fiber-reinforced epoxy matrix composites by means of high-fidelity micromechanical analyses on Representative Volumes Elements (RVEs). The analyses are carried out with the implicit solver in ABAQUS commercial software, and the models are generated using python scripts while the mechanical behavior of all the constituents, matrix, fiber and interface, is governed by means of a user-define material Fortran subroutine (UMAT). The matrix is considered as an isotropic elastoplastic damageable solid whose polymerization process during the cure is reproduced using a rheological

model capable of taking into account the shrinkage. Transversally isotropic linear elastic behavior is assigned to carbon fibers, while the fiber-matrix interface is modeled using cohesive elements. The analyses are divided into two steps, the first one, where a realistic thermal history is applied to the RVE, for simulating the curing process and the second one where the RVE is loaded in different conditions. In a first instance analyses are carried out considering regular fibers patterns at different volume fractions in order to investigate how the distance between the fibers may affect the curing induced damage. Subsequently the analyses have been performed on generic realizations of random fiber RVEs and a sensitivity study on matrix and interface failure properties has been performed. The two-step simulations allow, firstly, for the evaluation of the curing induced damage, and, in the loading step, the generated stress-strain curves show how the curing process detrimentally affects the mechanical properties of the pristine material.

MODELLING AND CHARACTERIZATION OF CNT-POLYMER COMPOSITES

247 | A novel micro/macromechanical approach to identify the mechanical properties of CNT polymer nanocomposites with experimental validation

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It is possible to produce the advanced composite materials with enhanced specifications, required by the aerospace industry, through adaptation of nanotechnology and nanomaterials applications to existing technology. These composites are also known as high performance polymer matrix composites (PMC) and they are produced from hard, high strength and aligned fibers and epoxy resins. Including nanomaterials such as carbon nanotubes (CNTs) to composites increases the mechanical performance as well as adds multifunctional properties such as electrical conductivity, with a minimal weight addition. CNTs with intrinsic properties such as high strength, low weight and high electrical conductivity have been used as reinforcements (usually as fillers or inclusions) for composites creating advanced composites for the last 10 years. However, CNTs do not show their full potential on mechanical and electrical improvements, due to problems arising from the agglomeration of them in polymer matrices caused by van der Waals forces when they are used as randomly oriented inclusions. A possible solution of this problem can be the production of CNTs in a vertically aligned fashion by chemical vapor deposition. These vertically aligned CNTs (A-CNTs) are used as reinforcements in polymer nanocomposites [1, 2], however, the reinforcing capabilities usually show lower mechanical properties that expected. This phenomenon has been attributed to a dominant morphological feature as the wavy nature of the CNT [3]. The effect of waviness on mechanical properties have been partially explained by some finite element models [4]. However, in all these approaches, calculations have been carried out under assumptions without necessary attention given to the structure and specifications of these CNT's. This leads to the fact that the results obtained are approximate and inaccurate. In this study, a novel micro/macro mechanical approach for the characterization of CNT polymer nanocomposites is presented. First, a finite element code for determining the fully anisotropic stiffness matrix of a CNT polymer matrix representative volume element (RVE) is developed in MATHEMATICA language. Then, micro mechanical numerical experiments are performed for different waviness ratios to identify the reinforcing capabilities arising from the morphological effect. The distribution of waviness ratios of a vertically A-CNT polymer nanocomposite is obtained from scanning electron microscope (SEM) images through image processing and a waviness distribution of (0.128±0.053) is obtained. Finally, these obtained waviness ratios are implemented as a random distribution of RVEs that form a macroscopic structure, from which the fully anisotropic stiffness matrix of the CNT polymer nanocomposite material is obtained, again, by using the finite element code developed. A good correlation is observed between the experimental and numerical results showing that the present micro/macromechanical approach can explain the effect of waviness on the mechanical properties of A-CNT polymer nanocomposites.

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MODELLING OF NANO COMPOSITES

170 | Investigations of linear and nonlinear eigenvalue problems in nanomechanics

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Modern engineering materials usually have anisotropic properties that can be studied at the macro, meso, micro or nano scale. The identification of their physical properties, considered not only in the sense of stiffness/rigidity but also as thermal properties, magnetic, electrical, energy levels, etc is one of the very important problems. Analysis of eigenvalues is a helpful tool for the material design at the nanoscale in order to determine their averaged (homogenized) physical properties. Generally, in this work, by nanomechanics one understands description of the methodology used both for solid state physics and quantum mechanics, which is located on the border of these two branches of mechanics. Originally the eigenvalue problem concerned the analysis of rotation of rigid bodies, however the area of applications has increased dramatically through the use of this methodology for the analysis of problems of stability, vibration, image recognition, determination of orbitals of atoms, or matrix diagonalization. Usually, eigenvalue problems are classified into two categories as: - Linear eigenvalue problems - Nonlinear eigenvalue problems. Possibility of application of eigenproblem analysis to identify homogeneous properties of carbon nanostructures, as well as semiconductors made of the so-called quantum dots (QD) embedded in the matrix, is discussed in details in this paper. The discussed problems are classified both as linear and nonlinear eigenvalue problems. The paper consists of three parts. In the first one the subject of linear and nonlinear eigenproblems is introduced in concise manner, also the determination of the eigenvalues with the finite element method is taken into account. The second part concerns the description of the application of linear eigenproblems to determine homogeneous mechanical properties of the both pristine carbon nanotube (CNT) and bond defects included in the structure of carbon nanotube. The last part presents the solution of nonlinear eigenvalues in order to characterize the discrete energy levels of the semiconductor. The detailed analysis is performed with the use of the quantum mechanics formalism with the aid of the Schrödinger equation.

60 | Modelling of Mg-Al-hydroxysilicate nanocomposite: a quantum mechanics first principle contribution

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The interest on phyllosilicates minerals as composite materials grew in the last decades, and these minerals are used today in several fields, for example as substrates for biotechnological applications and as inorganic-organic composites, such as organic containing geopolymers for structural applications. The interaction of phyllosilicates with organic molecules and the environment is driven by their physico-chemical properties of their extensive, flat surfaces. For this reason, it is of paramount importance to characterize the morphology, the chemical composition, the defective sites, the layer charge and mechanical stability of these phyllosilicates natural composites. This kind of information is of utmost importance to tailor their properties to the user needs. Among phyllosilicates, we focused our attention on clinochlore, a peculiar Mg-Al-hydroxysilicate. Clinochlore has a composite structure made up of two structurally and chemically different layers of sub-nm thickness and exhibits very interesting physico-chemical surface properties that can actively drive the interactions with organic molecules, with important implications for biotechnology and geopolymer applications. Among the characterization methods, ab initio quantum mechanical (QM) modelling can provide a large variety of properties, such as the structure, mechanical behaviour, surface potential, chemical interaction at the surface, infrared and Raman analysis, and many others. Clinochlore consists of an alternate stacking of mica-like and Mg-Al-hydroxide layers. The mica-like layer, 1 nm thick, is composed of two tetrahedral sheets bound together by octahedrally-coordinated magnesium cations. The Mg-Al-hydroxide layer, 0.4 nm thick, is made up of magnesium cations in octahedral coordination with hydroxyl groups. Both silicon atoms of the tetrahedral sheets and magnesium cations can be partially substituted by aluminium atoms (in the mica-like and in the hydroxide layers). At the interface between the two layers the surface of monoclinic crystal system of the mica-like layer deforms to match the trigonal crystal system of the hydroxide one. The two layers present very different nanomechanical properties, surface electric potential and hydrophilicity/hydrophobicity, depending on both the type of the layer and the local stoichiometry of

the mineral. In the present work, the phyllosilicate nano composite stability, surface potential, mechanical properties and interaction with organic matter were investigated by quantum mechanics simulations. The material was characterized taking into account the Al substitutions on both the composite bulk and surface structures, in order to quantify the mechanical strength of the hydroxide/mica-like layers and to characterize the surface electrostatic potential. The QM approach employed in this study relied on the Density Functional Theory (DFT), using all-electron Gaussian-type orbitals for each atom in the structure and the hybrid B3LYP functional. Dispersive (van der Waals) components were also considered (B3LYP-D* approach). Equation of states and elastic constants were also calculated. The presented results are in good agreement with available data reported in literature. The electrostatic surface maps calculated at 2 Å from the surface are comparable with those obtained with Kelvin probe microscopy. The knowledge on the modulation of the morphology and surface electrostatic potential induced by aluminium substitutions will be useful to create specific nanomorpho-potential patterns according to the application of this material.

6 | Mulitscale analysis of aluminum-carbon nanotube composites
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In this study, we utilize the newly developed Bridging Cell Method BCM to investigate the properties of aluminum nanocomposites reinforced with carbon nanotubes CNT. The concurrent multiscale model confines the atomistic region to the nanotube and its vicinity, where interaction mechanics are greatly influenced at the nanoscale. The rest of the domain is modeled with conventional Finite Element Method FEM, while the nanocomposites are set to be reinforced with three variations of CNTs structures; Single-Walled Nanotubes SWNT, Multi-Walled Nanotubes MWNT, and a bundle of SWNTs. All variations are successful towards reinforcing the metal, where Young's Modulus and failure strengths are computed for each structure type. Comparing the CNT reinforcing type showed similar behaviours under common conditions, where the difference between them are mostly evident within the extent of a selected reinforcement in enhancing the nanocomposite's overall strength.

MORPHING OF COMPOSITES

421 | Deformation analysis of fabric composites during dome draping process
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Generally, unidirectional fiber reinforced composites have high mechanical properties but are not suitable for forming complex shape structures. For this reason, fabric composites have become of interest in various engineering fields due to flexibility in the process of fitting a two-dimensional prepreg to a complex three-dimensional curved surface. Fabrics are composed of a bundle of fibers constructing tows and there are many different types of weaving patterns such as plain weave. And fabrics have a rotational degree of freedom at the intersection of tows as a form of hinge joint, which is advantageous for in-plane shear deformation. The macroscopic stiffness of the structure can be predicted using the measurement of the shear deformation but the exact local material properties involve microscopic deformation of the material. For more accurate measurement of mechanical properties of draped fabric composites, the exact measurement of the deformation of microstructures such as tows is required. This study quantitatively investigated the measurement of macro shear deformation and microstructure deformation as well to evaluate the exact local material propertied of the draped fabric composites. Various experimental conditions such as an environmental temperature and a clamping force were considered to investigate the effect of forming condition on draping force and the wrinkle generation and the results were compared for determining the best draping condition. The force-deformation relationships were observed and the correlation between the forming condition and the tow deformation pattern was closely investigated.

Acknowledgements: This research was supported by Nano·Material Technology Development Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT and Future Planning(NRF-2016M3A7B4910532).

392 | Thermally actuated composite helical lattices
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Helical lattice structures have been created from assemblies of composite strips that are kinematically constrained to lie upon a cylindrical surface. These lattice structures have demonstrated desirable non-linear force-displacement characteristics [1] and have been studied as part of hierarchical design concepts [2,3]. An analytical, energy-based model has been used to explore the lattices behaviour at constant temperature. In the present analysis, we investigate the effect of thermal stresses that can be harnessed to provide actuation between stable states. As was demonstrated by Pirrera et al. [1], careful tuning of the composite strips' stiffness and pre-curvature, together with the lattice geometry, allows the system to demonstrate bi-stable behaviour. Typically, bistable lattices are able to transition between stable fully coiled and fully extended states. Transitioning from one state to the other requires an energetic input. In this investigation, we demonstrate that thermal stresses affect the non-linear lattice stiffness sufficiently to achieve a change in the stability of the system, thereby causing actuation. In particular, our investigation focuses on composite strips with non-symmetric stacking sequences. The layups' non-symmetry causes warping during cure due to mismatch in the coefficients of thermal expansion. The extent of warping can be predicted using classical laminate theory [4] and is included in the energetic formulation of Pirrera et al. [1] as a thermal component of pre-curvature. We note that as a non-symmetric laminate is heated from room temperature, thermal stresses are released and residual curvature decreases. This has the effect of changing the effective pre-curvature of the helical strips, and thus their energetic landscape. Due to the sensitivity of the energy landscape to pre-curvature the position and existence of stable equilibria is altered. Through a careful balance of the composites stiffness, thermal response and mechanical pre-curvature (tooling), the desired temperature-dependent actuation is achieved.

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236 | Morphing structures with SMPC skins and kirigami patterned core

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Morphing structures have been developed to change the configuration with flexibility as well as to maintain the deformed shape with stiffness. The shape memory polymer composites (SMPCs), able to sustain a large deformation and to recover its deformed shapes above the critical temperature of the SMPCs, are considered as one of possible materials for the shape morphing. In this research, morphing structures with SMPC skins and Kirigami patterned core are fabricated and their thermo-mechanical characteristics are investigated. Shape memory polymers (SMPs) have interesting features such as a high sustainable strain and the shape recovery effect at the above glass transition temperature. For a flexible and shape recoverable skin, SMPC skins are manufactured by impregnating SMPs to triaxial woven fabrics (TWFs). Additionally, a core is developed to have a zero Poisson's ratio with a Kirigami pattern. So, the core can be longitudinally extended without a transversely decreased length. Finally, the tensile and bending characteristics of the morphing structures at various temperature are investigated to demonstrate the morphing behaviors.

MULTISCALE ANALYSIS OF NATURAL FIBRE COMPOSITES

199 | Damage assessment of jute fibre sandwich laminates with a cork core

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The use of fibre reinforced sandwich laminates, obtained by the stacking of pre-impregnated layers with a diverse material in the core, has been on a gradual increase. These materials have become one of the most interesting for engineers due to the opportunity of tailoring the mechanical properties according to design requests, thus allowing for weight reduction. The ability to create "tailor-made" parts by orienting the reinforcement fibers in view of the

specific requirements creates an almost endless scope of options for design engineers. Among the most interesting properties one can refer to the low weight and high specific strength and stiffness. Everyone can find examples of composite usage in daily life. In previous papers, the first author used the same experimental sequence to study the effect of damage in polymeric composites fabricated with epoxy resin and unidirectional sisal and banana fibres and in hybrid composites constituted of waste rubber particles and sugarcane bagasse fibres into a thermoset composite material. The use of cork to the production of innovative composites is now a matter of environmental need. It is also a concern related with the use of a natural material that is available in Portugal. The Portuguese cork industry is one of the most important of the country. According to APCOR – Cork Portuguese Association, it represents 0.7% of the GDP, 2.2% of the total national exportations and around 30% of the Portuguese exportation of forest products. The knowledge of alternative applications is of paramount importance for the cork Portuguese industry. The cork thermal and electrical insulation properties allied to a light weight allows for the creation of composites with large thickness, low weight and good properties regarding insulation and vibration absorption. This work aims to analyse the effect of drilling induced damage on the mechanical characteristics of sandwich plates with outer plies in epoxy resin reinforced with jute fibres and a cork core. For that, a batch of jute fibre sandwich laminates with a cork core are drilled to determine the effect of cork core and laminate thickness on damage extension caused by drilling operations and related mechanical properties. It is known that the heterogeneity of natural fibres affects the mechanical behaviour of these composites. The drilling operation was carried out in a radial drilling machine. To avoid additional variation of cutting parameters and evaluation factors, the cutting speed and the feed rate were kept constant and equal to 1120 rpm and 0.12 mm/rev, respectively. These cutting parameters were selected according to tool manufacturer's recommendation. A tool diameter of 6 mm was used combined with five drill geometries: Twist, Brad, Bidiametral, Dagger and Inverted Point, causing diverse amount of damage around the hole. After the drilling process, the delaminated region around the drilled hole was assessed by using enhanced digital radiography. In order to generate a contrast, the laminates were first immersed in di-iodomethane for some minutes. Then the radiographic images were acquired using a 60 kV, 300 kHz Kodak 2100 X-ray system associated with a Kodak RVG 5100 digital acquisition system. Characterization of mechanical properties of the sandwich will be carried previously by completing tensile and flexural tests. Finally, drilled plates will be tested for verification of mechanical loss due to damage using Bearing tests according to ASTM D5961M-13 and Open-Hole Tensile Strength Test according to ASTM D5766M-11. The results demonstrate the effect of the core cork on mechanical properties of the sandwich composites, the tolerance to damage of these materials and the importance of an adequate assessment of damaged area and proper selection of machining parameters to extend the life cycle of these laminates.

NANO-COMPOSITES

417 | Nanocomposites with different metals as magnetically separable nanocatalysts for oxidation of aldehydes

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In this study, two metals were chosen for composing two different nanocatalysts. Zinc acetate and nickel chloride anchored acetanilide that was attached to functionalized magnetic anoparticles (Fe3O4) coated by silica and made two complexes. Their identification was presented by scanning electron microscopy (SEM), X-ray diffraction (XRD), furrier transform infrared spectroscopy (FTIR), and gas chromatography mass spectrometer (GCMS). These nanocatalysts were used for oxidation of aldehydes: 3-hydroxybenzaldehyde, 4-methoxybenzaldehyde and 3-nitrobenzaldehyde. High efficiency, stability, recoverability, recyclability and selectivity were achieved by these nanocatalysts.

308 | CNTs growth on polymeric nanofibers as interleaves for thermoset composites

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The superior properties of carbon nanotubes (CNTs) make them potential candidate as interface reinforcement in advanced polymeric composites. Herein, we propose a novel approach to produce CNTs on a polymeric fiber unlike metal, ceramic and silicon substrates at high synthesis temperatures. Polybenzimidazole (PBI) nanofibrous substrate having a very high glass transition temperature as 427℃, were produced by electrospinning with mean fiber diameter of 170 ±10 nm and 10 μm mat thickness. A 15wt% PBI/DMAc solution was prepared and then used as a substrate for CNTs growth in a modified chemical vapour deposition (CVD) method. Then, these PBI/CNTs nanocarpets which have better 3D stress distribution and load transfer network at the interface were impregnated into epoxy resin to achieve PBI/CNTs nanoprepregs. The growth of CNTs were investigated by Raman Spectroscopy where G and D peaks were seen at 1402.0 cm-1 and 1571.3 cm-1 respectively. Morphological analysis by scanning electron microscope also pointed out the presence of randomly grown CNTs on polymeric substrate. The contribution of CNTs to electrical conductivity of fibrous webs was explored by 4-probe electrical conductivity measurements whereas single layer PBI/CNTs incorporated epoxy resins exhibit low conductivity as 3.79x10-15 S/m. Thermo-mechanical and mechanical properties of thermoset nanoprepregs were reported and interlaminar region of nanoprepregs were revealed by fractography images.

Acknowledgements: This study is funded by TUBITAK (THE SCIENTIFIC AND TECHNOLOGICAL RESEARCH COUNCIL OF TURKEY) (Grant Number: 116M427), under R&D Projects Career Development funding program.

430 | Smart polymer-matrix nanocomposites using embedded LPGFS

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Simulation results obtained in analysing and designing of a smart polymer-matrix nanocomposite material fabricated by embedding a long period grating fibre sensor (LPGFS) into its polymer-matrix are presented. The embedded LPGFS has the role of feedback signal generator/provider for further system automation of the polymer-matrix nanocomposite mechanical part as a reaction at applied ambient stimuli. The analysis is performed to improve the design of polymer-matrix nanocomposite materials and their medical, industrial, automotive, aerospace and security applications. The presented results are obtained investigating a plate made of polymer-matrix nanocomposite materials as a “generic” mechanical part. There are investigated materials better described as nanofilled polymer composites obtained by adding nanoparticles such as graphene, carbon nanotubes, molybdenum disulphide and tungsten disulphide to a polymer matrix. The LPGFS operation is based on the coupling process between the co-propagating fundamental mode guided through the fibre core and modes propagating through the fibre cladding. This mode coupling is accomplished by scattering on the Bragg diffraction grating of the fundamental light mode propagating through the SM optical fibre core and is macroscale observed as absorption bands induced into the transmission spectrum by light energy (power) transfer, loss from fundamental core mode to certain propagating cladding modes. The electromagnetic power transfer from core mode to certain propagating cladding modes has several discrete maxima corresponding to the wavelengths of absorption bands peaks, denoted as Bragg grating resonance wavelengths. Each of these Bragg grating scattering induced absorption bands has a FWHM bandwidth and a peak resonance wavelength which depend on SM optical fibre geometry (core and cladding diameters) and on the values of core, cladding and ambient refractive index. LPGFS operation basically consists of observing spectral shifts and/or birefringence caused splits of the peak resonance wavelengths and spectral broadening of absorption bands induced by any SM optical fibre geometry modification and/or ambient refractive index variation. The simulation model of embedded LPGFS smart polymer-matrix nanocomposite material consists of two main components: the first is the LPGFS itself and the second describes the interaction between LPGFS and its ambient which is the composite polymer-matrix containing nanoparticles. It is worth to underline that, regarding the interaction between LPGFS and polymer - matrix, there are investigated the transverse amplitude distributions of electric and magnetic fields components of the modes propagating through SM optical fibre cladding inclusive into the external zone of the cladding. These transverse amplitude distributions are accomplished in order to define the possible effects on the polymer-matrix and the nanoparticles mounted in it. The results of the performed simulations are compared with experimental results reported in literature observing a good agreement.

414 | Vibration of axially functionally graded nanorods and beams

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Vibration of axially functionally graded nano-rods and beams is investigated. Material properties are varying along to rod and beam axis directions. Ritz method with algebraic polynomials is used in the formulation of the problems. Stress gradient elasticity theory is considered in order to include nonlocal effects. Frequencies are obtained for different boundary conditions, geometrical and material properties.

431 | A core-shell structure nanocomposite powders for laser sintering

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Polymer Additive Manufacturing (AM) is a technology that builds 3D objects by adding layer-upon-layer of materials. Becoming aware of the potential offered by AM (low volume, complex structures with high degree of freedom and light-weighting), increased attention has been given to the development of new polymers and composites. In the powder bed processes (known as laser sintering), several methods of incorporation of fillers or nanoparticles have been studied: melt compounding followed by milling, dry and wet powder mixing. Melt compounding followed by milling is a conventional method to produce composite powders. However, this method is costly and ineffective due to the high energy consumption required to achieve appropriate particle size distribution. In addition, the success of this method depends on the intrinsic properties of the polymer such as toughness and the milling method applied. The milling process influences the morphology of the powder and its flow, a key criterion for the laser sintering process. Dispersion of fillers or nanoparticles into polymeric powders as dry mixtures can be successful at low concentrations of additives but can lead to agglomeration and poor dispersion when percentages increase. In addition, there are potential health risks when preparing and using the composite powders in the laser sintering process. In the case of wet powder mixing, large amounts of organic solvents have to be used, making the process less environmental friendly. This study presents a new method of fabrication of nanocomposite powders based on a core-shell structure. Graphene nano-platelets (GNP) were encapsulated in a polyvinyl alcohol (PVA) matrix shell with polyether ether ketone (PEEK) particles acting as core. The core-shell structure was confirmed by TEM. Hot-stage microscopy and differential scanning calorimetry (DSC) were applied to follow the coalescence process of particles and predict behaviour in the laser sintering process. This novel strategy could be applied for the preparation of various nanocomposite powders or blends for laser sintering.

201 | Investigation of spectral and electrical properties of solution processed PEDOT: PSS/reduced graphene oxide- carbon nanotubes hybrid composites

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Hybrid composites have been prepared by solution method using various MWCNT concentration and keeping rGO content constant in host poly (3, 4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) . Structural and morphological characteristics of the prepared composite films have been characterized by X-ray diffraction (XRD), Scanning Electron Microscopy (SEM), Field emission Scanning Electron Microscopy (FESEM) and Raman Spectroscopy, UV-Visible (UV-VIs) spectroscopy and Fourier transform Infrared (FTIR) Spectroscopy. The enhanced electrical conductivity as a result of improved dispersion of MWCNTs and rGO has been observed without affecting the optical properties in the visible region. The observed improvement in electrical and retaining of optical properties can be attributed to synergistic effect of MWCNTs-rGO network in the composite. This result suggests that such hybrid composite materials could be used as transparent conductor applications in optoelectronic devices.

352 | Failure and scaling of graphene nanocomposites

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Thanks to their outstanding specific mechanical and functional properties, the engineering use of polymer/graphene nanocomposites is becoming broader and broader. Current applications include electronics, additive manufacturing, energy storage devices and the use as nanoreinforcement for advanced carbon fiber composites. These outstanding properties have been extensively confirmed by a large bulk of literature aimed at understanding the mechanical behavior of these materials and optimizing their application. However, while a large bulk of data on the mechanical properties of graphene nanocomposites are available already, an aspect often overlooked in the literature is the scaling of the fracturing behavior. This is a serious issue since the design of large nanocomposite structures or small-scale graphene-based electronic components requires capturing the scaling of their mechanical properties. This is challenging since, due to the complex mesostructure characterizing graphene nanocomposites (and other quasi-brittle materials such as concrete, ceramics, rocks, sea ice, and many bio-materials, just to mention a few), the size of the non-linear Fracture Process Zone (FPZ) occurring in the presence of a large stress-free crack is usually not negligible. The stress field along the FPZ is nonuniform and decreases with crack opening, due to discontinuous cracking, nano-crack deflection by graphene platelets, and frictional pullout of graphene layers. As a consequence, the fracturing behavior and, most importantly, the energetic size effect associated with the given structural geometry, cannot be described by means of the classical Linear Elastic Fracture Mechanics (LEFM). To capture the effects of a finite, non-negligible FPZ, the introduction of a characteristic (finite) length scale related to the fracture energy and the strength of the material is necessary. This work proposes an investigation on the structural scaling of polymer graphene nanocomposites. Fracture tests on geometrically scaled Single Edge Notch Bending (SENB) specimens with varying contents of graphene were conducted to study the effects of nanomodification on the scaling. It is shown that, while the scaling of the pristine polymer follows Linear Elastic Fracture Mechanics (LEFM), this is not the case for nanocomposites, even for very low graphene contents. Through the analysis of the nominal strength as a function of the specimen size, it is shown that small specimens have a more pronounced ductility with limited scaling and a significant deviation from LEFM whereas larger specimens behave in a more brittle way, with scaling of nominal strength closer to the one predicted by LEFM. This behavior is due to the significant size of the FPZ compared to the specimen size which affects the overall fracturing behavior. Accounting for the FPZ size is of utmost importance to capture the scaling of the structural behavior and to correctly estimate the fracture energy of the material from fracture tests. It is shown that the use of LEFM to estimate mode I fracture energy leads to non-objective results, the fracture energy depending on the size of the specimen tested. It is also shown that, by introducing a length scale related to the FPZ size by means of an Equivalent Crack approach, a formula for the scaling which depends not only to the material fracture energy but also to the FPZ size can be derived. This formula, known as Bazant's Size Effect Law (SEL), enables an excellent fitting of the experimental data and the objective estimation of the fracture energy and the FPZ size. A comparison between LEFM and SEL showed that for the small specimen sizes investigated, the difference can be as high as 113%, this difference decreasing for larger specimens as the effects of the FPZ become less significant in the context of the larger portion of the specimens in the linear elastic regime. Finally, a re-analysis of a large bulk of literature data on other nanocomposites shows that the foregoing observations are salient features not only of graphene nanocomposites but of nanomodification in general. It is shown that most of the specimens tested in the literature belonged to the size range in which the behavior transitions from quasi-ductile to brittle for which, adopting LEFM can lead to severe underestimation of the fracture energy. For some of the data analyzed in this paper, the value of the fracture energy estimated in the literature was more than 150% lower than the estimate provided by SEL.

124 | Tribological performance and mechanical properties of nanocomposite TiVN/TiSiN multilayered hard coatings

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Ternary transition metal nitrides, such as TiSiN and TiVN, have been attracting great interest for industrial applications as hard protective coating materials due to their high hardness, wear resistance, tribological properties, and chemical stability. In this study, TiVN, TiSiN and nanocomposite TiVN/TiSiN multilayered coatings were deposited onto high-speed steels and tungsten carbide tools by Cathodic-arc evaporation (CAE). By controlling the different negative bias voltages (30 ~ 180 Volts), the nanocomposite TiVN/TiSiN possessed different microstructures and mechanical properties. The deposited TiVN/TiSiN films were anticipated to improve the hardness, fracture resistance by optimizing the bias condition of the deposition. The microstructure of the deposited coatings was investigated by field emission scanning electron microscope (FE-SEM) and field emission

gun high resolution transmission electron microscope (FEG-HRTEM), equipped with an energy-dispersive x-ray analysis spectrometer (EDS), Glancing angle X-ray diffraction was used to characterize the microstructure and phase identification of the films. Mechanical properties, such as the hardness and elastic modulus, were measured by means of nanoindention. The fracture toughness (Kc) of the films was determined by Vickers indentation to evaluate the resistance to crack growth, which was an important parameter in the reliability assessment of ceramic coatings. The adhesion strength of the coatings was evaluated by the scratch adhesion test. A ball-on-disc wear test at room temperature and high temperature was conducted to evaluate the tribological properties of the deposited coatings. The influence of multilayered TiVN/TiSiN films on the wear behavior and cutting performance of carbide cutting tools were investigated in end milling of aluminum alloys under high speed cutting environment. The design of TiVN/TiSiN coatings were anticipated to increase the hardness and wear resistance, which were expected to increase film thermal stability and cutting tool life, and make the coating suitable for high speed cutting applications.

105 | Highly filled boron nitride-phthalonitrile nanocomposites for exigent thermally conductive applications

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Highly filled phthalonitrile nanocomposites, reinforced with both native and silane surface modified nano-BN were investigated for their mechanical and thermal properties. The nanocomposites were prepared by a solution blending technique followed by compression molding. The thermal conductivity was investigated as the core of the study along with a bending test, a morphological behavior, thermal stability investigations, and thermomechanical properties measurements. The highest thermal conductivity value of 4.69 W/m.K was obtained at the maximum nanofillers loading of 30 wt.% treated BN. A high resolution TEM confirmed that the exceptional enhancements in the thermal conductivity are related to the formation of an effective conductive path assured by the silane surface modified nano-BN. The bending test also revealed consequent improvements in both the strength and modulus as the amount of the nanofillers increased. The SEM investigations revealed positive changes in the surface morphology of the neat resin, with a rougher and homogeneous state of surfaces for the hybrids. Moreover, the thermal stability at the maximum fillers loading was found to be one of the best ever reported in the field of high performance polymer-based composites, with a 5 wt.% weight loss temperature of 551 °C.

195 | Flexural properties of polymeric composites reinforced with nano-alumina cured with DDSA and MNA

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Nowadays the composite materials are increasingly used in a large number of applications as substitute of the traditional materials due to their good mechanical properties and lower weight. Epoxy resin nanocomposites (EPNCs) reinforced with alpha alumina nanoparticles (NPs), are currently used in aircraft, automotive, aerospace, shipbuilding, civil construction, etc. as metal substitutes, including under hard working conditions. Epoxy resins can be combined with several curing agents to obtain the final cured product. One of the most widely used curing agent to obtain EPNCs is Bisphenol A diglycidyl ether (BADGE or DGEBA - 2,2-Bis [4- (glycidyloxy)phenyl] propane) [1]. Most recent studies show that 4,4'- Diaminodiphenylmethane (DDM) is also appropriate as a curing agent for EP resins [2-3]. Until now the bibliography showed that dodecenyl succinic anhydride (DDSA) and methyl nadic anhydride (MNA) have been used as curing agents for EP resin embedding tissues for diagnostic transmission electron microscopy [4] nevertheless, no previous studies were found for the manufacturing of EPNCs with DDSA and MNA, as curing agents. So, in the present work these two different hardeners: DDSA and MNA, were used simultaneously. One of the advantages of DDSA as curing agent is that it do not need curing treatment, which represents a novel application as manufacturing process. The nanoparticles consisted on alpha alumina with irregular shapes (100 nm maximum size) pretreated with a silane agent (3-Aminopropyl

triethoxysilane, APTES). The weight fractions of alumina nanoparticles were 1, 3 and 5 wt.%. The experimental research presented in this work aims to study the reinforcing effects of pretreated alpha alumina nanoparticle on the flexural properties of EPNCs. The NPs influence in terms of static properties was analyzed by bending tests. Bending properties, namely bending stiffness modulus (E) and bending strength (σ), were obtained by performing 3PB tests on the EPNCs specimens cut nominally to 84 ′ 12 ′ 4 [mm3] and with a span of 64 mm, according to the standard ASTM D-790 - 2, and using a Shimadzu AG-10 universal testing machine equipped with a 5 kN load cell and TRAPEZIUM software at a displacement rate of 5 mm/min [5]. From the results, it is possible to observe that the average flexural modulus presents a general tendency to increase slightly with the NPs content. This increase, when compared with the neat EP, is around 9 % and 15%, for 3 wt.(%) and 5 wt.(%), respectively. However, no significant influence on the flexural strength of the EPNCs was observed by adding alumina NPs up to 5 wt.(%).

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65 | Particularity concerning the use of nanofluids, to obtain polymeric nanocomposites materials. Magnetic and mechanical behavior

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The paper presents the possibility of creating a new category of magnetic nanocomposite materials, using magnetic nanofluids (MNF) and resins (1). 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. 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.) (2, 3, 4). In addition to the intrinsic nanoscopic material properties and the possibility to make transparent metal–polymer combinations, these materials are interesting also because the presence of a very large filler–matrix interface area can significantly affect the polymer characteristics (e.g., glass transition temperature, crystallinity, free volume content, etc.), allowing the appearance of further technologically exploitable chanical and physical properties (e.g., fire resistance, low gas diffusivity, etc.).(3). The target of our project is to obtain new materials having magnetic and mechanical controllable properties. MNF, also known as Ferro fluids, are ultra-stable colloidal suspensions of ferri/or ferromagnetic particles – e.g. magnetite (Fe3O4) – in various carrier liquids. (5). The future of the magnetic Nano fluids presence, in a mass of composite materials, can be analysed for the potential applications in aeronautics or utilization to promote the Resin Transfer Molding (RTM) process (1, 6, 7, 8). The use of magnetic fields to evaluate, through Non-destructive Determination Test (NDT), the quality of the resin based magnetizable nanocomposite materials, as well as to increase the potential application of composite materials where magnetism is important (such as radar, magnetic levitation trains, kinetic energy accumulators and electric engine rotors), are, amongst others, objectives to pursue (8, 9).

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OPTIMIZATION TECHNIQUES AND METHODS

440 | Performance optimization of aerostatic thrust bearing

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The bearing capacity and the stiffness have a great influence on the performance of the aerostatic thrust bearing. It has a certain guiding significance on the practical application of the aerostatic thrust bearing to determine the structure parameters under the situation of the optimal performance of the aerostatic thrust bearing. Through the analysis of the preliminary work, it is found that the existence of the rarefied effect of the gas had an impact on the aerostatic thrust bearing. In this paper, based on the principle of optimization theory and the genetic algorithm, the performance of aerostatic thrust bearing are optimized by the genetic algorithm toolbox in the MATLAB simulation system software. First, according to the structural characteristics and the actual working characteristics of the aerostatic thrust bearing, the bearing clearance, the orifice diameter and the distribution of the orifice diameter are designed as the variables. The second, the performance of bearing are analyzed by the single objective function of the capacity and the stiffness. Then the multi-objective function is obtained by the weighting factor. After calculating, the optimal values of multi-objective optimization function which is consisted of the optimal carrying capacity and the optimal stiffness are obtained. The last, the simulation results indicate that the performance of bearing corresponding to the bearing parameters after optimization are promoted comparing to the before parameters. The bearing capacity is increased by 7.98% and the stiffness is increased by 9.17%, which provides a certain value to the improvement of machining accuracy.

333 | Numerical optimization of fibre glass repair system for gas pipelines using 3D parametric finite elements models

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The object of research is the fibre glass repair for gas transmission seamless hot-rolled steel pipe with part-wall metal loss defect. Part-wall metal loss defects of buried pipelines are mostly a consequence of electrochemical corrosion caused by oxidation, sometimes they are caused by a third party interference. This large material loss results in stress concentration in the pipe and can lead to an emergency situation. The basic idea of the reinforcement techniques is to transfer hoop stress, caused by the internal fluid pressure, from the defected area of the steel pipe to the composite sleeve. The significant problem is not only internal pressure but also resistance of the defected pipeline to the third party interference, such as penetration of excavator bucket teeth. The main goal of this study is to optimize composite repair wrap structure. Numerical studies where carried out using FE software with an explicit and implicit integration procedure. Pipeline FE model were developed using thick shell

elements and elastic-plastic material model, where plastic range was defined by stress-strain curve. The glass fibre composite structure was modelled using solid elements connected with cohesive elements described by bilinear traction-separation law, mixed mode delamination criterion and a damage formulation. When the maximum separation is reached, the cohesive element fails and is deleted from the model which leads to separation of the composite elements. The interaction between layers after fracture is defined by penalty contact algorithm with taking into account friction process. The prepared numerical models consider several types of composite material failure modes such as fibre breakage, intra and interlaminar cracks propagation parallel to the plane of layering, the propagation of longitudinal cracks in plane, bending and fragmentation of layers and transverse shear of layers. In optimization studies to reduce the computational time the simplified parametric FE models with appropriate boundary condition were used. The FE models with different number of composite layers and orientation angles were generated using pre-processor script. For each sampling point (set of parameters) the numerical analyses including two different load cases were performed. The first one – burst pressure loading and the second – an interaction of excavator bucket teeth caused by action of digging. The objective of optimization was to minimize the sleeve thickness (mass and cost) while the ultimate internal pressure and ultimate intender penetration force and applied external energy were kept at the level set by undamaged pipe. Finally, full 3D FE models of the pipeline with optimized repair system, the pipeline with wrap before optimization and the pipeline without composite wrap were developed. As a consequence, the results obtained from aforementioned three cases were compared to evaluate the effectiveness of the obtained optimized repair system.

POROUS AND CELLULAR MATERIALS

466 | Fabrication of carbon foam reinforced with composite particles

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The phenolic foams were reinforced with two types of carbon nanoparticles which are multi-wall carbon nanotubes (MWCNTs) and the composite particles (CP) to enhance the mechanical and thermal properties. The CP, multiwall carbon nanotubes reinforced polyimide particles, was fabricated to improve carbon yield of the precursor foam by polyimide and to enhance the dispersion of MWCNT in the phenolic resin. In addition, the MWCNTs in the CP was exposed on the CP surface by partially dessolving in the solvent to form the thermallly conductive path which makes the heat be uniformly transmitted to the inner part of the precursor foam during the carbonization process. The phenolic precursor foams with and without reinforcements were fabricated by microwave irradiation in a shrot time. The carbon foams were fabricated via carbonization of the phenolic precursor foams at 1000˚C in a nitrogen condition. The cell morphology was characterized by measuring the foam density and the cell density, and confirmed by scanning electron microscope (SEM) images. Mechanical and thermal properties of the foams fabricated under varying parameters were characterized by compressive tests and transient plane source method, respectively.

177 | Architected cellular materials with extreme mechanical properties

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The architecture of cellular materials can be designed to elicit mechanical properties that surpass those of existing solids. Examples include materials that can rapidly expand and collapse, fold and transform into a variety of shapes, or conversely robust architectures that do not dilate or shrink under large temperature swings. In this talk, I will focus on hybrid materials with both soft and hard mesoscale architecture engineered to exhibit shape transforming properties and thermal expansion tunability. Their common trait stands out as patterns of either voids or slits that are rationally integrated to provide multifunctional properties. Applications that most benefit from their thermal and mechanical properties are diverse and span from deployable structures and satellite antennas to medical stents and precision instruments.

246 | Evaluation of heat dissipation and structural response of cellular panel as heat exchanger

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Heat exchanger has been widely used for industrial boiler to air conditioner. The appropriate characteristics of heat exchanger are larger surface area, smaller pressure drop and lighter weight. One of the candidate for the best heat exchanger is cellular structure such as honeycomb or lattice panel. In this study, the performance of heat

exchanger composed by cellular panel was calculated using finite element method. In particular, effects of the cell shapes on the heat transfer and structural behavior were investigated. The main purpose of this study is to clarify the optimum shape with high rigidity and thermal characteristics as heat exchanger.

242 | Prediction of failure modes and peak loads in micro-lattice sandwich panels under three-point loading

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In this study, estimation of failure strength of lattice sandwich panel under three-point bending has been investigated by using FEM. In particular, the failure mode for lattice core panel is compared with that for conventional foam core panel. Similar to the form core panel, three kinds of failure mode (face yielding, face wrinkling, and lattice core shear yielding) can be observed, and the failure load for each mode can be evaluated by the theoretical equations.

271 | Structural strengthen with PMMA on solid cellular ceramics porous for water purificator

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Porous materials are found in nature forming their structure through small units called cells that have solid faces and edges and are found in materials such as wood, cork sponges and others (GIBSON; ASHBY, 1997). These natural elements have been studied and used for centuries, but only since the mid-twentieth century have they been used in the engineering field as a result of the development of methods that have produced synthetic cellular solids (TWIGG and RICHARDSON, 2007). Ceramic cellular solids are generally fragile materials with high porosity and have closed, open and / or interconnected pores in their structure (ZESCHKY et al., 2003). The conformation and structuring of cellular solids is done through interconnected elements, solid plates and filaments, structural components that are divided into two categories, cellular honeycomb structure (CHS) and ceramic solids. CHS´s have a prismatic geometry with base surface Hexagonal or pentagonal forming a right angle with a representative edge of the prism height (GIBSON, ASHBY, 1997). Syntheticals ceramic cell foams can be obtained through some classical routes such as: burning of organic particles, gel casting of ceramic foams, replica and others. The replica method consists of the impregnation of a sponge that could be of polyurethane with a ceramic suspension. After this impregnation is made the drying and burning of the polymeric foam, obtaining a material whose porosity and microstructure will be similar to the precursor sponge (SALVINI et al, 2004). To perform PMMA impregnation, two deposition, dip-coating and pyrolysis routes were used, and the performance of these systems was studied. In this work, SIVEX® commercial cellular ceramic solids, with 40 and 80 linear pores per inch (ppi) manufactured by Pyrotek® Inc. using the replication method were used. For a preparation of cylindrical bodies and prismatic blocks with adequate geometry, they underwent mechanical cutting procedure. PMMA was applied with the main objective of fixing nTiO2 and nAg to disinfect water with Escherichia coli, and the effects of PMMA deposition on the mechanical properties of the ceramic body were studied. Mechanical strength tests were performed on Zwick Roell® equipment from LaPFiMC UFRN in Brazil, with axial compression tests performed at 0.5 mm / min feed rate and at room temperature. In the compression analyzes rubber interfaces were used to improve the contact between test pieces and supports. The morphology of the ceramic cell solid used differs significantly from the theoretical model presented by Gibson and Ashby (1997), with dodecahedral structure with edges and faces constituted of porous material, containing triangular voids in its interior and closed faces. It was also observed that the cutting operation causes significant damage to the structure of the ceramic solid, causing cracks and filaments ruptured by bending, which provoke a sensible reduction in the mechanical resistance, by the insertion of points of tension concentrators. The coating layer deposited on the ceramic alumina solid by dip-coating and spray pyrolysis processes were analyzed considering their continuity on the faces and edges, as well as the filling of cracks, triangular voids and open pores. The results of the tests revealed that the PMMA deposition significantly increases the mechanical strength of the ceramic bodies, characterizing the direct influence of the PPMA film on the results of the compressive strength. This polymer, when diluted with acetone in suitable proportions, produces a solution with a viscosity capable of penetrating and filling the triangular cracks and voids in the ceramic alumina (Al2O3) cell structures. The results of the

compression tests on 40 PPI ceramic bodies without PMMA and with PMMA were respectively 0.15 and 0.20 MPa, and for 80 PPI without PMMA and with PMMA were respectively 0.25 and 0.70 MPa.

347 | Cellular thermoplastic manufactured using 3D printing: experimental characterization and finite element modeling of internal structure

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Polyetherimide (PEI) test coupons with cellular internal structure enclosed by PEI solid outer walls were 3D printed using fused deposition modeling. Material experiments were carried out using ASTM standard test procedures to measure the elastic modulus, Poisson's ratio, and the shear modulus in different material directions. The observed behavior was compared with typical cellular materials. A space frame lattice and shell finite element analysis was implemented to model the cellular internal structure. The linearly elastic response of the material was predicted using finite element analysis. The results form finite element analyses were correlated with the experimental results. This approach to predict linear elastic properties of 3D printed cellular material using finite element analysis provides an efficient procedure for designing and optimizing the geometry of the cellular structure of 3D printed parts. Smeared linear elastic properties were calculated for a representative continuum model of the cellular structure. These smeared properties were used to predict the linear elastic behavior of a larger structure with the same cellular internal structure.

307 | Utilization of CT scans for finite element simulations

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The X-ray microtomography (micro-CT) serves to render the three-dimensional phase information directly without performing a tedious and time consuming sectioning of two-dimensional images. This nondestructive technique allows for visualization of a 3D internal structure of an object. Note that in micro-CT imaging the dimensions of the reconstructed voxels (voxel is a volumetric pixel element) are in the micrometer range. From the limited physical dimensions of the used detector it implies that also the dimensions of the analyzed object are limited. The reconstructed samples of real systems provided by computational micro-tomography, i.e., voxel-type structure, can be exploited in numerical simulations. However, based on the resolution of the CT scans, such approach is computationally very demanding and additional post-processing steps, e.g., segmentation, filtering, resolution reduction, etc., must be performed. Unfortunately, the segmentation is crucially dependent on the quality and the resolution of CT scans. If the noise is too high or the resolution and contrast too low, then only some feature descriptors can be determined. The main difficulty lies in distinguishing the objects (defects) from one another. Therefore, the dual energy CT is utilized in this study to separate the individual phases. The reconstructed internal structure of wood is further utilized for mechanical and non-mechanical numerical simulations where it is directly employed, e.g., finite element mesh, or the additional information is extracted, i.e., the obtained volume fractions are used by the Mori-Tanaka method or the fabric tensor is determined to capture the anisotropy of material.

157 | Combining homogenization, experimental measurements and Bayesian inference in estimating the effective properties of spruce

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It has been shown that microfibril angle may severely reduce the longitudinal elastic stiffness of wood. The present paper address this issue by combining experimental measurements both on macro and microscale, image analysis, homogenization and Bayesian statistical method. To that end, the variation of microfibril angle and thus also of effective stiffness observed when estimating this quantity from a certain inverse approach employing indentation and homogenization will serve to provide its prior distribution. The results from a series of tensile tests carried out on thin samples of wood enhanced by digital image correlation are expected to give a new source of information to be used in improving the prior estimates in the framework of Bayesian inference. Owing to a

computational demand associated with the Markov chain Monte Carlo method the homogenization based on classical micromechanics will be adopted.

332 | Nonlinear modelling and characterisation of PMI-based foam core materials for FRP sandwich structures

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In the context of aerospace applications, sandwich structures made of PMI-based foam core materials and face sheets of fibre-reinforced plastics (FRP) are often considered a candidate to replace conventional thin-walled stiffened panels or similar honeycomb sandwich structures. These foam core materials offer the additional design opportunity for truly three dimensionally shaped panels including varying core thicknesses, enabled by machining and thermoforming. In particular, for high-volume parts these technologies may further reduce overall manufacturing process complexity and lead time. The required long-term durability of aerospace structures necessitates deep understanding of the material behaviour up, and in particular close to initial material degradation, whether it being for the accurate prediction of core stiffness related failure modes like face sheet wrinkling, or rupture of the core material itself for instance in the vicinity of locally introduced loads. Ultimately, those criteria determine the attainable minimum foam core density, a significant driver of the total weight of the structure and its competitiveness. However, previous studies found in literature primarily focus on the compressive damage and impact behaviour, and the associated energy dissipation, rather than generic quasi-static sizing at the various operational and environmental conditions. Conventional sizing methods such as the classical sandwich theory imply the assumption of quasi-constant elastic material properties until material failure. Detailed finite element analysis and coupon tests, however, frequently show significant nonlinear characteristics, which are captured accordingly by large knockdown factors. The present work thus aims at both, reducing these knockdown factors and improving the accuracy of material failure prediction. For this purpose, a series of PMI foam core material tests are conducted to determine the general nonlinear characteristics under tensional and compressive loads, including the optical measurement of lateral contraction, i.e. the Poisson ratio. The observed behaviour indicates strong nonlinear elastic properties throughout the whole domain of the load spectrum. Hence, the assumption of linear elasticity appears insufficient when the foam material experiences significant strain. However, the determined stress-strain curves exhibit a characteristic piecewise linear relation. That is, the elastic moduli are piecewise continuously and linearly decreasing with increasing strain. Similar trend is observable from measured lateral contraction, indication a linear dependency of the Poisson ratio and acting strains. Finally, it appears that early material degradation under tension can be associated with a particular change in the tensional stiffness gradient, pending further confirmation. Present paper discusses the key aspects considered for and from the performed material tests, the therefrom derived material model, its implementation in numerical finite element analysis and potential applications in general structural analysis. The model enables an improved decision basis in an earlier design phase to schedule detailed testing, and may support the identification of further subsequently triggered structural failure modes.

Acknowledgements: The presented work is part of the LuFo V project SCHACH, publicly funded by the German Federal Ministry of Economic Affairs and Energy, BMWi.

278 | Numerical Modeling of porous materials made with entangled fibers network

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Sandwich structures are widely used in aerospace applications for their very good stiffness to weight properties. Random fibrous materials have been elaborated from carbon fibers to be used as core material for sandwich structure. This material presents an attractive combination of properties such as an open porosity, multifunctional properties and the possibility to obtain complex shapes. Many studies have been carried out on the modelling of entangled material. Recently, an analytical model [2] have been achieved to optimize the core structure and to model the properties of these material. Durville has proposed a finite element approach that discretize the contact-friction interactions from intermediate geometries to simulate the mechanical behaviour of beam assemblies. The main objective of this work was the finite element modelling of the fibrous material. A 3D numerical model has been developed to represent reality compared to the mechanical behaviour in compression. At the beginning, fibers are randomly generated in Representative elementary volume (VER). Then, the connection and crossing

fibers would be managed. Afterwards, numerical tests would be carried out on VER. The experimental results of simple compression are confronted with those obtained from the numerical simulation. The proposed model is used to better understand the mechanical behaviour of entangled fibers and in particular to highlight the effects of different morphological (length and diameter of fiber ...) and mechanical parameters (density of material ...).

365 | Mechanical behaviour of a multifunctional panel for de-icing systems

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Anti-ice and De-ice are critical systems on modern airplanes. The potential hazards caused by the formation of ice on the external surfaces are various: from the loss of important flight data (such as flight speed and altitude) with the icing of air probes to more severe hazards such as the locking of the movable surfaces or also increase of drag due to the changing of the aerodynamic profile. To face this problem during the years different techniques have been adopted. One of the first solution was to add on the leading edges of the wing polymeric tubes to inflate with pneumatic air source; in this manner, the ice attached to the wing is removed mechanically. Other system uses different sources such as chemical sources (glycol) but are not suitable for large aircrafts. The most diffused plant takes hot air from the engines compressor and heat the sandwich panels of the wing blowing from the inner skin. This system requires feeding tubes (generally made of aluminium), valves and complex passageways to enhance the specific heat exchange surface. The proposed solution overcomes this adding of weight introducing a single sandwich panel with a porous cellular core, that have both structural and thermal functions. This device integrates, in a single component, the passageways of the hot air and the structure of the leading edges, without welding or bonding, due to the use of Additive Manufacturing (AM). In fact, this technique allows the production of complex geometries without additional costs. Moreover, it promotes the realization of components with a great by to fly ratio due to less use of material. Selective Laser Melting (SLM) is a Powder Bed Deposition AM technology: a technique that selectively melt the powders, deposited in layers, according with STereo Lithography interface format (STL) data provided. Layers by layers the component is produced and finally extracted from the machine, separating it from the un-melted powders that can be reused. The realization of a sandwich panel with a core in trabecular structure fully exploits the potential of the technology: as said before these structures are necessary to ensure a great heat exchange between the anti-icing panel material and the hot air tapped from the engine. To further improve the efficiency of the device, a material with a great thermal conductivity, like aluminium alloys, is chosen. In particular, the components are produced with AlSi10Mg powders, a traditional casting alloy, for which the SLM machine parameters are already been optimized. AM technology allows the production of sandwich panels with a very different structure in respect to the traditional one type actually used in aerospace industry: the component is made in only one material and in one piece, without welding and polymeric bonding. It a beneficial point for both the thermo-mechanical behaviour and the final weight of the device. The present work exploits the mechanical behaviour of this porous core sandwich with a comparison between experimental results collected from experimental characterization with numerical analysis based on a dedicated finite elements model. In particular, compressive tests will be presented for the porous core together with three points bending on the complete sandwich panel.

391 | The deformation mechanisms of fibre-network materials

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Fibre-network materials/structures widely exist, examples include the fibrous paper, the micro-sized extracellular matrix and the nano-sized cytoskeletal fibre networks of cells. Based on idealised geometrical model, we performed dimensional analyses and obtained the in-plane and out-of-plane Young's moduli and yield strengths as functions of the relative density of the fibre network materials, the Young's modulus and the yield strength of the solid material. It is found that the in-plane Young's of the fibre network materials is approximately proportional to if the relative density is small, and gradually becomes proportional to with the increase of the relative density. In contrast, the out-of-plane Young's modulus of the fibre network materials is always approximately proportional to

if the relative density is smaller than 0.2. It is also found that the in-plane yield strength of the fibre network materials is proportional to and the out-of-plane yield strength is proportional to. The analytical results show perfect agreement with the computer simulation results obtained from periodic random fibre network models and the experimentally measured results from metal fibre sintered sheets.

341 | Finite element simulation of microporous thermoelastic materials with metallized pore surface

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Porous composite materials are characterized by smaller density and acoustic impedance in comparison with similar dense materials. Their properties guarantee benefits of using porous materials for a range of applications, for example, in the elements of hydroacoustic emitters. However, the main drawback of porous materials is their lower strength, which limits their use in case of large mechanical loads. A directed change of physico-mechanical properties can be performed at the stage of manufacturing the porous materials, for example, by the methods of local alloying the pores by micro and nanoparticles of various substances. In the result, we can obtain porous materials with micro or nanoparticles of metal or polymer deposited at the borders of the skeleton with pores. The sizes of the pores can be of usual size, as well as of micro or nanosize. The pore structure also can be different. Different porosity types include closed and open porosity, stochastic, periodic, cluster structure, etc. This paper presents the results of the effective properties computation for thermoelastic porous ceramic materials with metallized pore surfaces for two types of porosity, namely, a simple random porosity structure and randomly determined structure that supports the connectivity of the skeleton. The research was carried out on the base of complex approach which included the effective moduli method, the representative volumes generation and the finite element solution of the set of static thermoelastic problems with standard boundary conditions for the effective moduli method. The representative volume was being created from cubic finite elements. At the first stage, we built cubic array of identical elastic cubic finite elements. Further, by using the random number generator or special algorithm supporting the skeleton connectivity, certain finite elements were chosen and their material properties were changed to the properties of pores. The most challenging stage was finding the edges of contact between ceramic elements and pore elements. After this stage, all the edges or part of the edges of contact between ceramic and pore elements were covered by shell elastic elements with the properties of metal. In the result, we got a representative volume that included cubic elastic finite elements with material properties of the skeleton, pore elements and shell elastic elements. For numerical solution of static thermoelastic problems in inhomogeneous representative volume we used ANSYS finite element software. The computational results of solving test problems enabled us to estimate the influence of the pore surface metallization and porosity structure on the values of the effective moduli.

Acknowledgements: This research was done in the framework of the RFBR project 16-58-48009 IND-omi and DST.

190 | Size-dependent and tunable elastic and geometrical properties of nano-structured hierarchical cellular materials

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The basic building blocks of nano-structured hierarchical cellular materials are nano-sized wires or plates. Due to the effects of surface elasticity and the initial stress/strain, their bending, torsion, stretching and transverse shear rigidities are not only size-dependent, but also tunable and controllable over a large range. Based on the closed form results of the bending, torsion, stretching and transverse shear rigidities of nanowires [1, 2] and nano-plates [3,4], the analytical results for the size-dependent and tunable elastic and geometrical properties are obtained for the first order nano-sized regular honeycombs [4,5] and open-celled foams [6], and the similar results are obtained for the first order nano-sized random irregular Voronoi honeycombs [7] and random Voronoi open-celled foams by computer simulation. Further, the size-dependent and tunable elastic and geometrical properties are obtained for nano-structured hierarchical and self-similar regular and irregular honeycombs and open-celled foams. The obtained results indicate that some very interesting and much desired elastic and geometrical properties, which do not exist in conventional cellular materials, become possible in their nano-structured hierarchical counterparts.

NOVEL COMPOSITE ARCHITECTURES

73 | The nanotransformation products of hydrocarbons and natural compounds by the usage of the magnetic nanocatalyst

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A comparative study between the oxidation products of aromatic, natural and non-aromatic compounds was performed by the usage of the magnetic nanocatalyst. Obtained products were evaluated by GC-MS and IR. The magnetic nanocatalyst (Zn-acetanilide@amino functionalized silica supported magnetic nanocatalyst) has been synthesized previously and was used for the oxidation of aromatic compounds: 3-nitrobenzaldehyde, 3-hydroxybenzaldehyde and 4-methoxybenzaldehyde. Here it was used for the oxidation of monoterpenes such as geraniol and α-pinene, and also for the oxidation of non-aromatic compounds like 1-propanol and cyclohexanol. The catalyst bears no metal leaching and can be rapidly recovered by the usage of an external magnet and reused several times.

346 | Modelling and design procedure of prestressed composite materials

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The paper introduces the concept of eccentrical prestressing of fiber reinforced polymer materials in order to improve their mechanical properties and global mechanical behaviour. Prestressing is here understood as application of the initial tensile stress to the fibres embedded in selected external layers of the composite material. The objective of prestressing is to increase stiffness of the composite and to obtain desired response to applied external loading. The main objective of this research work is to develop a comprehensive approach to analysis of prestressed composites, which includes analytical and numerical modelling of the static behaviour, optimal composite design, as well as, simulation of dynamic response. Initially, we derive simple and effective analytical model of prestressed composite based on models of individual prestressed plies and their homogenization. The analytical model is used to reveal beneficial influence of prestress on strain and stress distribution in particular plies and resulting increase of the composite stiffness. Further, three options for the FEM-based numerical modelling of prestressed composites are proposed and thoroughly compared with each other. Developed analytical and numerical models are used to propose methods of prestressed composite design in which optimization of prestressing forces is used to minimize required composite thickness or fiber volume fraction. Eventually, FEM simulations are applied to assess the influence of prestress force magnitude on natural frequencies and modal shapes of eccentrically prestressed composite beams of various fibre volume fraction. The final part of the paper summarizes the potential advantages of the prestressed composites and unveils their superiority in comparison to the standard ones. Potential applications of prestressed composite materials in civil engineering and aerospace industry are briefly discussed. In addition, challenges related to design and manufacturing of structures made of prestressed composite materials are presented.

183 | Multistep forming of thermoplastic composite parts

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Press forming of thermoplastic composite (FRTP) parts is usually performed on laminates with constant thickness and predefined and limited fibre orientations to facilitate in-plane shearing. This limits the potential of FRTP materials for a number of structural applications. In this research, the focus is on the feasibility of press forming FRTP parts in multiple steps. In each step, another laminate or layer is added by forming and consolidation to the already formed layers. Using this principle FRTP parts with thickness variations and/or unrestricted fibre directions are made. The research used prefabricated PEI/Glass fibre laminates, made of fabric material. These laminates are preheated with Infrared and transferred to be press formed using a preheated metal die and a pre-shaped rubber die. This resulted in parts having three different thicknesses and a quasi-isotropic fibre orientation. Subsequent to the forming steps the laminates are consolidated. Testing of the parts, by retrieving Mode I and ILSS test specimens from different sections of the part, show that the bonding between the different laminates is as good as for reference material, made of laminates consolidated in a flat platen press. Future developments, included in this paper, are focused on the reduction of the process time, which is current too high, use of UD prepregs, and on industrialisation of the concept.

383 | Hybrid effects in hybrid aligned discontinuous composites

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Hybrid discontinuous composites offer the possibility to tailor the properties of composites (stiffness, strength, ...) for specific applications. Moreover, using hybrid discontinuous fibres can also improve the manufacturability of composites, reduce cost by introducing cheaper fibres and enable to close the life-cycle loop of composites by using recycled fibres. However, hybridising different types of fibres often introduces hybrid effects which cannot be captured by simple models such as the rule-of-mixtures and are therefore challenging to predict and explain. This work explores different hybrid effects found in the mechanical response of aligned hybrid discontinuous composites. To do so, an analytical shear-lag based model was developed and considers (i) random or organised intermingling of the two types of fibres, (ii) random location of the fibre-end in the microstructure, (iii) a generic constitutive law for the matrix, (iv) stochastic fibre failure under non-uniform stress fields due to the presence of fibre-ends, and (v) unstable final failure from a critical cluster of damage. The model showed good agreement with experimental results, and was then used to perform parametric studies in order to understand what causes hybrid effects and how they can be promoted or avoided. The results demonstrate that interactions between different types of fibre are the main responsible for the reduction of the Young's modulus when hybridising discontinuous composites; this agrees with experimental results found in literature. Moreover, the model also suggests that hybridising two types of fibres with different diameters can reduce the stress concentration found in fibres due to neighbouring fibre-end, and hence increases the strain at which the low failure-strain fibres break. Moreover, high failure-strain fibres behave as a shield against the stress concentration due to the failure of low failure-strain fibres. Finally, both the model and experiments suggest that a good degree of intermingling of the two fibre types prevents the formation of large clusters of the low failure-strain fibres in the material, and therefore reduces the likelihood of premature failure of the specimen due to the failure of such clusters. The different hybrid effects captured and explained by the model can be amplified by increasing the degree of intermingling. However, not all of these effects are desirable, and a trade-off has to be found between stiffness, strength and failure strain. From these observations, the model was used to identify optimal configurations for hybrid aligned discontinuous composites, aiming to achieve a good balance of stiffness, strength and failure strain.

13 | Periodic architected interpenetrating phase composites

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In this work, we investigate the mechanical properties of a 3D printed interpenetrating phase composites (IPC) with periodic architecture. IPCs are composites with co-continuous phases that interpenetrate each other in such a way that if one of the phases is removed the remaining phase(s) will form a self-supporting structure. Traditional methods of fabricating IPC results usually in random distribution of the phases with limited control over the volume fraction and the spatial distribution of the phases. In this work, additive manufacturing techniques are employed to fabricate periodic architected IPCs, where one hard phase is used to spatially reinforce a rubbery soft material. The topology of the architected phase is based on the triply periodic minimal surfaces (TPMS). TPMS are surfaces created mathematically and have several advantages that make them a good candidate for use in structural systems. These surfaces are non-self-intersecting and have cubic symmetry that allow to pattern them in the three-dimensional space to take the shape any of desired object. Computer added design (CAD) is employed to design the IPCs, then 3D printing technique is used to fabricate the polymer-polymer IPCs using Polyjet 3D printing technology that allows printing two dissimilar materials at the same time. Electron microscopy is employed to investigate the quality of the 3D printed samples. Samples are tested in compression and the elastic and plastic behavior are investigated. Results show that the IPCs follow a bending-dominated deformation behavior and are potential candidates for applications where damage toleration and vibration damping is a requirement.

304 | Influence of tow architecture on permeability and laminate properties of 3D woven composite structures

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3D fibre architectures facilitate rapid, low-cost manufacturing technologies (for example high pressure RTM) and at the same time improve damage tolerance and through-thickness properties. This research is aimed at optimising 3D woven architectures that retain high degree of in-plane properties and at the same time provide inter-tow resin channels for rapid infusion. Individual binder and tow geometries have been captured using X-ray CT in order to compute resin permeability and laminate properties.

PLATE AND SHELL FINITE ELEMENTS

147 | A free-vibration thermo-elastic analysis of laminated structures by variable ESL/LW plate finite element

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In this work, the thermoelastic free-vibration analysis of multilayered plate structure is performed using some advanced theories, obtained by expanding the unknown displacement variables along the thickness direction using equivalent-single-layer (ESL) models, layer-wise (LW) models, and variable-kinematic models. The variable-kinematic models permit to reduce the computational cost of the analyses grouping some layers of the multilayered structure with ESL models and keeping the LW models in other zones of the multilayer. This model is here extended for the free-vibration analysis of thermomechanical problems. The used refined models are grouped in the Carrera unified formulation (CUF), and they accurately describe the unknowns' distributions along the thickness of the multilayered plate. One of the most interesting features of the unified formulation consists in the possibility to keep the order of the expansion of the state variables along the thickness of the plate as a parameter of the model. This model has already shown good results in the mechanical static analysis of multilayered composite plates [1], and for the thermo-mechanical static analysis of multilayered composite plates and shells [2]. The plate element has nine nodes, and the mixed interpolation of tensorial components method is used to contrast the membrane and shear locking phenomenon. The governing equations are derived from the principle of virtual displacement (PVD), and the finite element method (FEM) is used to solve them. The results, obtained with different theories within CUF context, are compared with the elasticity solutions given in the literature. Some results are given to prove the efficiency of the plate element based on the CUF for the study of thermomechanical problems of composite structures. The variable-kinematic models combining the ESL with the LW models permit to have a reduction of the computational costs, with respect with the full LW models, preserving the accuracy of the results.

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83 | MITC9 shell elements based on RMVT and CUF for the analysis of anisotropic structures

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This paper presents mixed two-dimensional models based on Carrera Unified Formulation for the analysis of mechanical response in anisotropic multilayered structures, with particular attention to the behavior along the thickness of the material. It is well-known that the properties of anisotropic materials are directionally dependent. Unlike isotropic materials that have material properties identical in all directions, anisotropic material's properties such as Young's Modulus, change with direction along the object. Common examples of anisotropic materials are wood and composite laminates. In the two dimensional modelling of multilayered plates and shells, the main interest is to study the mechanical response, that may change in the thickness direction. In particular, the transverse shear and normal stresses are required to be continuous in each layer interface (Interlaminar Continuity, IC). Among the computational techniques developed for layered constructions, a predominant role is played by

Finite Element Method (FEM). In this regard, two variational formulations are available to reach the stiffness matrices, the Principle of Virtual Displacement (PVD) and the Reissner Mixed Variational Theorem (RMVT). The PVD, formulated with only displacements, cannot describe a priori IC for transverse stresses. On the contrary, they can be a-priori assumed in the framework of RMVT, which consists of a mixed principle for multilayered structures. It is known that when FEM is used to study shell structures, the phenomenon of numerical locking may arise: the so-called membrane and shear locking. A well known remedy for the locking is the use of the Mixed Interpolated Tensorial Components (MITC) technique. In previous authors' papers [1-3], a strategy similar to MITC approach in the RMVT formulation has been introduced in order to construct an advanced locking-free finite element based on Carrera's Unified Formulation to treat laminates made of isotropic or ortotropic layers with fibres orientation 0° and 90°. The present work extends this element to the analysis of anisotropic composites with layers arbitrarily oriented.

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RECENT ADVANCES IN STOCHASTIC ANALYSIS OF COMPOSITE STRUCTURES (CHAIRED BY KHEIROLLAH SEPAHVAND)

1007 | Identification of random elastic and damping parameters of composite structures

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To improve the performance, durability and efficiency of composites structures, an exact knowledge of elastic and damping parameters is required. Such parameters exhibit significant uncertainties which arise from the variable characteristics of the individual layers, their interconnection and the manufacturing process. These parameters are normally represented as random variables/fields to present these uncertainties in numerical models, e.g. in a FEM model. As a tradition, the sampling-based, e.g. Monte Carlo, methods are applied for uncertainty quantification where obtaining trustable results requires large number realizations of uncertain parameters. Non-Sampling methods, in contrast, requires few realizations of parameters and accordingly very efficient in term of computational time. This work employs the non-sampling methods, e.g. generalized polynomial chaos and the Karhunen-Loève expansions to represent and identify damping and elastic material parameters of composite structures. To this end, the parameters are represented by truncated expansions with deterministic coefficients and random orthogonal basis. The unknown coefficients are estimated from experimental modal data for samples of composite plates. As well as the expansions are known, they can be combined with FE model to realize the random structural responses. The method is proven to yield closer predictions to the experimental data.

SMART COMPOSITES

443 | Shape reconfigurations in smart composite systems

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Smart structures integrated with active materials, such as shape memory, electro-active, and magnetostrictive materials, are appealing for the development of new generation of autonomous systems with sensing and adaptation ability. In this study, we analyze the deformation of smart flexible planar polymeric structures with integrated thin piezoelectric patches, in which deformations and shape changes are controlled by electric field inputs prescribed to the piezoelectric actuators. We consider active fiber composites (AFC), having piezoelectric fibers dispersed in polymeric matrix, for the piezoelectric component. One drawback with using piezoelectric materials is that they do not have shape retention ability once the electrical stimulus is switched off. Continuously inducing electric field often generates significant amount of heat, which could be detrimental to the polymeric structures. Thus, we consider integrating AFC and shape memory polymers for designing flexible and foldable smart structures. The shape memory polymers possess shape retention ability, eliminating the needs to

continuously prescribing the electric field for maintaining certain shape reconfigurations. We present analyses on flexible and foldable smart composite beams and plates, incorporating nonlinear kinematics and nonlinear constitutive material behaviors for the piezoelectric and polymer constituents. In these flexible structures, large deformations are mainly governed by large rotation, while the in-plane strains are relatively small. Reissner beam theory is adopted in formulating the large deformations for the beams, and modified in order to incorporate the deformation due to the electric field input. A nonlinear shooting method is used to analyze the deformation of the beam under both electrical- and mechanical stimuli. We also extend the slender smart beams to modeling smart flexible composite plates. Co-rotational finite element (CRFE) method is used for numerically solving the equations that govern the deformations of the electro-active composite plates. Several examples of shape reconfigurations are discussed and the advantages of using shape memory polymers as compared to inactive polymers are also assessed. The presented methods and examples of boundary value problems discussed in this study can help designers in simulating desired shape reconfigurations and determining arrangements of piezoelectric patches and external stimuli to be prescribed prior to fabricating smart and flexible composites. The analyses can also help in selecting materials for both substrates and actuators during the design of foldable and flexible composite structures.

387 | Numerical prototyping of piezoelectric morphing wing

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The current paper addressed the numerical Prototyping of morphing wing which include piezoelectric actuators for an unmanned aerial vehicle (UAV). The idea is to couple conventional composite wing with piezoelectric actuators to develop a kind of smart wing that have the ability of shape changing. The wing is designed using Ansys apdl code and subject to different analysis to test its ability and performance.

176 | Vibration control of smart composite beam

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In the present paper, the active vibration control of a composite beam using piezoelectric actuator is investigated. The space state equation is determined using system identification technique Based on the structure input output response developed in Ansys finite element analysis package. The Linear Quadratic (LQR) control law is designed and integrated into the Ansys to perform closed loop simulations. Numerical examples are presented and proved the efficiency and the accuracy of the proposed model.

358 | Multiscale modeling of the thermomechanical behavior of shape memory alloy / polymer composites by finite element square method

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Hybrid materials with multi-physical behavior could develop to contribute to the emergence of innovative applications taking advantage of the interesting properties of shape memory alloy (SMA) and polymer components. The fiber-matrix or multilayer composites SMA-Polymers could result in applications in energy recovery and conversion or in sensor-actuators. It is therefore important to have numerical tools for predicting the multi-physical, multi-scale and non-linear behavior of these composite materials. We propose a numerical tool for

modeling the effective behavior of SMA / Polymers composites based on the finite element square (FE^2) method. It is an iterative numerical approach where the deformations calculated at any point of integration of the structure are applied as boundary conditions at the level of the RVE associated with this point of integration. The behavior of the SMA phase is described by a law based on a thermodynamic approach where the driving forces associated with the internal martensite volume fraction and mean transformation deformation are derived from the postulate of Gibbs free energy expression. The behavior of the polymer is assumed to be linear and isotropic elastic. The FE^2 method is a technique of transition of numerical scale between a complex microstructure discretized by finite elements and the macroscopic structure. This approach allows to treat heterogeneities and complex behaviors of different phases. The microstructure and structure responses are calculated simultaneously and coupled. The procedure is implemented in the Abaqus finite element code via the UMAT routine. The state of constraints, volume fraction of transformation, and the corresponding tangent operators are thus calculated and considered as input at each point of integration of the mesh of the structure for the calculation of the global equilibrium. This multi-scale approach is validated on test cases in the literature. It will subsequently be used for the designing of a composite SMA / polymer application.

273 | Self-sensing glass FRP composites incorporating CNT fibers

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This paper summarizes a portion of the experimental work recently conducted by the authors [1]. Fiber reinforced polymer (FRP) composites are being extensively used in a number of fields such as aerospace, automotive, construction industry etc., due to their superior mechanical properties [2,3]. The in-service structural health monitoring (SHM) of these composites is crucial for safety and integrity of the structure. Several approaches have been proposed for damage detection in composite materials (i.e., embedded piezoelectric sensors, glass fiber optic sensors, acoustic emission etc.), however, most of them present limitations in terms of high cost, low resolution, time consumption etc. [3,4]. Recently, some researchers attempted to utilize the piezoresistive characteristics of carbon nanotube (CNT) fibers for stress/damage sensing of glass fiber reinforced polymer (GFRP) composites [3-5]. CNT fibers were embedded between two layers of GFRP composites during fabrication, and they exhibited excellent sensing ability compared to other techniques reported in the literature [3-5]. These results showed that it is a promising technique for continuous monitoring of FRP composites [3-5], however, keeping the CNT fibers straight during fabrication of composites is quite difficult. In this study, CNT fibers were incorporated in GFRP composites either in the form of pre-casted CNT fiber patches which were easily embedded in the center of GFRP composites during fabrication of composites (type A), or CNT fibers were attached on top of the GFRP composites after the fabrication and curing of composites (type B). Tensile cyclic loadings were applied on the samples up to 60 MPa, followed by loading up to failure. In both types of samples, CNT fibers showed excellent sensing characteristics i.e., resistance increased or decreased with the applied loading. Type A and B samples showed about 5% and 4% change in resistance at 60 MPa, respectively. Upon further loading up to failure, resistance kept on increasing gradually with a sudden increase at failure. The details of experiments and discussions will be presented.

Acknowledgements: This research was supported by the KUSTAR-KAIST Institute, KAIST, South Korea.

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350 | Smart composite blades for impact monitoring

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Renewable energy infrastructures have been well established during last several decades, but, as a side effect, they threaten wild animals' lives. For example, the 165 km2 Altamont Pass Wind Resource Area (APWRA) in west-central California includes 5,400 wind turbines and the annual bird fatalities including the rare and endangered birds are around 4,800 there. In order to monitor bird collision, some researchers developed several detection techniques using radar or infrared rays. These methods are fit for wide range animal monitoring, but they are not suitable for real-time impact monitoring of each wind turbine blade. In this study, we investigated on a wireless impact monitoring system to check where the impact occurs on the wind turbines remotely and rescue the birds quickly when impact was detected. Wind turbine blades were made from smart composite and can act as a sensor itself. So, this developed system can detect collisions on the blades in real-time. In order to use wind turbine blades as the sensor, a smart resin that was made by mixing PNN-PZT powder and epoxy was used instead of the epoxy resin used in the composite material. By impregnating glass fiber with the smart resin using Hand Lay-up and VARTM (Vacuum Assisted Resin Transfer Molding) molding method, the wind turbine smart composite blades were fabricated. The electrodes were made using a conductive coating on the inner surface and the outer surface of the wind turbine smart composite blades. In order to activate the blades, poling was conducted at room temperature for 30 minutes at 4 KV/mm using a high voltage amplifier. When the wind turbine smart composite blades were struck with an impact, it transmitted the output signals from the wind turbine smart composite blades wirelessly using a ZigBee module. Therefore, the impact on the wind turbine smart composite blades was monitored in real-time.

Acknowledgements: This research was supported by Leading Foreign Research Institute Recruitment Program (2011-0030065), and Leading Local New-Industry Human Resourcing Program (2016H1D5 A1910063) through the National Research Foundation of Korea funded by the Ministry of Science, ICT and Future Planning.

STABILITY OF NANO, MICRO AND MACRO COMPOSITE STRUCTURES

390 | Nonlinear and post-buckling behaviors of cracked cross-ply composite plates with or without initial imperfection using Rayleigh–Ritz approach

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A composite material is made by combining two or more materials, often ones that have very different properties. The two materials work together to give the composite unique properties. However, within the composite you can easily tell the different materials apart as they do not dissolve or blend into each other. The best advantage of modern composite materials is that they are light as well as strong. By choosing an appropriate combination of matrix and reinforcement material, a new material can be made that exactly meets the requirements of a particular application. Composites also provide design flexibility because many of them can be molded into complex shapes. Composite laminated plates and plate structures are increasingly used as structural components in various branches of engineering such as aerospace and marine engineering. These structures are often employed in situations where they are subjected to in-plane compressive loading. Thus, it is important to accurately predict the buckling and post-buckling of such structures [1]. Extensive research has been carried out in the past on buckling and post-buckling behavior of composite plates as reported in the reviews by Leissa [2] and Chia [3] Literature survey shows that a lot of work, especially for post-buckling, was devoted to the solution of thin plates modeled by the Classical Laminated Plate Theory (CLPT), which often fails to provide accurate results, as it neglects the transverse shear strains playing an important role in low transverse shear stiffness structures.The First-order Shear Deformation Theory (FSDT), with appropriate shear correction factors, is able to provide engineering reliable results for thin to moderately thick plates in the framework of a simple and computationally effective modeling [4].The finite element method is a widely used numerical tool for analyzing the post-buckling behavior of composite laminated plates. A number of papers have appeared on the post-buckling analysis of plates with various loading and boundary conditions (e.g., see [5–9]). The need to ensure structural damage tolerance, especially in aerospace applications, requires taking into account the possible presence of cracks and defects as they could lead to the premature failure of the structure. In this sense, the interaction among cracks or defects and buckling or post-buckling phenomena should be considered to assess the possibility of adverse effects [10]. Therefore, in this paper, a Rayleigh–Ritz approach for the analysis of nonlinear and post-buckling behaviors of cracked cross-ply composite plates is presented. The plate is modeled by the first order shear deformation theory and taking geometric nonlinearities into account through the von Karman's assumptions. Also the plate has an

initial geometric imperfection. The imperfect square plates have simply-supported boundary conditionson all edges and they are constrained for in-plane displacement at the one side of plate.The Rayleigh–Ritz method is used by Lagrange polynomials for the primary variable approximations.The necessary constraints for modeling the crack are provided by Courant penalty functions.The cross-ply laminated plates are subjected to biaxial compressive loads and then a sensitivity analysis is done with respect to the applied load direction along the tangent and normal to the crack.The integrals of potential energy are numerically computed by Legendre–Gauss quadrature formulas to get adequate accuracy.Then the obtained non-linear system of equations is solved by Newton–Raphson method.

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361 | Buckling analysis of double nanobeam systems using doublet mechanics theory

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This study considers the buckling of double nanobeams based on an Euler-Bernoulli beam model. Two beams are connected by each other by linear springs. A scale dependent doublet mechanics theory is used for modelling the double nanobeam systems. Critical buckling loads are obtained using doublet mechanics and results are compared with classical elasticity theory. Variation of critical buckling loads with different beam length, doublet separation distance and stiffness of the springs are investigated. It is obtained that doublet mechanics theory can be used for design of the nano length scale materials.

THERMAL PROBLEMS ON COMPOSITE STRUCTURES

313 | Temperature-dependent thermal and mechanical behavior of fiber-reinforced laminates under high-energy laser irradiations

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Composite materials are increasingly being used in civilian applications as well as in the field of security and defense. Because there are still needs in the understanding of the interaction of high-energy lasers (HEL) with composite structures, especially in the industrial domain but also in the military area due to newly-developed laser weapon systems, this study focuses on the high-temperature thermokinetic and thermomechanical performances of glass fiber-reinforced plastics (GFRP). Conventional thermal investigations have been employed at different heating rates from room temperature up to the degradation temperature of the matrix to analyze the change of the physical properties, mainly based on the characteristics of the polymer phase. Quasi-static tensile tests into a hot furnace were also performed to characterize the thermomechanical weakening of GFRP at elevated temperatures. Some transition models based on the kinetic parameters of the well-known Arrhenius law were derived from these experimental examinations to extend the observed material behavior to the drastic conditions of a high-energy laser irradiation where typical tensile tests samples can break within seconds.

162 | Effect of temperature on the abrasion wear of epoxy polymer reinforced with particle inclusions
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The increasing demand of carbon fibre reinforced composites in elements subjected to abrasion and high temperatures makes it necessary to improve their durability. The effect of the temperature on the mechanical properties is well known. However, the effects of the heat accumulation on abrasion wear requires specific analysis. The epoxy matrix phase plays an important role in the wear at high temperatures but also the incorporated additions. In order to identify the effect of particle inclusions on the abrasive wear at high temperature of carbon fibre composites and epoxy matrices, three types of fillers were investigated, such as: carbon powder, slags and Portland cement. Also, the used carbon powder and the slag particles are considered waste materials. The results revealed a slightly improvement of the abrasion resistance, making it a promising recycling for such residues.

TOLERANCE AVERAGING MODELLING IN MICROSTRUCTURED MEDIA (CHAIRED BY PIOTR OSTROWSKI)

42 | An analytical-numerical approach to analysis of non-linear vibrations of periodic Timoshenko beams
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Elastic periodic systems, such as beams, plates and shells with variable mass and stiffness properties exhibit dynamic characteristics that are interesting from the application point of view. The most commonly known is the existence of band gaps in the frequency spectrum. The paper is devoted to analysis of geometrically nonlinear vibrations of beams with cross-section periodically varying along the beam axis. Since a single periodicity cell can be considered as a thick beam, the Timoshenko theory of beams with midplane stretching nonlinearity is applied. This leads to a system of nonlinearly coupled equations with rapidly varying coefficients. The tolerance modelling technique, a method of averaging differential operators with highly oscillating coefficients, is applied to obtain averaged governing equations with constant coefficients and additional degrees of freedom. An analytical-numerical model based on this method, together with Galerkin orthogonalization is presented and applied as a tool in analysis of free and forced nonlinear vibrations of periodic beams in the low frequency range. The influence of the properties distribution in a single periodicity cell, as well as the length-to-thickness ratio is investigated.

30 | Thermoelastic behavior of a two-phase hollow cylinder with radially graded material properties
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The subject of this contribution is an investigation of the elastic response in a two-component heat conductor which has a space varying microstructure in one of directions, functionally graded macrostructure in second direction and invariable structure in remaining direction. To be precise, this conductor is a two-phase hollow cylinder with a dense system of radial inclusions in circumferential layout. The aim of the contribution is to formulate and to apply a macroscopic mathematical model describing heat conduction in linear elastic conductors having circumferentially periodic microstructure, apparent slowly varying in radial but constant properties in axial direction. The generalized period of inhomogenity is assumed to be sufficiently small when compared to the measure of the domain of argument. Heat transfer equations in a conductor under consideration, described by the Newton's and Fourier's law, have highly-oscillating and discontinuous coefficients involved. In order to derive the averaged model equations with continuous coefficients for heat transfer in an elastic conductor under consideration, tolerance averaging approach was applied. This technique is based on the concept of tolerance and indiscrenibility relations and on the definition of slowly varying functions. The general modelling procedures of this technique are given in [2], and its application to the simplest problems of thermoelasticity in hollow cylinder can be found in [1]. This consideration concerns non-stationary unidirectional phenomenon for isotropic material properties under various boundary value problems. Numerical results from the tolerance model equations (TM) and compared with those from Finite Element Method will be presented.

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31 | The effect of a microstructure in thermoelasticity problems of functionally graded laminates

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A coupled problem of thermoelasticity in a laminate is considered in this contribution. This laminate is made of two materials. In this medium cells can be distinguished. Every cell is consisted of two sublaminas, which are made of two various components. It is assumed that the thickness of the cell is constant and is denoted by l. However, thicknesses of sublaminas are various in every cell. Hence, the laminate of this kind has a microstructure on the microlevel, which can be described by so called tolerance-periodic (or nearly periodic) functions. On the other side, on the macrolevel properties of this composite can be varried continously along a direction normal to laminas. Hence, this object can be treated as made of a material with functionally graded properties, [5]. In a modelling of thermomechanical problems of these laminates are used various methods, which are well-known for periodic structures, which can be treated as macroscopically homogeneous. Unfortunately, governing equations of most of proposed averaged models neglect the effect of the microstructure size. Hence, in order to take into account this effect in model equations, the tolerance averaging method, [6], can be applied. This modelling method was proposed to describe different thermomechanical phenomena in periodic composites and structures, e.g. thermoelasticity of microperiodic media is analysed in [1]. The tolerance method was also adopted to analyse thermomechanical problems of functionally graded media with microstructure, cf. [6]. Some applications of this method to various cases can be found in a series of papers, e.g. nonstationary heat transfer in a functionally graded composite is shown in [3], examples of modelling thermoelasticity problems of functionally graded laminates are considered in papers [2, 4]. Using the tolerance modelling classical governing equations of microstructured media, with functional, highly-oscillating, tolerance-periodic and non-continuous coefficients, are replaced by model equations with slowly-varying coefficients. In the modelling procedure there 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 unknown fields are decomposed on macrofields and fluctuation parts, assumed in the form of a product of the known fluctuation shape functions and unknown fluctuation amplitudes. The new unknowns – macrofields and fluctuation amplitudes should be 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 three variants of the averaged models is shown: the tolerance model, the asymptotic-tolerance model, the asymptotic model. Governing equations of the first two models take into account the effect of the microstructure, but those of the third – neglect this effect.

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33 | The effect of probabilistic material properties in heat transfer in a periodic laminates

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This note deals with a problem of heat transfer in a laminate made of two materials, which are periodically distributed as micro-laminas along one direction (across the thickness). Material properties along this direction are piecewise constant, non-continuous and also uncertain. These material properties will be stand random variables with a priori given probabilistic distribution. Every periodic cell with constant length consists of two sub-laminas,

made of various material. The exact description of the heat transfer in the considered composite leads to equations with highly-oscillating periodic and non continuous coefficients. The exact solution can be reachable, but it is based on the large system of algebraic equations, and it could cause some numerical problems for sufficiently large number of sub-laminas. The modelling of heat transfer problems in microperiodic conductors, where differential equations are of non-continuous coefficients is considered in many papers. This disadvantage can be avoided applying the tolerance modelling method, cf. [8], to the formulation of a mathematical model of the periodic laminated conductor. This modelling technique allows to obtain governing model equations, which describe the effect of the microstructure on the overall response of the composite. Moreover, in some special cases this method leads to the same solution as the exact description. Applications of the tolerance method can be found in a series of papers, e.g. for heat transfer in periodic composites [2]; for some problems of heat conduction in biperiodic composites [7]; for nonlinear vibrations of slender periodic beams by [1]. This modelling method is also adopted to analyse various problems for functionally graded materials, e.g. for heat conduction in composites [3, 5], for thermoelasticity in laminates [6]. In this note, there is considered the effect of uncertainty of physical or geometrical properties on the overall behaviour of the composite. Similar problems in microheterogeneous materials can be found in a large scope of papers. The tolerance method was used to analyse dynamics of periodic composite rod with uncertain parameters under a moving random load [4]. Governing averaged equations of the tolerance, the asymptotic-tolerance and the asymptotic models for the heat transfer in periodic laminates are derived here. Then, these equations are applied to special problems of heat transfer in a composite with uncertain material properties. The main aim is to consider and analyse the uncertainty effect using statistical tools and Monte-Carlo method.

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35 | Some remarks on modelling of vibrations of periodic sandwich structures with inert core

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Composite structures have many applications in modern engineering. Their remarkable physical and mechanical properties are often the effect of much complicated geometry, which brings many difficulties in the modelling process. That is why, many scientists are interested in developing useful, comprehensive modelling procedures in order to improve the optimization process of special-use composites. In this presentation, the vibrations of three-layered sandwich structures are considered. Sandwich structures are certain specific composites made of three layers - outer layers, which are treated as beams, thin plates or shells, and inner layer made of an elastic material, so called core. In such composites, the outer layers are the main bearing parts of the whole structure (hence, they are usually made of materials characterised by high mechanical properties), while the light-weight core, apart from standing for acoustic and thermal isolation, provides the additional stiffness of the structure. As a result, we obtain a complex composite characterised by remarkable strength-to-weight ratio, which behaviour is well worth investigating. In our considerations, the outer layers of the described composite are being modelled as two Kirchhoff's type thin plates, while the elastic core of the structure is being replaced by a system of uniform, longitudinally vibrating bars (in literature such material is often referred to as the Murakami's type elastic material). Moreover, it is assumed, that every each of those layers can be characterised by periodically varying material properties and thicknesses. Hence, the coefficients in the initial governing equations can be periodic, non-continuous and highly oscillating functions. As a result, the modelling of vibrations of such complicated structure requires a special modelling approach. The whole modelling procedure is based on the tolerance averaging technique developed and described by Woźniak et al. (2000, 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, governing equations with constant coefficients are obtained. 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. Such feature resulted in many different applications of this approach in modelling of various thermomechanical problems, for example: an analysis of nonlinear vibrations of meso-periodic beams by Domagalski and Jędrysiak (2016) or the thermoelasticity of transversally graded laminates by Pazera and Jędrysiak (2015). In this presentation, the tolerance modelling of the aforementioned composite will be presented. Moreover, the application of the proposed model in free vibration analysis will be shown and the influence of the varying material properties on free vibrations frequencies will be discussed. Eventually, the obtained results will be verified with the use of well-known Ritz method.

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27 | Free vibrations of rectangular thin functionally graded plates with microstructure

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The problem under consideration is the microstructure effect on free vibrations of thin functionally graded plates with microstructure in planes parallel to the plate midplane. These plates have tolerance-periodic microstructure along only one direction, but along the normal direction they have constant properties. On the macrolevel these plates can be treated as made of a functionally graded material, [12], and called microstructured functionally graded plates. It is assumed that the microstructure size is the same order as the plate thickness [4]. Mechanical problems of these plates are determined by partial differential equations, with highly-oscillating, tolerance-periodic, non-continuous functional coefficients, which are not a good tool to analyse these problems. Thus, various averaged models are proposed leading from these equations to equations with smooth, slowly-varying coefficients. Functionally graded media are often described by the known modelling methods, applied to periodic composites [12]. Many averaged models of periodic plates are based on the asymptotic homogenization method [6] or on concepts of microlocal parameters [8]. Governing equations of these models neglect the microstructure effect on the plate behaviour. Theoretical and numerical results of various problems of functionally graded structures are shown in a large series of papers, e.g. free vibration frequencies of functionally graded plates are analysed using meshless methods [2]; dynamics of functionally graded shells is considered [13]. In order to take into account the microstructure effect in model equations the tolerance modelling method, [14], is used here. Various mechanical problems for periodic media are analysed using this method in a series of papers, e.g. for periodic plates – [10,3,7]; for periodic beams [9,1]. The tolerance method is also used to different problems of functionally graded structures, e.g. for longitudinally graded plates with dense system of ribs [11]; for transversally graded thin plates – with the plate thickness small comparing to the microstructure size [5], or with the microstructure size of an order of the plate thickness [4]. The main aim of this note is to apply three models – tolerance, asymptotic-tolerance and asymptotic, to calculate free vibration frequencies of microstructured rectangular plates with various boundary conditions, for different distribution functions of material properties.

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VARIABLE STIFFNESS COMPOSITE LAMINATES

267 | Dynamic stability of variable stiffness composite plates

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Composite structures may be submitted to combined in-plane periodic loadings which can promote their instability. To overcome this undesirable behavior, it is important to predict under which conditions it may occur and attempt to optimally adequate the structure to those operating conditions. Variable stiffness composites are known to provide a greater flexibility when compared to the unidirectional composite laminates, and may constitute an effective alternative to these latter concerning to the dynamic stability behavior. With the present work, it is intended to carry out a parametric study concerning the dynamic stability of variable stiffness composite plates, which may assume different aspect ratios and boundary conditions It is additionally considered the influence of other parameters that describe tow placement. To the purpose of this study, one considers the Rayleigh-Ritz method implemented through the use of orthogonal polynomials. The conclusions are supported by a set of illustrative numerical results.