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27th International Conference on Composite Structures

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Book of Abstracts

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Michele Bacciocchi

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Welcome Address

The abstracts collected in this book represent the proceedings of the conference 27th International Conference on Composite Structures, 3-6 September 2024. This book aims to help you to follow this Event in a timely and organized manner. Papers are selected by the organizing committee to be presented in phisical/virtual format. The event, held at the School of Engineering and Architecture, Ravenna Campus, University of Bologna (Italy), follows the success of the first 26 editions of ICCS. As the previous ones, this event represents an opportunity for the composites community to discuss the latest advances in the various topics in composite materials and structures.

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Contents

Abstracts

70th Birthday Prof. Sadowski (invited talks only)

Global stability of hybrid FGM-FML and laminated columns with a rectangular cross section

abst. 1125
DANTE
Thursday
September 5
10h40

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This study investigated the problem of the global stability of hybrid FGM-FML and laminated columns with different layups, considering many coupling effects of the stiffness submatrix. The lowest eigenvalues were determined by 4 methods. The first two are analytical beam methods (i.e. 1D modelling approaches) based on the use of the Euler-Bernoulli theory. The third is an analytical-numerical ANM perturbation method based on Koiter's theory (i.e. 2D plate modelling), and the fourth method is the FEM (3D shell approach) which is used for the verification of the previous calculations. Method 1 for 1D was based on the longitudinal flexural stiffness of the column and load reduction into the centre of stiffness of the cross section. Method 2 for 1D used the inverse stiffness matrix, or the longitudinal flexural flexibility. The 3 ANM method was based on Koiter's theory for thin-walled plates, or 2D. Compressed thin-walled structures usually fail due to loss of stability. This can encompass various types of phenomena, i.e. global buckling, interaction buckling or distortional buckling. Local buckling, which does not lead to failure but can significantly reduce the load carrying capacity of a thin-walled structure because of its interaction with another buckling mode, should also be considered in the column design. In slender structures, the global buckling mode caused failure. Because of practical aspects, particularly the specific mechanical characteristics of the thin-walled structures under study, it seems reasonable to ask whether their behaviour must be described using the general shell or plate theories. In practical applications, the finite element method can be used. For selected cases too, a simple beam model could be developed in accordance with the Euler-Bernoulli theory in order to accurately estimate the lowest eigenvalue load. The ease of calculations by the beam model makes it possible in engineering applications to effectively optimize compressed thin-walled structures exposed to loss of stability. Hybrid multi-ply prismatic columns and a rectangular cross section were investigated in the study. Each ply was made of different materials satisfying Hooke's law. The Euler-Bernoulli beam theory for conservative systems was adopted. The columns were slender, simply supported and subjected to uniform compression in the elastic range. The x-axis direction describing the length of the column did not necessarily have to coincide with the orientation of the reinforcing fibres in the glass/carbon fibre-reinforced plastics (GFRP, CFRP). From the classical laminated plate theory (CLPT) directly followed the constitutive relationships and expressions for the stiffness and flexibility matrices. Local buckling of the column was omitted. Very good agreement was obtained for the 50 cases of columns analysed using Methods 2-4, while for Method 1 the largest error was unacceptable as it exceeded 250%. Given the ease of obtaining solutions, it is recommended using Method 2 (1D model) because it yields results that are as accurate as those produced with the much more labour-consuming Methods 3-4 (2D and 3D models). The investigations of Andrzej Teter were financed within the Lublin University of Technology – contract no. M/KMS/FD-20/M-5/122/2022.

abst. 1171
DANTE
Thursday
September 5
09h40

Experimental study on the electrical conductivity and strain sensitivity of fibre-reinforced thermoplastic for structural health monitoring

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This experimental study investigates the mechanical and electrical properties of conductive thermoplastic polymers made with both carbon and glass short fibres on specimens obtained from panels produced with the injection moulding technique. The work aims to investigate the effect of local anisotropy due to the manufacturing process on the mechanical properties and conductive properties. Tensile tests showed that the specimens along three main directions of the panel, flow direction and transversal direction, led to significant differences in the mechanical properties due to the orientation of the particles that were shown throughout microscopy analysis. Contrarily, electrically conductive tests showed that there is a slight difference between the conductivities of the specimens cut in the flow and the transversal direction. The study also investigates the variation of the electrical surface and bulk resistance when the distance between the electrodes changes by finding an increase of up to 7 times for some specimens. The strain sensitivity is presented on graphs that report the stress-strain curves together with the variation of the resistance. The strain sensitivity tests showed the local anisotropy related to the short fibre distribution is more effective on the variation of the resistance although characteristic trends can be found in all the analysed curves. Computed tomography analysis showed the orientation of the fibres and was used to measure the particle contents.

abst. 1182
DANTE
Thursday
September 5
10h00

Experimental and Numerical Investigation on Low Velocity Impact of Carbon, Flax and Hybrid Composites

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Composite materials represent some of the most advanced engineering materials today. Natural fibre composites are an alternative to traditional synthetic composites and can offer a more sustainable, environmentally friendly way to reinforcement composite laminates. Moreover, natural fibre reinforcements have also been proved to have specific benefits in vibration damping and absorption. In this context, such study provides an experimental and numerical analysis of composite laminates subjected to Low Velocity Impact (LVI) tests at different energy levels, after an initial mechanical characterization of the materials. In particular, flax and carbon fiber fabrics embedded in a toughened epoxy resin are considered, both individually and combined together in two different hybrid configurations. Moreover, two stacking sequences are also investigated, with the layers placed at 0° and in a quasi-isotropic orientation, respectively. A comparison of the performance in terms of energy absorption capability under impact is conducted. Numerical models of tensile, compressive and LVI tests are then implemented and simulated using LS-DYNA solver. The obtained results show good agreement with experimental ones, highlighting the numerical potential to reproduce such impact phenomenon and emphasizing the potential of hybrids in structural applications.

Modal characteristics of functionally graded porous Timoshenko beams with variable cross-sections

abst. 1321
DANTE
Thursday
September 5
10h20

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The study focuses on the free vibration analysis of beams composed of functionally graded porous materials and characterized by a variable cross-section along their length. The equations of motion are derived using Hamilton's principle in conjunction with the Timoshenko beam theory. These governing equations, subject to distinct boundary conditions (clamped-clamped, clamped-free, clamped-pinned, and pinned-pinned), are solved semi-analytically using the differential transform method. To validate the proposed solution technique, computed natural frequencies are compared with existing literature results for tapered inhomogeneous beams and uniform homogeneous porous beams. Notably, new results are obtained for tapered inhomogeneous porous beams. The findings deepen our understanding of the modal characteristics of functionally graded porous beams, providing valuable guidance for engineering design and structural optimization in relevant applications.

Additive manufacturing

abst. 1009
Repository

Large deformable vibration of toroidal sandwich shells with auxetic honeycomb core and nanomaterial enriched coatings and under periodic/impulsive pressure

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Sandwich shells are categorized in a special class of composite thin-walled structures incorporating two strong and also moderately thin coating layers with a thick and lightweight core between them. The core may be made of various compositions such as metal foams, lattice or truss-like structures, corrugated plates and honeycomb cells. The main objective of this paper is to evaluate the dynamic behaviour of sandwich toroidal shells composed of a core with negative Poisson ratio (auxetic honeycomb material) and nanocomposite enriched coating layers under impulsive/periodic pressures considering the geometrical nonlinearity. The set of nonlinear equilibrium equations based on the first-order shear deformation theory are and the resultant nonlinear differential motion equations are approximately solved by the Galerkin method and 4th-order Runge–Kutta solution, respectively. By comparing the results of some criterion examples from the existing references with the present results, the present method is validated. Then, this method is utilized for evaluating the effects for various geometrical, mechanical and loading parameters on the geometric forced nonlinear vibration of the proposed shells. The achieved responses show that the amplitude of outward deformations is intensively increased when the proposed sandwich shells are subjected to rectangular periodic and impulsive loadings which shows the destructive effects of this type dynamic loading. However, the performed parametric studies shows that these destructive effects can be controlled by changing the geometrical properties of the honeycomb cells and the volume fractions of the nanocomposites in the coating layers. It is notable that in the previous studies the nonlinear dynamic response of toroidal shells subjected to various periodic and impulsive pressures was not investigated. However, in the present work, the mentioned dynamic responses were achieved and investigated without spending time-consuming computational. In fact, the novelty of this work is to develop such a robust and efficient tool.

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abst. 1061
TEODORICO
Wednesday
September 4
09h40

Scaling effects in the mechanical response of 3D printed continuous fiber reinforced corrugated sandwiches

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This paper present scaling effects in the compression response of all-composite corrugated core sandwiches using both experimental and analytical methods. Sandwich structures with four corrugation core configurations are designed and manufactured using an 3d printed continuous fibre reinforced composites. The compressive behaviour and failure mode of sandwiches based on corrugated circular cores have been shown to change with the scale size, whereas no significant scale effects are observed in the failure mode of the remaining corrugated structures. Sandwiches composed of rectangular and trapezoidal cores have been shown to absorb more energy and offer a higher compressive strength than similarly-sized samples based on circular and triangular cores. The test results and analytical calculations both indicate that a simple scaling law does not apply to the mechanical performance of a range of sandwich

structures based on different corrugated cores. Finally, a panel-core overlap method, employed in the fabrication of the sandwich structures, is studied by comparing the compressive performance of specimens manufactured with different overlap proportions. The evidence suggests that sandwiches with greater areas of the panel-core bonding significantly out-perform those with smaller overlaps.

Microstructure Prediction in Laser Additive Manufacturing Using Machine Learning and Cellular Automata Approaches

abst. 1079
TEODORICO
Wednesday
September 4
10h00

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Laser Additive Manufacturing (LAM) has become one of the significant repair methods for ships, pipelines, and other high-strength alloy components in unconventional environments. During the process of addition, the laser parameters directly impact the transient temperature of the base material to be repaired, and the transient temperature distribution plays a significant role in the morphology of the heat-affected zone, microstructure formation, residual stresses, and fatigue properties. To deeply investigate the influence of laser process parameters on the nucleation and growth process of crystalline microstructures during the additive process, it is necessary to couple the macroscopic temperature field based on the exact shape of the heat source distribution using the microscopic simulation method of cellular automata. A machine learning-based transient temperature distribution prediction provides a unique microstructure simulation approach. In this study, half of the specimen was modeled in Abaqus and combined with a dual ellipsoidal heat source to simulate the process of laser additive repair on high-strength alloy materials. The correlation between the input laser parameters and the output transient temperature field was realized by training a physical-embedded machine learning model. Furthermore, the output temperature field was coupled using a cellular automata approach to simulate the microstructure evolution during the solidification process after laser melting of the base material, considering the competitive mechanism of boundary columnar crystal growth and the isometric crystal transformation. Based on the multi-fidelity model theory, this study uses the temperature history of the additive process captured and extracted by infrared imaging in the experiments as high-fidelity data to optimize the low-fidelity data generated by the simulation. Combined with the coupling of cellular automata algorithms, a surrogate model with input laser parameters and repair position was built for fast and accurate prediction of the melt pool microstructure. The results show a close consistency by comparing and analyzing the microstructure morphology with the pictures taken from physical experiments. This method reduces the experimental cost and improves the research efficiency while significantly reducing the dependence on physical experiments for microscopic studies in additive manufacturing processes. In addition, a user-friendly recommendation mechanism is created to pre-demonstrate the possible effects of different laser parameters on microstructure morphology, thereby targeting the optimal laser parameters in advance. The experimental results validate the effectiveness of this method for transient temperature field computation and microstructure prediction for laser additive manufacturing and have the potential to be extended to other manufacturing processes.

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abst. 1091
TEODORICO
Wednesday
September 4
10h20

Modeling of local meso-scale interactions in metal-composite joints based on 3D anchors matrix

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The escalating demand for efficient multimaterial joining techniques, with high strength/weight ratio and simplified fabrication processes, necessitates the exploration of innovative methodologies to overcome the traditional assembling based on mechanical fasteners or adhesive bonding. With this purpose, innovative joining methods based on self-anchoring mechanisms utilizing engineered metal surfaces are explored to eliminate the necessity for supplementary fasteners. In this study, the joining of metal and composite materials, which involves embedding fibers into a matrix of additively manufactured (AM) anchors on the metal adherent, is explored. The aim of this work is to develop a reliable numerical model to describe the interactions and the failure modes among the structures composing the joint, including the metal anchors, the polymer matrix and the carbon fibers. Specifically, the focus of the numerical investigation lies on a single lap joint configuration comprised of AlSi10Mg metal and long fiber composite adherents. Boundary conditions were determined to replicate a simple tensile test scenario, whereby the single-lap joint is fixed at one end while a displacement is applied to the other end. In this joint category, the global strength is determined by the sum of the structural strengths between each single anchor and the interacting fibers, according to a modular problem. The force transfer among the adherents is a consequence of this micro-scale contact problem. Furthermore, the technological parameters of the building process play a crucial role on the joint design. Among these parameters, the percentage volume of fibers, the shape and size of the anchors, the curing setup, and material properties are the most influential. According to a macro-scale approach, the authors [1] conducted a comparative analysis of the maximum load attained with varying anchor geometries to discern the most promising configurations. Following the identification of the better performing anchor geometries, in this paper the effort is directed towards the construction of a suitable Representative Volumetric Element (RVE). This RVE must support the investigation of the structural response of metal anchors incorporating carbon fibers and epoxy matrix at a meso-scale level. To ensure statistical equivalence to real distribution, under fixed volume fiber ratio, a spatially random distribution of fibers is applied within the RVE in alignment with a reference CFRP material. The RVE, encompassing three phases of material, models interfaces between the metal-matrix and matrix-fiber and as zero-thickness elements assigned with cohesive properties. In order to extend the global joint description to a macro-scale, the homogenized model of the RVE has been developed to interpret the overall joint strength and compared to previous macro-scale results. Furthermore, a comprehensive three-dimensional numerical analysis is undertaken, with a specific emphasis on inspecting the elastic-plastic behavior and damage criteria of the epoxy matrix, AlSi10Mg metal, and carbon fibers, alongside interface responses. This information is the input data for the prediction of crack propagation and failure mode prediction in the meso-scale. In this last part of the work, the prediction of the candidate locations for failure initiation and following propagation is presented. In fact, the local stress peaks reveal the location of cracks formation, preferably at the interface between fibers-matrix or metal-matrix. In conclusion, through the application of advanced modeling techniques, this research provides some meaningful insights into the structural behavior of innovative multimaterial joints. The potential benefits encompass weight reduction and complexity mitigation in manufacturing processes.

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abst. 1096
TEODORICO
Wednesday
September 4
12h10

Experimental and numerical investigation of additively manufactured continuous carbon fiber-reinforced composite structures

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Several additive manufacturing methods are being advanced to realize the next-generation lightweight structures; among them is the continuous fiber-fused filament fabrication (CF4) process that realizes the deposition of continuous carbon fiber-reinforced polymer (CCFRP), allowing an effective and sustainable process to design lightweight composite structures, in contrast to the conventional techniques. This is achieved through CF4's ability to offer a significant degree of freedom by continuously altering the orientation and distribution of the CCFRP material during the printing process. The utility of the CF4 enables the adoption of computational design tools such as topology optimization (TO), which has become a design practice accommodating CF4's more advanced manufacturing capabilities. On the other hand, the CF4 is still limited for industrial use due to the wide range of design parameters available, such as the deposition of multi-material and intricate patterns (and topology) yielding advanced multiscale materials with complex microstructures, including anisotropic behavior. Therefore, recent studies recommend adopting such performance-driven design practices, i.e., Design for Additive Manufacturing (DfAM), which can fully support the designer in exploiting the CF4 for general industrial applications. This study aims to design a DfAM framework for a Markforged (Mark Two) 3D printer. The printer can employ several materials, such as Onyx (nylon combined with short carbon fibers) and nylon. In addition, continuous fiber reinforcement can be carried out using carbon, kevlar, glass fiber, etc. However, this work investigates only the parts fabricated using the Onyx matrix that are simultaneously reinforced through continuous carbon fibers. Therefore, to examine these CF4's parts, we proposed a DfAM framework that provides an integrated and modular tool that considers several design strategies. First, CF4's manufacturing constraints are considered when designing and optimizing components, such as the rectilinear fiber orientation and fixed thickness in each layer. Second, optimizing the spatial orientation of the CCFRP material is essential due to its directional stiffness. The optimization module allows the evaluation and definition of the fiber deposition path throughout the geometry section, i.e., layer-by-layer approach, to improve performance measures, such as stiffness or alignment of the fiber along the principal stress direction. The module exploits commercial software such as ANSYS and MATLAB. Lastly, experimental studies are performed to investigate the mechanical characterization of the printed components and test their response under operational load conditions. These experimental investigations provide sufficient know-how of the printed part by conducting statistical analysis of data collected from several tests. Consequently, these experimental studies can provide an effective way to develop a robust DfAM framework. However, integrating experimental studies with the proposed DfAM framework is postponed for future work.

Optimization of Layer Adhesion in Large Format Additive Manufacturing with Glass Fiber reinforced ABS

abst. 1122
TEODORICO
Wednesday
September 4
12h30

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Large Format Additive Manufacturing (LFAM) is becoming increasingly important in the molds manufacturing industry. However, due to residual stresses generated after the cool down of these molds, undesired deformations are observed, hence some dimensions will not meet the required tolerances. This warpage phenomenon is strongly related to adhesion quality between layers, mainly affected with the thermal gradient between layers during their deposition. Therefore, this paper proposes a complete parametric study of layer adhesion in LFAM with glass fiber (GF) reinforced acrylonitrile butadiene styrene (ABS). The printing parameters studied include deposition time per layer, extrusion factor, nozzle temperature and printing angle. Most of these factors affect directly to layer adhesion quality as they influence deposition temperature of new layers on older ones. An innovative approach is developed by introducing the use of infrared cameras to record thermal measurements during the LFAM process.

A standardized tensile testing procedure is performed to obtain the stress-strain curves for very case studied. Thermal and mechanical results, obtained for each case, are compared to understand which printing parameters influence more heavily layer adhesion. A combination of printing parameters are concluded to optimize layer adhesion in a controlled environment.

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abst. 1126
TEODORICO
Wednesday
September 4
12h50

The use of lattice structures as sandwich cores: approaches to modelling and design

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Sandwich panels are lightweight structures that are widely used in numerous industrial areas due to their outstanding specific mechanical properties. The demand for more cost-efficient and high-performance materials has raised interest in substituting metal face sheets by fiber-reinforced materials. Regarding the core structure, honeycomb is still one of the most used core materials in sandwich panels. Triggered by advances in additive manufacturing, 3D lattice structures can be fabricated and used as core materials. Introducing this kind of novel structures to industrial applications poses challenges in the design process, since the behavior of these additively manufactured lattice structures may deviate from that of conventional core materials. This study presents analytical models to analyze lattice core sandwich panels subjected to several load cases. The work focuses on strut-based lattice structures. The core behavior is taken into account at the macro- and mesoscale. Both structural stability and strength under several load cases are considered. To verify the presented model, detailed finite element calculations are performed. Based on the comparison with the numerical results, it can be demonstrated that the analytical model enables reasonably the prediction of the failure load in lattice core sandwich panels. To highlight the differing behavior of these structures, a comparison with conventional honeycomb cores is conducted.

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abst. 1235
TEODORICO
Wednesday
September 4
15h30

Hybrid manufacturing and mechanical performance of single and interpenetrating phase metallic metamaterials

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Hybrid processes that combine additive manufacturing with casting techniques have opened new potentials in the engineering of advanced single and composite, interpenetrating phase materials. The current contribution investigates the microstructural attributes and effective mechanical response of architected materials manufactured through hybrid casting processes, as well as the engineering of metal-metal architected composites. Different metamaterial topologies are engineered and their microstructural properties arising from the hybrid casting process are thoroughly assessed using Scanning Electron Microscopy and Computer Tomography methods. Moreover, quantitative insights into their effective static and impact response mechanical performance are provided and thoroughly compared with the ones recorded in PBF-based methods. Distinct elastic and post-elastic characteristics, along with failure modes are identified and comprehensively evaluated. The work provides benchmark results on the process-structure-property attributes of hybrid-manufactured AlSi10Mg-based metamaterials, revealing enhanced ductility and energy absorption characteristics. Moreover, the creation of AlSi10Mg-S316L architected composites is elaborated, based on gyroid steel additively manufactured inner reinforcement phases. Their constitutive response is assessed both experimentally and numerically, revealing a characteristic stress-strain performance that well exceeds the bounds of the individual phases, allowing for significant post-elastic stiffness and overall energy absorption attributes that surpass the ones reported

for most known metallic architected engineering materials. Finite element modeling is employed to analyze the role of the second interpenetrating phase on the inner stresses developed, while Ashby-type graphs classify their performance with respect to a wide range of advanced architected materials.

Impact and compression after impact (CAI) characteristics of continuous fibre reinforced 3D-printed composite laminates

abst. 1239
TEODORICO
Wednesday
September 4
15h50

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Additive Manufacturing (AM), commonly known as 3D printing, has emerged as a prominent alternative to traditional manufacturing methods. Originating from Charles W. Hull's patent in 1984, the technology experienced an increased interest post-2009, coinciding with patent expirations [1, 2]. Market forecasts predict an estimated value of $ 44.5 billion by 2026 [3]. The appeal of AM lies in its capabilities for automated production, simultaneous manufacturing of multiple parts, versatility with diverse materials, and the ability to closely replicate final product components. However, a challenge in AM is the dependence of mechanical properties on various parameters, including material properties, printing technology, process parameters, environmental conditions, and post-processing techniques. Thermoplastic polymers, predominantly employed in AM, encounter limitations in mechanical properties, hindering their suitability for load carrying components. To address this challenge, numerous researchers have focused on solutions such as reinforcing the thermoplastic matrix with short or chopped fibres and/or nanoparticles like graphene and carbon nanotubes (CNT). More recently, a significant advancement has been demonstrated in mechanical properties through the incorporation of continuous fibres [4] which is a promising approach to obtain high-performance 3D-printed components. Currently, there is a clear lack of studies exploring the impact and Compression After Impact (CAI) properties of 3D printed composite laminates, a critical aspect in design due to the substantial reduction in compression strength, reaching up to 50%. Therefore, this study specifically examines the impact and CAI characteristics of 3D printed composite laminates with continuous carbon fibre reinforcement and Onyx matrix (developed by Markforged). The investigation involves comprehensive X-ray computed tomography (X-ray CT) of unidirectional and cross-ply layups for a detailed damage analysis and characterisation. References 1. Blanco I. The use of composite materials in 3d printing. Journal of Composites Science. 2020; 4(2). Available at: DOI:10.3390/jcs4020042 2. Attaran M. The rise of 3-D printing: The advantages of additive manufacturing over traditional manufacturing. Business Horizons. 'Kelley School of Business, Indiana University'; 2017; 60(5): 677–688. Available at: DOI:10.1016/j.bushor.2017.05.011 3. Hubs. 3D Printing Trend Report 2022. HUBS: A Protolabs Company. 2022; 1–23. 4. Kabir SMF., Mathur K., Seyam AFM. A critical review on 3D printed continuous fiber-reinforced composites: History, mechanism, materials and properties. Composite Structures. Elsevier; 2020; 232(June 2019): 111476. Available at: DOI:10.1016/j.compstruct.2019.111476

Additive Manufacturing of Bolted CFRP Composite Joints with Tailored Fibre Steering

abst. 1251
TEODORICO
Wednesday
September 4
16h10

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The primary focus of this study is the application of additive manufacturing techniques to develop CFRP composites with tailored continuous carbon fibre orientations. This innovative approach investigates

how these orientations influence the mechanical properties and behaviour of bolted joints. Utilising advanced numerical techniques, a detailed multi-scale finite element model incorporating the LaRC05 failure criteria was meticulously constructed. This model was validated against a robust experimental framework that included load-displacement measurements and micro-computed tomography (micro-CT) scans. Experimentally, the study involved conducting double-lap bearing tests on four different composite cases, each distinguished by unique fibre orientations around the bolt holes. To enhance the understanding of the underlying damage mechanisms, digital image correlation (DIC) and micro-CT scanning techniques were employed. These techniques provided a detailed view of the damage identification within the composites, thereby facilitating a deeper understanding of the structural behaviour. The findings from the experiments reveal that steering fibres around bolt holes substantially mitigates stress concentrations and enhances load transfer capabilities, crucially improving bearing performance. Notably, changing the fibre orientation by 180 degrees effectively distributes strain more uniformly and reduces the maximum absolute strain value by about half. This strategic manipulation of fibre paths significantly enhances initial damage resistance and delays crack propagation, critical factors for the longevity and reliability of jointed structures. The numerical simulations point out the crucial role of filament continuity in preventing premature failure and optimizing the load distribution across the joint. This aspect of the study highlights how different orientations of the steered fibres influence shear-induced damage propagation and overall composite performance. The multi-scale model provides crucial insights into potential enhancements in composite performance through strategic fibre steering, offering a powerful tool for designing advanced composites. The study's findings, supported by the numerical model, lay down a comprehensive framework for designing advanced composites using additive manufacturing techniques. This approach not only addresses existing research gaps in modelling composite joints but also introduces new possibilities for industrial applications, especially in sectors such as aerospace, where customised material properties can lead to substantial enhancements in design and functionality. In conclusion, by integrating additive manufacturing with advanced numerical modelling and optimization methods, this research presents a transformative approach to the development of composite materials. The ability to control the orientation and continuity of carbon fibres reveals significant opportunities to enhance the mechanical properties and performance of CFRP composites. This innovative methodology promises to revolutionize applications in high-performance engineering fields, leading to the creation of more efficient and robust designs tailored to specific performance needs. The convergence of experimental insights and numerical tools in this study not only fosters a deeper understanding of composite behaviour but also catalyses the development of next-generation materials that are both resilient and adaptable to diverse operational demands.

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abst. 1273
TEODORICO
Wednesday
September 4
16h30

The interface role in Al2O3/AlSi12 composite

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The composite is created via an interpenetration procedure by introducing a liquid aluminum alloy (AlSi12) into an alumina skeleton under pressure. Both materials, representing two phases of the composite, create interface layers between them. The skeleton is modeled as elastic brittle, and the matrix is elastic-plastic. The presentation evaluates the shape and fracture of the sample during impact. CT scanning determines the composite's microstructure, obtaining information about the sample's internal structure. [1] shows the importance of interface modeling. [2] evaluates the interface properties at the microscale. The results enhance the role of the interface. Acknowledgement The results presented in this paper were obtained within the framework of research grant No. 2019/33/B/ST8/01263 financed by the National Science Centre, Poland. The numerical analyses were done and in CYFRONET in Kraków, Poland and on LUMI, Finland. References [1] Postek, E. and Sadowski, T. Qualitative comparison of dynamic compressive pressure load and impact of WC/Co composite. Int. J. Refract. Hard. Met. (2018) 77: 68-81. [2] Tahani, M., Postek, E., Sadowski, T. Investigating the Influence of Diffusion on the Cohesive Zone Model of the SiC/Al Composite Interface, Molecules, (2023) 28: 6757-1-6757-19.

Additive manufacturing method for manufacturing composite structures with embedded fibre Bragg grating sensors

abst. 1285
TEODORICO
Wednesday
September 4
13h10

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Fibre reinforced polymers (FRP) have recently very popular in many branches of industry. Their wide applicability is linked with a requirement for structural health monitoring (SHM) systems. Such systems can determine the real loading conditions as well as the operational time of a structure. One of the sensor types is a fibre Bragg grating (FBG) sensor that can be used for strain measurements. Due to the geometrical and mechanical features, FBG sensors can be embedded into FRP elements during their manufacturing processes. Nowadays, an increasing popularity of additive manufacturing (AM) techniques is observed because they allow the fabrication of complex elements with a limited amount of waste. The paper aims to present the AM method for manufacturing FRP elements with embedded FBG sensors. The utility of the sensors for SHM will be analysed on thermal loading. Additionally, the influence of embedded optical fibres on the mechanical strength of the samples will be analysed based on the tensile test. The achieved results will be compared with the numerical ones (finite element method) or the experimental ones performed on composites with similar structures but manufactured using standard fabrication techniques. It is worth mentioning that AM composite structures differ from similar composites manufactured using standard methods. It will be analysed using NDT techniques, like THz spectroscopy.

Maximizing Sustainability: Enhancing GF-ABS Mold Recycling for Large Format Additive Manufacturing

abst. 1294
TEODORICO
Wednesday
September 4
10h40

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Large Format Additive Manufacturing (LFAM) has stablished as a promising process to produce molds for large scale components across many industries. However, considering the relative early-stage development of these manufacturing techniques, the life cycle of these molds is very short. Basically, they go to waste once the number of desired components had been produced using such mold. Previous studies demonstrated the feasibility of recycling machining waste or virgin material by itself. Therefore, to improve their life cycle, this study delves into the characterization of recycling end life molds of glass fiber reinforced acrylonitrile butadiene styrene (GF-ABS) produced by LFAM. The recycling process consists of milling and processing the shredded material into feedstock, disregarding the recurrent repalletization to minimize the process cost. Consequently, a complete parametric study is conducted to analyse the mechanical properties of recycled GF-ABS. The printing parameters studied are deposition time per layer, nozzle temperature and extrusion factor. Standardized tensile and flexure tests are performed, alongside thermal monitoring during layer deposition, resulting in stress-strain curves and heat transfer cooling rate tables. The results obtained are compared to those of pristine molds regarding tensile

strength, elastic modulus, surface roughness, complex viscosity, fiber length and fiber orientation. As a result, this paper proves the viability of this technique to serve as a feasible feedstock for large format additive manufacturing.

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abst. 1372
TEODORICO
Wednesday
September 4
16h50

Mesoscale analysis and RVE random generation of shot-earth mixtures

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Shot-earth mixtures are concrete-like composites where part of the aggregate is replaced by the soil excavated during the building process. This allows to enhance the sustainability of the constructions since the problem of the disposal of the excavated soil is partly reduced. Nevertheless, the material obtained has a lower strength than the ordinary concrete. Moreover, since it is a new material there is the need to fully assess the behaviour of the material both in the elastic and in post-elastic phase. To better understand the response of the material, an experimental campaign was conducted, aimed to evaluate the response under cyclic load in elastic phase and monotonic load until failure. In the present work we present results concerning the study in the elastic range. Two set of specimens where used, with dimensions 50 mm x 50 mm x 50 mm and 100 mm x 100 mm x 100 mm in order to assess possible size effects. The testing machine was a Zwick Roell AllroundLine Z150, with a maximum test load of 150 kN with an adjustable drive speed. Each sample was instrumented with two linear strain-gages on opposite lateral faces and two bi-axial strain- gages each of opposite lateral faces. The readings from strain-gages were acquired by means of an IMC Cronos-PL with a sampling rate of 1000 Hz, while the force applied was measured directly from the testing machine with a sample rate of 100 Hz. In particular, the internal composition of the tested samples was identified by means of Computed Tomography (CT) analysis, using a Wenzel exaCT-U tomograph with 300 kV of X-Ray voltage and 350W of X-Ray power. We recall that CT is based on the different reaction of the materials due to their physical density, and the resulting acquisition is post-processed to identify all the different regions that compose the heterogeneous mesoscale structure (matrix, voids, inclusions). CT is therefore often employed with concrete-like materials to accurately reproduce the heterogeneous internal structure of the samples. Anyway, the shapes reconstructed by means of CT are usually very complex and do not allow a parametric representation which can be easily used to generate synthetic samples for numerical simulations accounting for the stochastic nature of the distribution of the aggregates. To this aim, a procedure to reconstruct numerically shot-earth samples based on the CT acquisitions has been developed. This allowed us to build digital twin models of the specimens. The geometrical characteristics (size, volume, inertia tensor) of the aggregate inclusions detected experimentally have been analysed by means of statistical methods. Then, we developed a procedure to generate samples having two phases, matrix and inclusions, where the inclusions are ellipsoids whose shape is consistent with the statistical analysis previously developed. The generated sample can be considered as Representative Volume Elements (RVE) of the shot-earth material. The samples are then modelled using finite elements in order to apply an homogenization procedure using essential and natural boundary conditions to estimate the stiffness tensor. The elastic characteristic estimated allows us to perform a Monte Carlo analysis able to show the correlations between geometrical and elastic characteristics. Moreover, the effect of the increasing size of the samples is accounted for. This gives us the possibility to characterize and optimize the shot-earth material for possible use in particular applications as replacement of ordinary concrete allowing to achieve a better sustainability of the constructions.

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abst. 1376
Repository

Mechanical Characterization of 3D Printed PLA and Carbon Fiber Reinforced Sandwich Structures Fabricated Using Fused Filament Fabrication

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Additive manufacturing plays a crucial role in industrial production. With this technology, it is possible to produce innovative structures and use a wide range of materials, representing a significant turning point in design and production processes. Commonly known as 3D printing, this technology enables the creation of complex, customized components by depositing material layer by layer, eliminating many limitations associated with traditional manufacturing methods. In this context, this study focuses on the mechanical characterization of advanced sandwich structures, emphasizing two crucial factors. The first factor concerns the use of composite materials. We achieve this by using filaments consisting of PLA polymer (polylactic acid) reinforced with short carbon fibers to produce the facings of the sandwich structure. The second key factor is the core, which consists of innovative cellular structures produced by fused filament fabrication additive manufacturing. These core cell structures are inspired by triply periodic minimal surfaces. Through three-point bending tests, we thoroughly investigate the mechanical behavior of these sandwich structures and compare them to PLA-only sandwich structures. The results show that using carbon fibers to reinforce PLA sandwich structures decreases the flexural stiffness and strength compared to the PLA-only counterparts. Optical microscopy reveals the presence of imperfections and defects during the deposition of the polymer and carbon fibers. Failure tends to start at the connection points between the lower face of the sandwich structure and the core, leading to debonding of these two parts and subsequent failure of the lower face due to excessive tensile loads during flexural loading. In contrast, failure in the PLA-only sandwich structures tends to start at the lower face and then propagate to the core without debonding, due to better connection. In conclusion, this work provides a solid basis for future developments in the design optimization and practical application of 3D-printed TPMS core sandwiches and opens new perspectives in advanced material engineering. Additionally, the use of continuously printed fibers may offer a better solution than short fibers, and this will be investigated as a potential improvement.

Environmental cryogenic cyclic aging of additively manufactured carbon-fiber reinforced polycarbonate

abst. 1415
TEODORICO
Wednesday
September 4
15h10

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A novel experimental approach to study the long-term behavior of additively manufactured composite material in cryogenic environment is addressed in this work. Aiming to describe the cryogenic cyclic aging effects, viscoelastic and mechanical properties were assessed and comparisons with different aging protocols have been conducted. Furthermore, to characterize the influence of the porosity content, the studied samples were printed with two different infill percentages, namely 25% and 100%, via Fused Filament Fabrication (FFF). Subsequently, the samples were cryogenically conditioned using different protocols of cyclic immersion in liquid nitrogen (LN2), at a temperature of -196 °C, and then exposed to room temperature (RT) for the same amount of time. Thus, samples were aged at time intervals of 20 min for 100, 200 and 300 cycles, as well as 72 h and 240 h, for 5, 10 and 15 cycles, respectively. The characterization of the materials after aging was performed visco-elastically and mechanically by means of Dynamic Mechanical Thermal Analysis (DMTA) and tensile testing, while Fourier Transform Infrared Spectroscopy (FTIR) was employed to assess physico-chemical changes due to aging. Lastly, the internal structure of the samples was evaluated employing X-ray Computed Tomography scanning to study its evolution, due to cyclic thermal aging, and any possible changes in the porosity content.

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abst. 1012
GIUSTINIANO
Friday
September 6
11h50

Mechanical Behaviour of 3D Printed Carbon Fibre Reinforced Composite Metastructure with Various Filling Rates

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This paper evaluated the influence of filling rate and printing direction on the mechanical properties of composite metastructure via experimental and numerical approaches. A representative volume element (RVE) and finite element method were adopted to estimate the tensile and flexural properties and verify the applicability of these methods in the 3D printing of composite metastructure. Results showed that apparent tensile and flexural properties drop with decreasing filling rates. The tensile and flexural strength reached 70.7 MPa and 131.1 MPa for solid specimens. The bending test for samples with different printing directions showed that the printing direction of the core has no noticeable effect on flexural strength, but the +45°/-45° sample exhibited the highest modulus. The numerical estimation showed similar tread compared to experimental results for both tensile and flexural properties. Such an attempt provides the feasibility of designing a composite metastructure with an optimum weight-strength relationship.

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abst. 1015
GIUSTINIANO
Friday
September 6
11h30

Arbitrarily shaped laminated thin plates in nonlocal elasticity: a finite element solution based on Hermite isoparametric mapping

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The main aim of the research is the development of a finite element approach able to deal with laminated composite thin plates with by arbitrarily shaped domains. The theoretical model is based on Kirchhoff assumption for thin plates. Nonlocal features are added according to the strain gradient theory for laminates. In this framework, a unique parameter is introduced to include the size-effect amplifying the stress terms defined by the divergence of the gradient of the strains. The peculiar theoretical model requires the Hermite interpolating functions to approximate the membrane and bending degrees of freedom. Consequently, conforming and nonconforming finite elements are developed. They are implemented in a proper code to guarantee C1 and C2 continuity requirements, respectively for membrane and bending states. This feature has always limited the applicability of such an innovative scheme in arbitrarily shaped domains. The authors have introduced a peculiar isoparametric mapping to overcome these difficulties. Numerical applications are carried out in this context.

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abst. 1034
GIUSTINIANO
Friday
September 6
12h10

Vibration, Buckling and Bending Analysis of Composite Structures via Higher Order Haar Wavelet Method

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This study covers development and implementation of the higher order Haar wavelet method (HOHWM) for Vibration, Buckling and Bending analysis of composite structures. The Haar wavelet method (HWM) approach introduced by Chen and Hsiao is implemented as reference solution. The attention is paid

simultaneously on accuracy and simplicity of implementation. The HOHWM provides principal increase of accuracy without significant increase in implementation complexity in comparison with reference solution. The obtained results are compared also with weak formulation based mainstream numerical methods (finite difference and generalized differential quadrature methods). The time complexity of the HOHWM studied and compared with that of HWM. It has been observed that time complexity of the HOHWM depend on boundary conditions applied and grading of the material/structure. However, in the case of all considered case studies performed the time complexity of the HOHWM remain lower than that of the HWM.

AN EXACT 3D ELECTRO-ELASTIC SHELL MODEL FOR STATIC AND FREE VIBRATION ANALYSIS OF SMART STRUCTURES

abst. 1039
GIUSTINIANO
Friday
September 6
12h50

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The future design of aircraft and spacecraft is directly connected to the improvement in knowledge about multilayered and single-layered piezoelectric smart structures. In multilayered piezoelectric smart structures there is the possibility of embedding several layers made of isotropic, orthotropic and composite materials in order to have some specific peculiarities and the structural capability to withstand operative loads. The electro-elastic coupling of the piezoelectric materials has multiple uses, such as the capability to adapt their shape as an electric potential act onto the structure (the so-called "actuator" behavior), the capability to provide a specific electric potential in output in the case of deformations acting on the structure (the so-called "sensor" behavior) or the capability of detecting and suppressing vibrations in wing structures. All these capabilities are fundamental in the health monitoring of aerospace structures. A wide-range knowledge about the behaviors of these multilayered smart structures in terms of geometry and material stacking sequence is mandatory for the future design of aircraft structures that must be able to manage the action of multi-field loads during a classical in-flight operative condition. The present work is related to a coupled 3D exact electro-elastic shell model for the static and free vibration analysis of smart structures. The proposed formulation is based on a set of four equations that must be simultaneously solved in closed form. The set of equations is composed of the 3D equilibrium equations for the elastic field and the 3D divergence equation of electric displacement for the electric field. This set of second order partial differential equations is written considering the mixed curvilinear orthogonal reference system valid for spherical shells. Proper considerations regarding the radii of curvature along the two in-plane directions allow to specialize this formulation for plates, cylinders and cylindrical shells. The solution method involves the Navier harmonic forms in the in-plane directions and the exponential matrix method in the thickness direction. The simply supported constraints are analyzed to obtain a closed form solution. The layer-wise approach is granted thanks to the correct imposition of interlaminar continuity conditions in terms of displacements, transverse shear/normal stresses, electric potential and transverse normal electric displacement. This approach is useful to obtain a proper evaluation of the three-dimensional behavior of piezoelectric multilayered structures having in-plane and out-of-plane elastic and electric anisotropy. Some tabular and graphical results will be presented for the static and free vibration analyses of simply supported spherical and cylindrical shells, plates and cylinders to understand the global behavior of multilayered smart structures. Static analyses are performed in terms of displacements, stresses, strains, electric potentials and electric displacements along the thickness direction when an electric potential or a mechanical load is applied at the outer surfaces of the structure. Free vibration analyses are computed in terms of circular frequency values and vibration modes in both open and closed circuit configurations. The proposed results can be useful for those scientists interested in the development of two-dimensional or three-dimensional numerical/analytical formulations for static and free vibration analyses of single-layered and multilayered piezoelectric smart structures.

Dynamic modelling of rotating axially functionally graded pre-twisted blades with chord length variations

abst. 1069
GIUSTINIANO
Friday
September 6
09h00

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In this study, dynamics of rotating blades is investigated considering geometric, material, and rotational complexities. A comprehensive modeling approach, characterizing blade geometry in terms of pre-twist and pre-set angles, as well as chord length curved variations is employed based on the theory of surfaces. Depending on the chord length variation, the width of the blade can narrow towards one end. Axially functionally graded material is considered for the blade operating under intense centrifugal stresses. The rotational stiffening effects are incorporated into the model via direct integration of centrifugal forces (DICF). The integral boundary value problem governing the dynamics of the rotating blade, is derived following extended Hamilton's method. A framework based on Spectral Chebyshev technique is developed that enables accurately and efficiently predicting the dynamics of the problem. This framework can handle geometry and material variations in the spatial domain and provides a compact standard form formulation for complexities due to rotational effects. To validate the precision of the presented solution method, the present results are compared to those obtained through finite element method. The results are in excellent agreement, yet the presented method can solve the integral boundary value problem in a fraction of time compared to the FEM.

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abst. 1146
GIUSTINIANO
Friday
September 6
09h40

Damage and repair of honeycomb absorbing structures

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Absorbing honeycomb structure is a typical composite material structure that integrates structure and function. Widely used in high-tech fields such as aerospace. However, during service, it is easy to cause delamination, impact and other damages under external loads, which directly affect its mechanical strength and absorption characteristics. In addition, the repair of absorbing honeycomb structures is currently an important research direction, and the matching of mechanical and electromagnetic properties of the repaired absorbing honeycomb structures is the main difficulty. This article mainly studies the damage repair model and performance evaluation of absorbing honeycomb structures. Firstly, a predictive model for the absorption performance of absorbing honeycomb structures under electromagnetic force coupling was established; Secondly, the influence of delamination, indentation and other damages on the mechanical and electromagnetic properties of absorbing honeycomb structures was revealed; Finally, a design model and evaluation method for the repair of absorbing honeycomb structures were proposed. These results will provide a scientific theoretical basis for damage assessment and repair design of absorbing honeycomb structures. Keywords: Absorbing honeycomb structure; Damage; Repair; Mechanical properties; Electromagnetic performance

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abst. 1160
GIUSTINIANO
Friday
September 6
12h30

An efficient augmented finite element method for arbitrary cracking and crack interaction in solids with mix-mode cohesive element

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The augmented finite element(A-FEM) is currently a significant approach for solving arbitrary and multiple discontinuity problems within two-dimensional solid elements. However, accurately characterizing the mechanism within the internal discontinuous regions poses a major challenge in current research. This paper presents an augmentation method that adopts mix-mode cohesive element to reflect the coupled damage evolution between internal nodes. It thus enables a unified and precisely treatment of damage evolution for any discontinuities such as single crack or multiple interactive cracks, all within a single element that employs standard external nodal DoFs only. An elemental condensation procedure

to solve the internal nodal DoFs as functions of the external nodal DoFs has been developed for reversible, piece-wise linear cohesive laws. The Newton-Raphson method is utilized to solve the nonlinear equilibrium iterations at elemental level. The new A-FEM with high-fidelity simulation capabilities to solve solid problems with interactive cracks initiation and propagation have been demonstrated through several classical numerical examples. The numerical examples are compared with ABAQUS and experimental results, and it is shown that the proposed new A-FEM is numerically efficient accurate, and robust.

Meshless analysis of fracture propagation in adhesively bonded double-lap joints

abst. 1161
GIUSTINIANO
Friday
September 6
13h10

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The application of meshless techniques to numerically solve diversified science and engineering problems is increasing in both academic and industrial sectors. In complex problems such as large deformation, fracture analysis and crack propagation, meshless methods provide attractive assets, distinguishing these techniques from typical finite element methods (FEM). The radial point interpolation method (RPIM) is hereby used to study fracture propagation in adhesively bonded joints. The lap joint domain is discretized with an unstructured nodal set, being nodal connectivity established by the overlap of flexible influence domains. RPI shape functions are constructed based on aforesaid influence domains, enforcing nodal connectivity and consequent banded stiffness matrix. Crack propagation is then predicted using a local remeshing algorithm of the background integration cells and field nodes. The numerical results are compared with experimental tests performed on double-lap joints and demonstrate the suitability of the developed meshless framework to analyze fracture in adhesively bonded joints.

Injection Molding Glass Fiber-Reinforced Polypropylene: What is the Effect of Fiber Orientation on Mechanical Properties

abst. 1176
Repository

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Injection molding is a widely used manufacturing process for producing parts made of various materials, including plastics, metals, glass, and rubber. However, achieving optimal part quality and strength in plastic injection molding relies heavily on controlling variables such as fiber orientation, air gap, warpage, and shrinkage, which can directly impact the mechanical properties of the final product. These thermoplastic composites find applications across various industries including automotive, aerospace, civil engineering, and electronics due to their versatile properties. However, the mechanical behavior of these composites is complex and influenced by factors such as resin content, fiber distribution, and processing techniques. Accurately predicting the mechanical behavior of short fiber reinforced thermoplastic composites is crucial for component design. Finite element analysis (FEA) has become instrumental in simulating mechanical part behavior, particularly in complex loading scenarios where analytical evaluation is limited. However, modeling the anisotropic structure and mechanical properties of these composites requires sophisticated material models. This paper presents a study focused on integrating the effects of fiber orientation into finite element analysis of 30% glass fiber reinforced

polypropylene (PP) material. Mold flow simulation in MOLDEX3D was conducted to capture fiber orientation, and this data was transferred to the DIGIMAT program for further analysis. Tensile analysis of open hole tensile specimens was performed using ABAQUS, both with and without considering fiber orientation effects. The results were compared to assess the impact of fiber orientation on mechanical analysis outcomes, including maximum stress, displacement, and regional stress variation. This research contributes to enhancing the accuracy of predictive models for short fiber reinforced thermoplastic composites, aiding in the optimization of part design and manufacturing processes.

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abst. 1186
GIUSTINIANO
Friday
September 6
09h20

A Molecular dynamics study on the mechanical properties of Nylon-6/SiO2 nanocomposites

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Nylon-6, recognized for its superior comprehensive performance as a thermoplastic engineering plastic, finds widespread application in aerospace, electronics, and other domains. However, with escalating demands for material properties, the strength and toughness of pure Nylon-6 no longer meet current requirements. Nano-SiO2, distinguished by its exceptionally high specific surface area and interfacial activity, forms a strong interfacial bond with Nylon-6, significantly enhancing its mechanical properties. While the majority of research on Nylon-6/SiO2 nanocomposites has been experimental, the complexity and abundance of interfaces within these composites, especially those too small for traditional macroscopic analytical methods, necessitate deeper investigation. This study employs molecular dynamics simulations to explore the reinforcement and toughening mechanisms of nanoparticles within Nylon-6/SiO2 nanocomposites at the molecular atomic level. In the fabrication of the composites, the particle size and volume fraction of nano-SiO2 emerge as critical parameters for creating high-performance nanocomposites. Molecular dynamics simulations have yielded conclusions consistent with experimental outcomes, indicating that Young's modulus of the composite material decreases with an increase in nano-SiO2 particle size and increases with an increase in its volume fraction. To further optimize composite material performance, models of nanocomposites with various modified grafting were constructed. Calculations revealed that the enhancement effect of toluene diisocyanate (TDI) covalent grafting was the most significant. Additionally, in addressing the abundance of interfaces within the composite materials, an interface model between Nylon-6 and SiO2 was established. The interaction energy, interaction configurations, and radial distribution function between nanoparticles and the reinforcing phase were calculated, linking the macroscopic mechanical properties of the composite materials with microscopic interfacial actions. This in-depth exploration of the mechanical properties for nanocomposite materials and their microscopic mechanisms offers new perspectives for the research, development, and preparation of materials, promoting the advancement and application of nanocomposite materials.

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abst. 1192
Repository

Neural Network Modeling for Predicting the Elastoplastic Behavior of Short Fiber Reinforced Polymers

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One popular strategy for describing the mechanical characteristics of fibrous materials at the macroscopic level is to model material behavior at the microscale using micromechanical techniques. Typically, this method uses a Representational Volume Element (RVE) to describe the microstructure and uses finite element (FE) simulations to apply mechanical loads. Homogenization techniques are then used to produce macroscopic behavior. Nevertheless, carrying out these micromechanical simulations can be computationally expensive, particularly for 3D models that discretely reflect material microstructures. This research presents the implementation of an artificial neural network to predict the elastoplastic characteristics of polymers reinforced with short fibers. The Sobol sampling method is used to efficiently generate the number of RVE samples for neural network training. The database comprises the results of finite element simulations for three-dimensional RVEs conducted on each sample. Once the trained neural network model is trained, it can be used to study the effect of 11 distinct RVE parameters, including fiber volume ratio, fiber aspect ratio, matrix phase characteristics, and fiber orientation on the behavior of composite. It has also been demonstrated neural network model after proper training can efficiently predict the elastoplastic characteristics of polymers reinforced with short fibers. The average prediction accuracy compares favorably to the outcomes of the traditional Mori-Tanaka and Mean field homogenization methods.

FE modeling of FRCM reinforced curved pillars under shear tests: Employing classical cohesive contact and user-defined material in ABAQUS

abst. 1193
GIUSTINIANO
Friday
September 6
10h20

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External application of Fiber Reinforced Cementitious Matrix (FRCM) composites to building surfaces is increasingly adopted in building reinforcement, particularly for masonry structures, owing to better material compatibility and reversibility. In line with this trend, reinforcing structural members with curvature, such as arches and vaults, has become common and necessary. However, the issue of curved cases remains relatively understudied. Shear tests conducted on FRCM-strengthened curved masonry pillars reveal that substrate curvature significantly influences bond behavior, leading to discrepancies in failure mode, strength, and ductility of the system. However, the experimental data remain scarce, with high variability, and the mechanism of debonding requires further investigation. Although several simplified 2D numerical models have been developed to simulate the system under shear tests, they typically focus on interface nonlinearity while neglecting the deformability of certain components, such as the substrate and upper mortar layer. In this context, a sophisticated 3D Finite Element (FE) model would be beneficial for considering individual component failures and complex interactions within the system. However, computational costs could be substantial, and the high nonlinearity of the system may pose convergence challenges. In this study, the authors develop sophisticated 3D FE models to replicate the shear behavior of FRCM-strengthened pillars, with particular emphasis on curved cases. The masonry pillar and mortar matrix are modeled using the Concrete Damage Plasticity (CDP) model, while the PBO fiber sheet is assumed to behave elastically, as it seldom reaches its tensile limit in tests. Interactions among components are simulated using 'cohesive contact' implemented in ABAQUS. Model parameters are calibrated based on an experimental campaign carried out at the University of Florence, and the experimental results are utilized to validate the numerical model. Moreover, to alleviate the computational burden in modeling such complex problems, a user-defined material is employed for the FRCM composite, based on tensile behavior provided by a previously developed analytical model by the authors. This FRCM composite package is then bonded to the masonry pillar via cohesive contact. While this approach allows for faster calculation, it sacrifices some detail within the composite. The study compares results, including global curves and computational efforts, between the two modeling approaches, and offers suggestions for their respective utilization scenarios.

Experimental characterization and numerical modeling of viscoelastic behaviour of woven prepregs during compression molding

abst. 1199
GIUSTINIANO
Friday
September 6
14h50

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Compression molding is employed to rapidly produce composite materials with complex shapes and superior performance. The process involves intricate phenomena such as large deformations, anisotropy, and multi-field coupling. Two-dimensional woven composites exhibit improved formability and isotropic properties. Continuous simulation of woven fabric reinforced thermosetting composite molding is crucial for exploring mechanical properties and optimizing designs. Current research typically considers the deformation of woven prepregs, including tension, shear, bending, and interlaminar friction, while often overlooking the viscous behavior introduced by thermosetting resins. This study investigates the mechanical characteristics of thermosetting woven prepregs under viscoelastic effects through mechanical experiments, theoretical analysis, and finite element simulations. Leveraging principles from the continuum mechanics of fiber-reinforced composite materials and the generalized Maxwell viscoelasticity theory, a constitutive model for the shear deformation of woven prepregs is proposed. Specifically, a generalized Maxwell viscoelastic constitutive model established using Prony series is employed to describe the shear viscoelastic behavior of woven prepregs. The constitutive model has been implemented in an ABAQUS user subroutine. Stress relaxation experiments of woven prepregs at different temperatures and rates are conducted, and regression analysis of the curves yielded relaxation time and modulus, which serve as inputs for finite element simulations. The accuracy of the model is validated through off-axis tensile experiments. Finally, through a case study involving experimental and simulated hemispherical molds, the quality of molding was evaluated based on shear deformation and stress-strain distribution. The study also investigated the influence of process parameters such as temperature, rate, and blank holder force on compression molding.

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abst. 1202
Repository

Influence of interfacial debonding on mechanical properties of finitely strained microstructured materials

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The study of the behavior of nonlinear composite materials is crucial in order to maximize their capabilities in various engineering fields (civil, aerospace, etc.), especially as the scientific interest of the research community is increasing in the creation of new materials with multifunctional properties obtained by appropriately tailoring their microstructure [1-2]. Such materials, also known as metamaterials, could be subjected to multiple microscopic failure mechanisms, such as fracture, decohesion, instability, and compression-induced contact, leading to a massive impact on their static and dynamic properties. It is, therefore, necessary to develop accurate and efficient numerical models that can appropriately describe the structural performance of metamaterials under nonlinear failure phenomena with reference to their static and dynamic mechanical responses. To this end, the present work presents a novel nonlinear homogenization scheme for characterizing the failure behavior of periodic reinforced hyperelastic composite metamaterials assessing the influence of interfacial debonding and contact due to the onset of macro and micro instabilities under a static regime. Moreover, the formulation can be extended to analyze incremental wave propagation properties of finitely strained metamaterials, taking into account

the geometry transformation induced by microscopic instabilities, in order to investigate how failure phenomena arising at the damaged interfaces affect the dynamic wave propagation characteristics of finitely strained metamaterials under macroscopic loading conditions.

A multi-fidelity neural network model for fiber-reinforced composites

abst. 1230
GIUSTINIANO
Friday
September 6
15h10

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Data contemporarily plays a crucial role in the evaluation and design of composite materials and structures. Nowadays, several data sources is available, including experimental testing, numerical simulations and theoretical predictions with fidelity of various levels. It is known that higher-fidelity data from experiments is usually costly and laborious which is the reason researchers turn to lower-fidelity numerical and even theoretical predictions with over-simplified assumptions. However, it is still difficult to synchronize those data of different accuracies. With the advancement of data technology and deep/machine learning techniques, this study introduces the recently proposed multi-fidelity neural network (MFNN) model to learn the relationship between low-fidelity and high-fidelity data with the aim to minimize the demand for high-fidelity data without sacrificing simulation's accuracy. The proposed MFNN is then employed to evaluate the elastic constants and yield surfaces of fiber-reinforced composites (FRC), based on plentiful low-fidelity data obtained from existing classical micromechanics theories and a limited amount of high-fidelity data from numerical simulations. We train the MFNN not only for the forward prediction of the equivalent elastic constants of the FRCs but also for the inverse identification of constituents' constants. We also validate the accuracy of the MFNN against experimental data which is not involved in the training. Compared with approximate classical micromechanics and fully connected neural networks (FCNN), MFNN demonstrates the best predicted performance. Our proposed MFNN model reduces the need for high-fidelity data and is expected to be a new approach for research and design of FRCs.

Multiscale analysis of in-plane periodic thin composite beams

abst. 1241
DANTE
Tuesday
September 3
16h50

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In this work, we propose a FE2 formulation based on the Euler beam model and first-order computational homogenization for large deformation of composite beam. On the macroscale, the Euler beam model accompanied with Updated Lagrangian formulation and corotational coordinates is developed, which can simulate large rotation and large strain problems. On the microscale, we use a first-order through-thickness representative volume element (RVE) discretized by solid element. In terms of scale transition relation, the membrane strain and curvature at each integration point of the macroscale are transferred to the RVE, while using an in-plane stress homogenization combined with a through thickness stress integration, the force resultants are transferred to the macroscale. Owing to the application of the local orthogonal basis fixed on the deformed configuration in the corotational system, the proposed model obtains the true stress satisfying the plane stress condition and avoids transferring the macro large rotation to RVE, simplifying the boundary value problem of RVE. The results show the proposed model is accurate for analysis of large rotation and large strain problems.

Thermoforming simulation of CFRTP prepregs for enhanced component performance

abst. 1252
GIUSTINIANO
Friday
September 6
10h00

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The integration of material and structure is pivotal in modern engineering for improving component performance and efficiency. However, the forming processes which considerably effect the material-structure relationship and cause the defect formation are always underlying in the trial-and-error procedure. To efficiently design and manufacture material structures, establishing a practical process simulation is crucial. This study focuses on the thermoforming process of continuous fiber reinforced thermoplastic composite (CFRTP) prepregs, exploring the full-process analysis from form to performance. Employing a thermal-mechanical coupling model based on FEA method, this research estimates the defect formation during the forming process, such as wrinkling and fiber redistribution. The fiber orientation deformations are estimated by non-orthogonal configuration. To present both the out-of-plane and in-plane properties simultaneously, the mutually constrained shell and membrane elements are used in this model. The ply/ply slippage behavior under varying temperatures are revealed by the temperature friction coupling relationship obtained from experiments. By evaluating the performance of the formed parts, it will help reduce the formation of defects and optimize process parameters. Forming experiments are conducted on typical parts, and the results show a high congruence between the experimental and simulation results. This form-to-performance simulation analysis provides a practical guidance for the realization of material-structure integration and further understand the catalysts for defect formation in the thermoforming process.

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abst. 1267
GIUSTINIANO
Friday
September 6
10h40

A novel finite element model for predicting elasto-plastic progressive damage in composite materials

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This study introduces a comprehensive three-dimensional finite element analysis (FEA) model for the prediction of elasto-plastic behavior and progressive damage in composite materials under axial compression. Incorporating established damage criteria and evolution schemes with defined plastic flow rules, the model advances the capability to simulate failure behaviors with enhanced accuracy. The application of the cohesive zone model (CZM), rooted in previous research, is particularly emphasized for accurately simulating the debonding interactions between stiffeners and panels. Custom 'VUMAT' subroutines facilitate the model's integration into Abaqus/Explicit software, ensuring fidelity in simulations. Validation against experimental data from axial compression tests on composite-reinforced panels demonstrates the model's effectiveness. Results confirm its superior predictive accuracy in determining load-bearing capacities and strain distributions, highlighting improvements over conventional elastic models. This research enriches the toolkit available for the analysis and design of composite structures, underscoring the necessity of accounting for elasto-plastic behaviors and damage mechanisms.

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abst. 1324
GIUSTINIANO
Friday
September 6
15h30

A physics-informed ANN-based framework for generating representative constitutive model of composite materials

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Machine learning methods are increasingly being utilized in the scientific applications to describe the mechanical behavior of composite materials, offering significant advantages over traditional numerical simulations. In this paper, a physics-informed artificial neural network (ANN)-based framework is proposed to capture the nonlinear behavior of composite materials. This framework accurately generates material stiffness matrixes by leveraging the capabilities of neural networks and captures the nonlinear mechanical response of materials by considering historical variables during the training process. Unlike data-driven neural networks, the proposed framework integrates finite element methods with the ANN knowledge to derive an ANN-defined material stiffness matrix. The proposed framework comprises three main modules. The first module generates finite element models to obtain the training data. The second module is an ANN-based neural network training module. The third module generates

FORTRAN programs, which ultimately implement the framework as a UMAT subroutine. Validation results show that the proposed stiffness matrix is both general and effective. Two test cases demonstrate the reliability and accuracy of the proposed ANN-based framework, confirming its potential in capturing the nonlinear mechanical response of composite materials.

An effective modeling strategy for simulating crack propagation mechanisms inside nano-filled composite structures under general loading conditions

abst. 1370
GIUSTINIANO
Friday
September 6
14h30

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This study presents an effective numerical method to simulate crack propagation mechanisms within nano-filled composite structures. The proposed approach is based on the idea of enhancing a standard Finite Element (FE) set with a Moving Mesh (MM) technique, which is used to reproduce the evolution of the computational domain caused by the changes induced by randomly growing cracks. In particular, the MM approach adopted is consistent with the Arbitrary Lagrangian-Eulerian (ALE) formulation, which governs the distortion of finite elements in such a way as to avoid significant distortions, thus reducing the occurrence of computational issues and the need for remeshing actions during the simulation. The kinematics of the computational mesh nodes occur in accordance with classic fracture criteria, which are typically expressed in terms of Stress Intensity Factors (SIFs) at the crack front. Therefore, accurate evaluation of SIFs is crucial for reliable predictions. To achieve this, the proposed method is the ALE formulation of the M-integral, which allows fracture variables at the crack front to be extracted during the movement of computational nodes. The validity of the proposed strategy is assessed through comparisons with experimental and numerical data available in the literature.

Closed form solution of the elastoplastic constitutive relation in three-dimensional solids

abst. 1416
GIUSTINIANO
Friday
September 6
15h50

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In the present analysis three-dimensional boundary value continuum problems are analyzed and an exact closed form solution is presented for the local constitutive problem in elastoplasticity, see De Angelis and Taylor [1][2]. In the present analysis small strain elastoplastic problems are considered and nonlinear kinematic hardening rules are adopted in modelling the mechanical behavior of ductile materials. In the literature a notable exact closed form solution of continuum problems with elastoplastic behavior has been presented e.g. by Simo and Govindjee [3]. However, therein the analysis is referred to plane stress problems and elastoplastic constitutive behavior with linear kinematic hardening. At variance, the present approach is well suited to be applied to three-dimensional inelastic problems [4]. In addition, the present analysis is developed for elastoplastic problems characterized by nonlinear kinematic hardening rules. Accordingly, the present approach can be properly applied to modelling the mechanical behavior of solids and structures subject to cyclic plasticity. The proposed procedure reduces the local constitutive equation to the solution of a single variable algebraic equation. It is shown that the analytical solution of the algebraic equation can be found in exact closed form. A remarkable feature of the present approach is that no iterative solution method is required to solve the local constitutive equations of three-dimensional continuum problems in elastoplasticity. The consistent tangent operator is furtherly

derived thus ensuring a quadratic rate of asymptotic convergence for the global solution procedure of the structural problem, see e.g. [5][6][7]. Finally, numerical applications and computational simulations are illustrated for elastoplastic continuum problems with different types of cyclic loading conditions. References [1] De Angelis, F., and Taylor, R.L., An efficient return mapping algorithm for elastoplasticity with exact closed form solution of the local constitutive problem, Engineering Computations, Vol. 32, Issue 8, 2259 - 2291 (2015). [2] De Angelis, F., Taylor, R.L., A nonlinear finite element plasticity formulation without matrix inversions, Finite Elements in Analysis And Design, Vol. 112, 11-25 (2016). [3] Simo, J.C., and Govindjee, S., Exact closed form solution of the return mapping algorithm for plane stress elasto-viscoplasticity, Engineering Computations, Vol. 3, 254 - 258 (1988). [4] De Angelis, F., A multifield variational formulation of viscoplasticity suitable to deal with singularities and non-smooth functions, Int. Journal of Engineering Science, Vol. 172, Art. 103616, pp. 1-16, (2022). [5] Simo, J.C., and Hughes T.J.R., Computational Inelasticity, Springer-Verlag, Berlin, (1998). [6] Zienkiewicz, O.C., Taylor R.L., and Fox, D., The Finite Element Method for Solid and Structural Mechanics, 7th ed., Elsevier, Oxford, (2013). [7] De Angelis, F., Cancellara, D., Multifield variational principles and computational aspects in rate plasticity, Computers and Structures, Vol. 180, pp. 27-39, (2017).

Development of an innovative powder adhesive based on epoxy-polyester and lignin for production of particleboards

abst. 1086
GIUSTINIANO
Thursday
September 5
12h10

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The dry manufacturing process of composite materials presents a significant advantage in terms of reduced water consumption and reduced wastewater production, and the dry manufacturing process can be further enhanced by using powder adhesives instead of liquid adhesives. The utilisation of powder adhesives generally enables lower dosages of adhesives, offers longer processing time and reduces cleaning demands. In this study, we present a development of flat-pressed particleboards bonded with powder adhesive. Hybrid lignin-epoxy-polyester adhesive was used in order to bond wood particles, and the variants of 0%, 10%, 20%, 30%, 50%, 70%, 80%, 90% and 100% of lignin content were examined. Both physical and mechanical properties of produced flat-pressed composite materials were observed. Namely, water uptake, thickness swelling, internal bonding, modulus of rupture, modulus of elasticity, vertical density profile and thermogravimetric analysis were used to characterise the produced variants of composites. The results indicate that pulverised lignin can be used in the dry form to be mixed with pulverised epoxy-polyester adhesive basis; the variants with lower lignin content exhibited better physical and mechanical properties. These findings correspond to the structural analysis of bond rupture conducted using scanning electron microscopy.

Tensile response of NTRM composites analysed by multilinear analytical approaches Vs. cohesive zone models

abst. 1295
GIUSTINIANO
Thursday
September 5
12h50

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The scientific community is increasingly interested in innovative inorganic matrix composite systems for the structural retrofitting of masonry buildings. TRM composites represent a class of materials with appropriate compatibility features with masonry substrates. Nevertheless, the growing environmental issues have enhanced the need to adopt more sustainable products and techniques as alternatives to the most widely used composite materials. Natural fibres represent a challenging system for structural strengthening purposes, but they still represent an open issue due to their intrinsically complex mechanical behaviour. In particular, the understanding of Natural TRM composites response under uniaxial tensile loading is investigated in this research by means of experimental tests and analytical modelling. From the experimental side, NTRMs with flax textiles are prepared and tested, considering

composite coupons with single and multiple layers. The coupons are tested under pure traction and their stress-strain response is obtained also with the support of DIC analysis. The results of the experimental campaign are compared with those obtained in similar testing campaigns currently available in the literature on NTRM systems. Subsequently, the experimental results are interpreted by adopting two different approaches: multilinear analytical formulations and cohesive zone models. From both sides, this research presents existing formulations and proposes novel models. Three multilinear analytical models are considered from the literature: the Aveston Cooper Kelly (ACK) model [1] and two modifications. The first one was proposed by Minafò and La Mendola [2], who adopted a homogenisation approach for calculating the first cracking stress. The second modification is characterized by the tension-stiffening effect assumed for calculating the post-cracking phase. All these models mainly apply to TRM systems which exhibit multiple cracks under traction. However, when vegetable fibres are used, the tensile test could exhibit a single crack failure. Therefore, a simplified trilinear model is proposed here, characterized by the first stage as in ACK formulation, followed by a vertical stress drop up to a last stage ruled by the textile behaviour. The advantage of multilinear approaches is that they can be considered design-oriented models, useful for practical applications. However, even though design-oriented models can be faster and simpler to use, they may not be as accurate as cohesive zone based-models. Therefore, this research also considers the model recently proposed by Focacci et al. [3] and proposes a closed-form solution for the interpretation of single-cracked specimens. In the proposed model, the material is simulated as a mono-dimensional TRM composite element, made by mortar and flax layers fixed at the ends, subjected to tensile load. This analytical formulation is validated against the experimental dataset previously mentioned, considering only the results of single-cracked specimens. Parametric analyses are finally presented to highlight the influence of the number of layers, thickness, and material strength and stiffness on the mechanical response of the NTRM composite system. [1] Aveston, J.; Cooper, G.; Kelly, A. Single and multiple fracture, the properties of fibre composites. In Proceedings of the Conference National Physical Laboratories, Guildford, UK, 4 November 1971; IPC Science and Technology Press, Ltd.: Teddington, UK, 1971. [2] Minafò, G.; La Mendola, L. Experimental investigation on the effect of mortar grade on the compressive behaviour of FRCM confined masonry columns. Compos. Part B Eng. 2018, 146, 1–12. [3] Focacci, F., D'Antino, T., Carloni, C. Tensile testing of FRCM coupons for material characterization: Discussion of critical aspects. Journal of Composites for Construction 2022, 26(4), 04022039.

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abst. 1330
Repository

On the bending, buckling and free vibration analysis of bio-inspired helicoidal laminated composite shear and normal deformable beams

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The mechanical behaviours of bio-inspired helicoidal laminated composite (BIHLC) beams are investigated via the Ritz method. By exploiting the variational formulation, equations of motion along with element stiffness, geometrical stiffness, and mass matrices are derived. The study conducts a thorough examination, covering bending, buckling stability, and free vibration analyses of BIHLC beams with various lamination schemes. Validation of the developed model against existing literature on conventional composite laminated and BIHLC beams is performed. Furthermore, an examination is conducted on the mechanical response of BIHLCs, considering the influences of boundary conditions, lamination schemes, orthotropy ratios, and aspect ratios. Notably, deflections, critical buckling loads, and fundamental frequencies demonstrate variations contingent upon the specific lamination scheme, boundary condition, and aspect ratio. Novel findings, presented for the first time, offer valuable insights for future studies in this area.

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abst. 1345
GIUSTINIANO
Thursday
September 5
12h30

Enhanced mechanical properties of hydrogel reinforced by microcrystalline celluloses

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Hydrogels are widely used in biomedicine because of their water retention and biocompatibility. The composite hydrogels with high mechanical properties can be used as biomimetic replacement aterials for damaged skeletal muscle, articular cartilage and other biological tissues. Microcrystalline cellulose is a research hotspot of biomimetic composites because of its degradability and biocompatibility. We utilized microcrystalline cellulose as a reinforcing material for hydrogels to fabricate microcrystalline cellulose-reinforced composite hydrogels. We delved into the influence of different particle sizes of microcrystalline cellulose on the tensile and fracture mechanical properties, examined its sensitivity to strain rate at various rates, and further investigated its hysteresis characteristics to unveil the energy dissipation mechanism. We developed a kind of microcrystalline cellulose reinforced hydrogel with high strength and toughness, optimized the energy dissipation mechanism of hydrogel, promoted the application of composite hydrogel in the field of biomedicine, and provided a new idea for the design of strong and tough materials.

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abst. 1043
LLA PLACIDIA
Wednesday
September 4
16h50

Thermal Buckling Analysis of Variable Stiffness Laminated Composite Beam using Semi-Analytical Approach

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This study aims to investigates the stability characteristics of variable stiffness laminated composite beams subjected to thermal loadings. A semi-analytical model is developed that uses displacement-based Ritz approach to derive the matrix representation of the governing equations. Modified constitutive relations are derived to account for the Poisson effects that arise due to the development of zero-stress conditions in the width direction of beams. The material properties and temperature variations are assumed to be constant across the thickness of the beam. Numerical results are obtained to elucidates the effect of slenderness ratio, modulus of elasticity ratio, boundary conditions, number of layers, and ply-sequence on the instability characteristics of variable stiffness laminated composite beams exposed to thermal environments.

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abst. 1060
LLA PLACIDIA
Thursday
September 5
16h30

Process-Structure Properties of Polymer-Metal Sandwich Composites manufactured by in-situ Injection Molding

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As industries seek innovative solutions, there is a general need to adopt hybrid materials such as polymer-metal structures. The combination in polymer-steel sandwich composites - consisting of a polymer core to transmit shear forces and two metal face layers to absorb tensile and compressive loads - meets the primary objective of minimizing the weight per unit area under flexural load. Manufacturing these structures typically involves secondary processes such as bonding or mechanical joining. However, the industry's focus is on time and cost efficiency, automation, and mass production with guaranteed reproducible mechanical properties. This contribution investigates the process-structure properties of polymer-metal sandwich composites manufactured by in-situ injection molding, focusing on the optimization of metal face sheet pre-treatment by laser structuring and the associated injection molding parameters. To meet the demand for streamlined processes, an in-mold assembly approach using variothermal processing is applied. This involves heating the mold and metal blanks to the temperature of the polymer melt to facilitate in-situ bonding of the metal face sheets to the polymer core. Laser structuring is used to create micro- or nanoscale structures on the metal surface to improve infiltration and has been analyzed in detail, with particular emphasis on the profile and its properties. The increased metal surface temperature also reduces the viscosity of the polymer melt, which is critical for effective infiltration and improved adhesion, thereby contributing to the strength of the composite. Investigations into the influence of variothermal mold operation and the associated injection molding parameters on the flow behavior of the polymer have been performed and will be presented.

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abst. 1088
LLA PLACIDIA
Thursday
September 5
16h50

Ritz-Legendre approach for capturing the mode jumping phenomena in variable-stiffness composite fuselage panels

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In this work, a semi-analytical model is proposed for addressing the mode jumping phenomenon in variable-stiffness composite fuselage panels. The Ritz approach is implemented for deriving the analytical formulation of the geometrically nonlinear response. A composite skin bounded by two frames and two stringers is considered. The skin is modelled as a plate based on the classical lamination theory with nonlinear von Kármán strain–displacement relationships. The displacement field is approximated with trial functions built as products of one-dimensional Legendre orthogonal polynomials. The system of nonlinear equations is then obtained from the stationarity of the total protentional energy. The involved matrices are numerically computed and the nonlinear load-deflection path is traced by the normal flow algorithm. The panel is restrained using appropriate boundary conditions at the locations of the frames and stringers and loaded in two consecutive steps. In the first step the panel is loaded by pressure and in-plane tensile loads leading to an initial mode shape. In the second step, the panel is loaded by an in-plane axial compressive load which triggers an abrupt mode-shape change in the initial mode resulting in a mode jumping event. In order to investigate the effects of the stiffness variation created by the curvilinear fibres on the mode jumping response, the fibre orientation angles are varied along two main directions, perpendicular and parallel to the direction of the load that causes the mode jumping. The accuracy of the predicted results obtained from the semi-analytical model is verified using Abaqus. It is demonstrated that the mode jumping of the variable-stiffness composite laminates can be captured successfully. It is concluded that by varying the stiffness via changing the fibre orientations from location to another within the laminate, the configuration of the mode after jumping can be tailored and its occurrence can be delayed.

abst. 1059
DANTE
Wednesday
September 4
09h40

Some aspects of unsymmetric laminated composite plate – Second bifurcation

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It is widely recognized that certain structures, when subjected to static compression, may exhibit a bifurcation point, leading to the potential occurrence of secondary equilibrium path. Also, this may occur in tendency of bifurcation point for imperfect structures. In this paper, a relatively unknown phenomenon is investigated which is a transition from secondary equilibrium path to a new one as tertiary equilibrium path or second buckling load. In this regard, some non-square plates with unsymmetric layer arrangements are subjected to uniaxial in-plane compression. By considering the geometrically linear and nonlinear problems, the bucking modes and post-buckling behaviors e.g., the out-of-plane displacement of the plate versus the load are obtained by ANSYS software. Through a parametric analysis, the possibility of this phenomenon is described in detail.

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abst. 1085
DANTE
Wednesday
September 4
10h00

Flexural-Torsional Buckling of Composite Beams using Generalized Beam Theory (GBT) and Ritz Method

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The analysis of thin-walled beams has always been challenging when it comes to buckling conditions and its complex deformation modes. It can be more challenging when the beam is made of composite materials. Therefore, high computational efficiency is needed and beam theories can provide it. One of them is the Generalized Beam Theory (GBT) that was originally developed by Schardt (Schardt 1983) and may be viewed as an extension of Vlasov's classical prismatic bar theory that accounts for both cross-section out-of-plane (warping) and in-plane deformation (Gonçalves et al. 2009). In GBT, the deformed configuration or buckling mode shape of a given member is expressed as a linear combination of pre-determined cross-section deformation modes with longitudinally varying amplitudes. This quite unique modal feature renders the application of GBT considerably more versatile and efficient than the use of "equivalent" (similarly accurate) finite strip or shell finite element models (Gonçalves et al. 2009). Indeed, it has been shown that GBT constitutes a powerful, elegant, and clarifying tool to solve structural problems involving prismatic thin-walled members. The longitudinal displacement amplitudes and the critical loads can be obtained by solving a Generalized Eigen-value Problem (GEP) in which its parameters have been determined using the GBT method. Eigenvalue buckling is generally used to estimate the critical buckling loads of stiff structures that carry their design loads primarily by axial or membrane action, rather than by bending action. The objective of this study is to present the main concepts and procedures involved in the formulation of a GBT intended to analyze the linear buckling behavior of members displaying thin-walled open composite cross sections. The member walls are made of an arbitrary number of orthotropic layers, each with an arbitrary orientation. The proposed GBT formulation enables the full analysis of composite thin-walled members using a combination of the Ritz method and the Generalized Eigenvalue problem (GEP) to fulfill a very highly efficient method for buckling analysis of thin-walled composite beams. References: Schardt R. The generalized beam theory. In: instability and plastic collapse of steel structures, Proceedings of the M.R. Horne conference, University of Manchester, 1983, 469–475. Gonçalves R., Dinis P.B., Camotim D. GBT formulation to analyze the first-order and buckling behaviour of thin-walled members with arbitrary cross-sections. In: Thin-Walled Structures 47(5), 2009, 583-600.

A semi-analytical solution for critical buckling loads of stiffened orthotropic circular cylindrical shells

abst. 1101
DANTE
Wednesday
September 4
10h20

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Stiffened plates and shells are widely used in various engineering fields as main load-carrying components. There have been numerous researches on buckling analysis of circular cylindrical shells, but still few researches on analytical or semi-analytical solutions for eigenbuckling of stiffened circular cylindrical shells with arbitrary homogenous boundary conditions. Based on the Rayleigh's principle, this work aims at developing a semi-analytical method for solving the critical buckling loads of stiffened orthotropic circular cylindrical Donnell–Mushtari thin shells with arbitrary homogeneous boundary conditions. Different from all the previous semi-analytical methods needing to anticipate the mode functions of the stiffened cylindrical shells, the mode functions in the present method are the superposition of the closed-form mode functions of the shells without stiffeners, and the closed-form mode functions are achieved with the extended separation-of-variable method, which is a solution method for the eigenvalue problems of plates and shells. The critical buckling load of the stiffened cylindrical shells can be arrived at by substituting the superposition form mode function into the Rayleigh's principle. The accuracy of the results can be improved by adding the superposition terms. Numerical experiments validate the accuracy of the present solutions, and the parametric study is conducted.

Analysis of magneto-electro-elastic FGM plates by the Moving Finite Element Method

abst. 1113
DANTE
Wednesday
September 4
12h10

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With the development of new classes of smart materials, such as magneto-electro-elastic ones their application is widespread in the several branches of engineering practice. Mainly as actuators and sensors for the controlled performance of engineering structures. Such a smart structures are usually made as laminated composites from ceramic slices. Discontinuities of material coefficients on the interfaces between two or more layers lead to concentrations of gradient fields. Such a concentrations can play a crucial role in the failure of the laminated composite structures. This problem can be solved by using functionally graded materials (FGM). In this paper the unified formulation for bending of magneto-electro-elastic plates is derived with incorporating the assumptions of the Kirchhoff-Love theory as well as the 1st 1nd 3rd order shear deformation plate bending theories. By proper selection of two key factors and material coefficients, we can switch between various theories. The governing equations which are given by the 4th order partial differential equations (PDE) are decomposed into the 2nd order PDEs in order to overcome the inaccuracy of approximation of high order derivatives of field variables. The strong form formulations for solution of plate bending problems are developed in combination with novel Moving Finite Element (FEM) approximation scheme. The attention is paid to the study of the influence of various parameters of gradations of material coefficients on the behaviour of the plate.

Distributions of transverse normal and shear stresses on laminated plates and shells by a positional FEM formulation

abst. 1270
DANTE
Wednesday
September 4
12h30

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Shell and plate structures made of laminated composite materials exhibit complex transverse stress distributions through the laminate thickness. The simple use of linear kinematics and stress-strain relations is not sufficient to adequately predict the mechanical behavior of such structures. This study presents a kinematic shell model enriched with linear functions per layer throughout the thickness coordinate for simulating displacement and stress distributions of symmetric laminated plates and shells. An alternative formulation of the Finite Element Method (FEM), the so-called positional FEM, is applied. It is a nonlinear geometrically-exact and total Lagrangian formulation that uses nodal positions of points lying on the shell's reference surface and generalized vectors as degrees of freedom, i.e., three coordinates and three vector components per node in the three-dimensional (3D) space. A further five degrees of freedom are introduced from the kinematics development, which is based on the equilibrium of longitudinal forces at an infinitesimal beam element. Although the kinematics takes into account two-dimensional assumptions, the stresses are not reconstructed a posteriori. Each layer follows the Saint Venant-Kirchhoff law for orthotropic material. The final formulation can predict the zig-zag effect of displacement and the distribution of transverse stresses in symmetric shells with no need to apply shear correction factors. The results of laminated cross-ply plates are compared against exact 3D elasticity solutions from the literature.

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abst. 1320
DANTE
Wednesday
September 4
12h50

A unique HSDT theory for porous materials powered by machine learning

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This paper presents a unique HSDT for the bending analysis of porous materials. The novelty of the present theory is the use of strain shape functions that are calibrated by machine learning techniques. The proposed plate model is based on a 4-unknown HSDT. The governing equations are derived from the principle of virtual works, and Navier-type closed form solutions have been obtained for simply supported FGPs subjected to bi-sinuisoidal transverse pressure. The accuracy of the PHDT is assessed by comparing the results of numerical examples with a 3D elasticity solution, and the best HSDTs reported in the literature. The results show that quasi-3D displacement and stress distribution are obtained using a set of tuning parameters for the shape strain functions. So, a new frontier for the development of others shear deformation theories is delivered.

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abst. 1342
DANTE
Wednesday
September 4
10h40

A comprehensive analysis of laminated composite, sandwich and bio-inspired helicoidal composite curved beams: Part 1- bending

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This paper presents bending analysis of laminated composite, sandwich and bio-inspired helicoidal composite curved beams using various refined shear deformation theories, which considers simultaneously three effects such as normal and shear deformation as well as anisotropy coupling. A two-node beam element satisfying C1 continuity requirement is utilized to compute displacements for beams with various boundary conditions. Numerical results of the sinusoidal, third-order, first-order and classical theories are presented to show the effect of material distribution on the deflections. The effects of fibre angle, lay-up and span-to-height ratio on displacements are studied. New results of bio-inspired helicoidal composite curved beams, which can be useful for future references, are also given.

Shell and Solid-Shell Finite Elements for Forming Simulations of Thick CFCR Stacks at the Macroscale

abst. 1373
DANTE
Wednesday
September 4
13h10

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Composite materials offer a lightweight structural alternative to the metals traditionally used in the aeronautical and automotive industries, leading to fuel savings that reduce the environmental impact and increase overall performance. Continuous fibre composite reinforcements (CFCR) can be used for these structural applications. Liquid composite moulding processes for dry textiles [1] and thermoforming of prepregs [2] constitute two forming processes for CFCR that can deliver a high volume of structural parts. The material is draped by a mould when the resin is yet to be injected/hardened, producing complex shapes, often with double curvature. Numerical tools replace the expensive trial and error tests that are currently used in the designing face, reducing the manufacturing cost and expanding the available design options. These tools should be able to predict the final fibre orientation and the appearance of possible defects such as warping and fibre sliding/fracture. Incorrect fibre orientation and/or excessive defects (in particular warping) can lead to poor final properties, resulting in different mechanical properties and permeability (leading to an incorrect resign flow, which can result in a poor distribution/voids). The mechanical behaviour of CFCR materials is complex and characterised by interactions at multiple scales: at the microscale, millions of microscopic fibres are bundled together comprising a yarn; at the mesoscale, visible yarns interact with each other; at the macroscale, the reinforcement is draped into the desired shape. At the macroscale, the deformation of the preform is driven by four different mechanisms [3]: inter-fibre shear (change of fibre orientation), inter-fibre slippage, fibre buckling and fibre extension (small due to high stiffness). When stacked, specific deformation occurs [4], due to the high stiffness in the fibre direction and an absence of a binding agent between the plies (allowing inter-ply slippage): initially normal lines to the mid-surface do not necessarily remain normal to it and plies can curve even when the initial normal lines do not rotate; at the same time, the thickness does not remain constant; thus not being describable by Kirchhoff nor Mindlin hypothesis. Experimental works show all the previously described behaviours can be uncoupled from each other, thus a different model can be picked for each one. In this talk, we present shell and solid-shell finite elements with top and bottom surface DoFs for the simulation of thick CFCR stacks. For each layer, fibre extension and inter-fibre shear are modelled as a hyperelastic material and bending as a thin plate. The material directors (lines initially perpendicular to the mid-surface) are obtained from the relative displacement between the top and bottom DoFs. The compaction is modelled with a non-linear elastic law. [1] E. M. Sozer, P. Simacek, and S. G. Advani, Resin transfer molding (RTM) polymer matrix composites, Manufacturing Techniques for Polymer Matrix Composites (PMCs) 245-309 [2] D. H. - J. A. Lukaszewicz and K. D. Potter, The internal structure and conformation of prepreg with respect to reliable automated processing, Composites Part A: Applied Science and Manufacturing 42 3 (2011) 283-292 [3] C. D. Rudd, A. C. Long, K. N. Kendall, and C. G. E. Mangin, Liquid molding technologies, Woodhead Publishing, in Cambridge: SAE International, (1997) [4] B. Liang, J. Colmars, and P. Boisse, A shell formulation for fibrous reinforcement forming simulations, Composites Part A: Applied Science and Manufacturing 100 (2017) 81-96

Composite structures and materials

abst. 1017
TEODORICO
Thursday
September 5
16h30

Generalized Differential Quadrature for the static and free vibration analysis of doubly-curved shells made of advanced innovative materials employing higher order theories

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Various engineering disciplines have seen significant advancements in the design of structures of complex geometries and innovative materials. In this context, it is essential to develop computational models that can deliver highly accurate results while minimizing computational costs. In the present contribution, two-dimensional models are presented for the static and the dynamic analysis of laminated doubly-curved shell solids of arbitrary shapes [1]. These shells are characterized by variable thickness and are made of innovative anisotropic materials. Based on the adoption of higher order theories, they follow either the Equivalent Single Layer (ESL) and the Layer-Wise (LW) approach with a generalized formulation. Starting from a geometric description of the solid through differential geometry's principles in curvilinear principal coordinates, the fundamental equations are derived from the Hamiltonian principle, and they are solved in both the strong and weak form using the Generalized Differential Quadrature (GDQ) method [2]. An efficient strategy is adopted for the assessment of generalized surface and concentrated loads, and the influence of a Winkler-Pasternak elastic foundation is examined [3]. In addition, general boundary conditions are modelled through an arbitrary distribution of linear elastic springs distributed along the lateral surfaces of the shell. Finally, an efficient recovery procedure provides an accurate prediction of the three-dimensional structural behavior of the doubly-curved shell panel. A comprehensive set of numerical examples is presented, showing the bending and the vibrational responses of structures with various lamination schemes and curvatures. These results are successfully compared to the outcomes of high computationally demanding three-dimensional solutions. Various configurations of the stacking sequence with an arbitrary number of layers are considered, accounting for arbitrary variations in the material properties and orientation angle [4]. Furthermore, the impact of porosity is investigated. Various types of reinforcements are considered within the layer, including continuum fibers, agglomerated Carbon Nanotubes (CNTs), honeycomb and anisogrid cores, modelled as a continuum. Various parametric analyses are conducted, showing the influence of the main geometric and mechanical parameters on both bending deflection and modal response in these structures. The present formulation is a valid tool for accurately predicting the structural response of moderately thick and thick laminated panels with a limited computational effort, therefore it can be a valid alternative to commonly used numerical procedures implemented in most commercial software. References: [1] Tornabene F., Hygro-thermo-magneto-electro-elastic theory of anisotropic doubly-curved shells, Esculapio, Bologna, 2023. [2] Tornabene F., Viscoti M., Dimitri R., Free vibration analysis of laminated doubly-curved shells with arbitrary material orientation distribution employing higher order theories and differential quadrature method, Engineering Analysis with Boundary Elements, 152 (2023), 397-445. [3] Tornabene F., Viscoti M., Dimitri R., Static analysis of anisotropic doubly-curved shell subjected to concentrated loads employing higher order layer-wise theories, Computer Modeling in Engineering Sciences, 134 (2023), 1393-468. [4] Tornabene F., Viscoti M., Dimitri R., Rosati L., Dynamic analysis of anisotropic doubly-curved shells with general boundary conditions, variable thickness and arbitrary shape, Composite Structures, 309 (2023), 116542.

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abst. 1019
TEODORICO
Thursday
September 5
14h30

Experimental research of composite cylindrical shell type offshore structure

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Sustainable design and manufacturing of low-carbon structures is a major concern for the offshore renewables industry. FRP composite materials are seen as a suitable alternative to traditional structural materials due to their high strength and light weight. Due to the high potential of offshore wind farms and high expectations from the industry mentioned benefits provide significant savings in subsea and

offshore applications of FRP composite materials. Safety, structural integrity, and corrosion resistance are essential factors to consider aggressive offshore and subsea environments. Current research presents a comparative experimental investigation and introduces a new type of the reel considering composite material such as glass fiber reinforced polymers (GRP) in lieu of conventional carbon steel for high voltage cable storage, sea transportation and subsea installation. Due to lack of standard and experimental results, a new prototype is experimentally tested on site based on large scale experimental program. Identified priorities reflected to this research work by promising application of GRP composite material may find innovative use in offshore environment.

Post-buckling analysis of composite plates including bending twisting coupling

abst. 1025
TEODORICO
Thursday
September 5
15h10

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Thin-walled composite structures, valued for their lightweight potential, find extensive application in the aerospace and shipbuilding industries. However, the stability behavior of these structures needs to be considered. As a locally post-buckled structure demonstrates the capacity to withstand increasing loads without immediate failure, it necessitates not only a buckling analysis but also a post-buckling analysis to fully leverage its lightweight potential. Many commonly used composites exhibit bending-twisting coupling effects, a significant factor influencing the buckling behavior. Despite this, computationally efficient buckling analyses often neglect bending-twisting coupling. To achieve optimized designs, it is crucial to employ analysis methods that consider these effects. Therefore, a Ritz method tailored for post-buckling analysis of rectangular plates featuring bending-twisting coupling is introduced. Derived based on energy methods, this approach enables the description of stability behavior, modeling deformation, load distributions, and characteristic quantities such as effective width. The novel computational model is utilized to evaluate the impact of nondimensional parameters associated with bending-twisting coupling on the buckling and post-buckling behavior of composite plates. This research contributes to the development of computationally efficient methods for designing optimized thin-walled composite structures.

An adaptive learning method based on multi-fidelity Kriging model and metaheuristic algorithm for multiscale reliability analysis of composite structures

abst. 1033
TEODORICO
Thursday
September 5
15h30

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Composite structures, owing to their characteristics such as high strength, large stiffness, and lightweight, find widespread applications in practical engineering. However, uncertainties exist in structural parameters at micro, meso, and macro scales. Accurately quantifying the impact of these uncertainties and conducting structural reliability analysis is crucial for ensuring the integrity of composite structures. Nevertheless, achieving efficient and accurate reliability analysis at low computational costs is a significant challenge in practical engineering. In response to these challenges, this study proposes an adaptive-learning method based on multi-fidelity Kriging model and metaheuristic algorithm for multiscale reliability analysis of composite structures. The proposed method addresses these challenges by constructing an adaptive learning function, referred to as the M-function, based on the correlation

between trends in metaheuristic optimization algorithms, First Order Reliability Method (FORM), and high/low-fidelity models. In the presented adaptive learning approach, the M-function adaptively selects update samples for the multi-fidelity Kriging model. Simultaneously, the constructed Kriging model is utilized in conjunction with the FORM to achieve efficient reliability assessment. The effectiveness and efficiency of the proposed method are validated through comparisons with several state-of-the-art methods, utilizing three numerical examples and three composite structure problems. The results demonstrate that the proposed method can achieve accurate reliability assessments with reduced computational costs, showcasing its effectiveness in practical engineering applications.

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abst. 1036
TEODORICO
Thursday
September 5
15h50

ANALYSIS FOR DEFORMATION OF THE 3-BAR TENSEGRITY STRUCTURE

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The 3-bar tensegrity structure is the foundation of the tensegrity structures. It is helpful to obtain more complicated tensegrity structures by researching more about the 3-bar tensegrity structure. Based on the regular 3-bar tensegrity structure, this paper establishes the mathematical model of the structure and the equilibrium equations of the deformed structure whose nodes were shifted, and gets the equilibrium matrix. Then, based on the idea that the equilibrium matrix of the self-stabilized tensegrity structure is rank deficiency, that is, the determinant is 0, the determinant of the equilibrium matrix is solved. The feasibility of the self-stabilized 3-bar tensegrity structure is analyzed by changing coordinates of one node and two nodes at the same time respectively, and the relationship between the deformation coefficients of the self-stabilized deformation structure is obtained. The stability of the deformed structure is further evaluated by analyzing the influence of the deformation coefficient on the force density of the component. Through the analysis of this paper, an analysis method for obtaining stable deformed 3-bar tensegrity structure by shifting several nodes is developed, which provides new ideas and methods for constructing the stable tensegrity structure.

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abst. 1037
TEODORICO
Thursday
September 5
14h50

The method for assembling -bar tensegrity units into a regular polyhedral tensegrity structure

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Various regular polyhedral structures have been used as basic frameworks for engineering structures. In this paper, a method for assembling p-bar tensegrity units into a regular polyhedral tensegrity structure is developed. Firstly, corresponding to original regular polyhedron, the number of tensegrity units assembled into the regular polyhedral tensegrity structure is equal to the number of vertices, and p—number of bars in each unit—refers to the number of edges connecting to each vertex. Secondly, a novel rule for assembling the tensegrity structure according to the characteristics of the tensegrity is presented. Thirdly, based on equilibrium of nodal forces, a criterion derived from conditions for coplanar vectors is employed to judge whether the structure is self-stabilized. Finally, several stable regular polyhedral tensegrity structures are obtained by determining only two parameters. Through the analysis of this paper, such a method for assembling stable regular polyhedral tensegrity structures has the advantages of less variables, simple rules and easy implementation.

Predicting the Structural Behavior of Type IV Composite Pressure Vessels through Ring Burst Testing

abst. 1053
TEODORICO
Tuesday
September 3
15h10

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The increasing adoption of environmentally sustainable transportation has led to a surge in interest in hydrogen storage technology. Especially, type IV hydrogen tanks for storing high-pressure compressed hydrogen gas have been used for the gas storage in fuel cell electric vehicles. They are mostly manufacutred through a filament winding process using carbon fibers with resin and a polymer liner. The performance of the hydrogen tanks is intricately influenced by a combination of factors, including winding patterns, material types, and environmental conditions. To evaluate the performance, a hydrostatic test has commonly been used. However, the construction of hydrostatic testing facilities is cost-prohibitive, and only a single data is obtained from one specimen, liming its efficiency in providing a comprehensive understanding of pressure resistance across diverse hydrogen tank configurations. To overcome these issues, a ring burst test was proposed to evaluate the hoop strength of a ring specimen from the pressure tank. The ring burst test device consists of a tapered column, fan-shaped segments and a bottom plate. As the column moves down, it pushes the segments to stretch the ring specimens. Horide, A. et al analyzed a fracture process through observing the fracture behavior during the ring burst test. Kim, W.T. et al modified the ring burst test device to reduce the variation in the hoop strain of the ring specimen. Previous researchers have used soft layers to apply uniform pressure to the ring specimens. However, a maximum pressure of hydrogen tanks is too high to accommodate the use of the soft layer in the ring burst test. Accordingly, their studies are confined to exceedingly thin thicknesses of the ring specimen. In addition, a detailed analysis of the correlation between the ring burst test and hydrostatic test should be conducted. Therefore, this research aims to predict structure behavior of the high-pressure compressed hydrogen tank based on the ring burst test. To set same manufacturing conditions, two composite vessels were concurrently manufactured using the first and second floors of a winding machine. The hydrostatic test and the ring burst test were used for evaluate burst pressures and failure strains. To obtain composite properties of the ring specimens, a ring burst test simulation and the actual ring burst test was compared. From the comparison between the ring burst test and its simulation, the fiber volume fraction of the composite vessel was 65% and the maximum strain 1.9% at the inner surface of ring specimens when the specimen failed. In the outer strain-pressure curves of the hydrostatic test and its simulation, the error of slope was within 2%. In the hydrostatic test, the burst pressure was measured 105 MPa due to failure occurred in a dome section. From the failure strain obtained from the ring burst test, the predicted burst pressure was calculated as 152 MPa when the hoop burst in the cylinder section. Overall, the composite properties from the ring burst test represented the structural behavior of the hydrostatic test.

Buckling of compressed orthotropic cylindrical panel resting on elastic curvilinear foundation with nonlinear change of transverse displacement over the thickness

abst. 1070
TEODORICO
Thursday
September 5
13h10

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Investigation of buckling of thin-walled structures resting on an elastic foundation is topical and required when solving various practical engineering problems related to structural analysis. This applies to both,

conventional and modern advanced applications. In overwhelming majority of such applications, a thin-walled structure can be modelled as a thin rectangular plate. To analyse typical buckling mode shape for such a plate, it is essential to have an appropriate deformation model of elastic foundation. To date, a few models have been developed to simulate deformation of the foundation based on the plate deflection. Among these models, the Winkler-Pasternak model is the most popular due to its relative simplicity. Over the last decade, a number of interesting studies of buckling behaviour of thin plates resting on the foundation having the form of parallelepiped was completed and reported in literature. However, it could be noted that not much attention was given to date to the buckling analysis of cylindrical panel resting on elastic curvilinear foundation. Such analysis is of substantial practical interest and, among other things, requires application of more complex model of elastic deformation of curvilinear foundation than the Winkler-Pasternak model. In this paper, for the first time a solution of buckling problem formulated for a compressed orthotropic cylindrical panel resting on elastic orthotropic curvilinear foundation is presented. The solution was obtained using the Ritz method. To realise this method, a functional of total energy of the structure corresponding to its perturbed state has been formulated. The functional is presented as a sum of the functionals of energy of panel deformation, the work of pre-buckling forces, and the energy of deformation of the curvilinear foundation, for which the original model of deformation is proposed. According to this model, the panel deformation under buckling causes only transverse displacements in the foundation. These displacements are fading in the nonlinear manner over the thickness of foundation. The rate and character of this fading is determined by the corresponding decay parameter. Application of this model allows the three-dimensional energy functional to be replaced by a two-dimensional one. Displacements and deflection of cylindrical panel have been approximated using the clamped-clamped beam functions and their first and third derivatives. Such an approximation allows the boundary conditions corresponding to a moving clamped edges of cylindrical panel to be satisfied. This reflects a situation where the curvilinear edges of the panel move towards each other in the process of panel deformation under buckling. Realisation of the Ritz method yields formulas that can be used to calculate a critical buckling load. The search for this load is completed by using a minimization with respect to the wave formation parameter and the parameter of decay of the transverse displacement in the foundation. Based on this, the effects of the panel's radius and thickness, and modulus of elasticity of foundation on the values of critical buckling load and the decay parameter have been analysed. This analysis allowed the main trends in a variation of critical load to be identified. In addition, the results obtained confirmed a nonlinear character of fading of transverse displacement over the thickness of curvilinear foundation. Verification of the results of calculations have been performed using the finite element method. The corresponding model was composed of three-dimensional elements. The computations performed confirmed the fidelity of the results obtained based on the created model of the deformation of elastic curvilinear foundation. In addition, the buckling analysis has been performed for the panel resting on the Winkler-Pasternak type elastic foundation. This analysis showed that the application of the Winkler-Pasternak model overestimates the values of critical buckling load and should be carefully and critically assessed. Based on the proposed methodology of buckling analysis, the efficiency of the design selection of elastic parameters of the foundation has been demonstrated for various examples of cylindrical panels made of composite materials.

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abst. 1084
TEODORICO
Tuesday
September 3
15h50

Polyvinylidene fluoride-co-trifluoroethylene/graphene oxide (PVDF-HFP/GO) composite as separator for high-performance lithium-oxygen battery

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The objective of this research is to form an effective composite coating and separator for lithium-oxygen (Li-O2) batteries. The polyvinylidene fluoride-co-trifluoroethylene with graphene oxide additive (PVDF-HFP/GO) was developed to improve the battery cycle life. Both symmetrical Li-Li cell and full Li-O2 battery with the PVDF-HFP/GO layer exhibited longer lifetime and smaller over-potential than those without such composite or with pure PVDF-HFP alone. The optimal GO load was 0.6%.

The GO additive can improve the ionic conductivity, therefore the impedance of the full battery was reduced by 48% of the control cell without GO additive. The analysis on aged anode revealed that the PVDF-HFP/GO coating effectively prevented the LiOH formation during the battery cycling. This electrolyte-impregnated PVDF-HFP/GO serves as an efficient separator and solid electrolyte.

The Effects of Pore Morphology on Mechanical Response and Hot-Spot Formation in Pre-billets of HMX-Based PBXs under Press Loading Process

abst. 1102
TEODORICO
Tuesday
September 3
13h10

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The microstructure of pre-billet of HMX-based PBXs mainly contains explosive particles with different morphology and size distribution, chemically inert binders and plasticizers, and pore defects. Owing to the variability of the material microstructure, hot spots and unequal damage may result from the isostatic pre-billet charge extrusion process. However, at the microscopic scale, the extrusion process of pre-billet of HMX-based PBXs may lead to uneven damage and hot spots. A numerical crystal plasticity model based on a polycrystalline HMX material subjected to press loading is provided to evaluate the effects of initial pore defects on the failure mode, effective compressive strength and hot spot formation of PBXs. The size, distribution and volume ratio of the initial pores were mainly considered, and the expansion, connection and closing processes of the pores under different loading conditions were simulated. The effects of the parameters of the pores on the micromechanical deformation process and the formation of hot spots of pre-billet of HMX-based PBXs were analyzed. It is helpful to further reveal the mechanical response and hot spot formation rule of HMX based PBXs preform under press loading process.

Novel multifunctional pre-impregnated coatings for polymer matrix composites (PMC) - manufacturing technology and adhesion tests

abst. 1153
Repository

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Surfaces of PMC materials are often exposed to erosion, thermal shocks or impact loads, which can cause local damage to both the matrix and reinforcement. Depending on the level of damage, repair can be costly and time-consuming and require prior nondestructive testing. Various coatings, such as gelcoats, rubber mats or spray metallization, can be used to prevent internal damage to the structure. This paper presents new multifunctional preimpregnated coatings (NMPCs) in terms of their manufacturing technology and adhesion tests. The coatings were made based on thermoplastic materials as well as metal and oxide powders of different gradations. By appropriate selection of materials, both different thicknesses and mechanical properties can be obtained. The presented coatings can also perform decorative functions, for example, in composite facade panels. The multifunctional layer in the form of a prepreg has the advantage that it is flexible and can be cut and applied to curved surfaces, which expands the range of applications. It can be used in conjunction with various composite manufacturing techniques such as autoclave curing with CFRP prepregs or vacuum infusion. However, to ensure that the coating can fulfill its role, there must be adequate adhesion to the substrate so that delamination does not occur due to mechanical or thermal stresses. In this study, 8 batches of samples each made by two techniques: vacuum infusion and autoclave curing with NMPC applied were tested. Specimens with a diameter of 25mm were cut from the fabricated plates, which were bonded to aluminum rods and subjected to uniaxial tensile tests. A maximum adhesion value of 7.2MPa was obtained for the vacuum-infused samples, while 7.8MPa was obtained for the autoclaved samples. Acknowledgments: This research was funded by the National Centre for Research and Development of Poland grant number LIDER XIII 0135/L-13/2022.

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abst. 1195
TEODORICO
Tuesday
September 3
16h50

Single-lap Shear Testing of Additively Manufactured Sandwich Composite Inserts

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Joining structural components with mechanical fasteners is common in many engineering applications across numerous industries. This study investigates combining novel additive manufactured inserts using Fused Deposition Modeling with sandwich composites consisting of aluminum honeycomb cores with carbon-fiber reinforced facesheets. The inserts possess a unique capability of micro structural features for better integration and distributing of the paste adhesive for more efficient integration into the composite sandwich structure. The combination of these components offers an integrated, lightweight solution when mechanically fastening sandwich composites. The experimental and numerical investigation explores the influence insert geometry has on the structural response of a sandwich composite under single-lap shear load scenarios. Various failure modes are observed during experimental analysis for both the additively manufactured inserts and standard inserts. The additively manufactured inserts show increases in maximum force and total energy absorption. Stress fields in the honeycomb core, debonding stresses, and overall panel deflections are investigated with finite element models, which further validate the mechanics observed experimentally. These results illustrate the potential of an integrated approach to mechanical joint technology by combining these novel additively manufactured inserts within sandwich composite structures.

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abst. 1198
TEODORICO
Tuesday
September 3
16h30

Tensile and flexural elastic properties of woven fabric composite laminate with a small number of plies

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Composite materials represented by carbon fiber reinforced plastics are increasingly being applied to lightweight structural components in aerospace engineering. Composites reinforced with woven fabrics are used in the structure with curved surfaces because of their conformability to the complex shape. These woven fabric composites are typically used as laminated plates or shells. When evaluating the mechanical properties of such composite laminates, each lamina (ply) is usually treated as a homogeneous material. However, the intralaminar inhomogeneity of the mechanical properties of the constituent materials is more significant in woven fabric composites than in unidirectional fiber reinforced composites because yarns are interwoven within each ply and the thickness of each yarn takes up large percentage of the thickness of each ply in the woven fabric composite. Thus, the intralaminar inhomogeneity may affect the mechanical properties (elastic properties) of woven fabric composite laminates, especially the laminates with a small number of plies. In particular, the space deployable boom using single-ply woven fabric composite which has been under development by a Japanese research team raised the importance of elucidating the elastic properties unique to single-ply woven fabric composite lamina, which may be different from those of laminates. In this study, the tensile and flexural moduli of plain-weave fabric composite laminates (especially laminates with a small number of plies) are evaluated by the finite element (FE) analysis. To simplify the FE modelling, it is assumed that all the plies included in the laminate have the same yarn direction and that the weave structures of all the plies are aligned along thickness direction. Taking into account the in-plane periodicity, the FE based homogenization method to calculate equivalent plate stiffness is used. On the other hand, assuming that the number of plies in the laminate is infinite, in other words, that there exists not only in-plane periodicity but also out-of-plane periodicity, the macroscopic 3-D continuum elastic properties of the plain-weave fabric composite are evaluated using the homogenization methods to calculate the effective 3-D continuum elastic properties. These homogenization methods are then used to investigate the effect of the number of plies, or more precisely, the effect of intralaminar inhomogeneity, on the tensile and flexural moduli of the plain-weave fabric composite laminates. Furthermore, to confirm the validity of the analytical results,

experiments such as tensile and flexural tests are performed on specimens with different number of plies (from 1 to 5 plies). The analysis shows that both the tensile and flexural moduli of the woven fabric composite laminates are constant, and both converge to the Young's modulus of the equivalent 3-D continuum if the number of plies is large (three or more plies). While, both tensile and flexural moduli decrease as the number of plies decreases. The tensile modulus and the flexural modulus of single-ply lamina decrease by 23% and 68%, respectively, compared with the Young's modulus of equivalent 3-D continuum. In particular, the flexural modulus of a single-ply lamina decreases significantly to about one-third of the flexural modulus of laminates with three or more plies. The results of tensile test and flexural test show good agreement with those of the analysis and thus the validity of the analytical results is confirmed. The investigation of the strain distribution within the ply obtained from the analysis reveals that the out-of-plane deformation in the warp/weft intersection region may cause a decrease in the tensile modulus of single-ply lamina, while the low local flexural stiffness in the gap region between the warp/weft intersections may cause a decrease in the flexural modulus of single-ply lamina.

Comparison of effect of glassy carbon admixtures on mechanical properties of selected bone cements.

abst. 1231
TEODORICO
Tuesday
September 3
12h10

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Poly methyl-methacrylate (PMMA) bone cements are crucial in orthopaedic surgery, yet their mechanical properties can deteriorate prematurely, leading to prosthetic loosening and revision surgeries. Recent research has explored augmenting PMMA with various admixtures to enhance its mechanical resilience, biocompatibility and osteointegration. This study evaluates the selected basic mechanical properties of two commercial PMMA bone cements (Palamed® Heraeus and Refobacin Plus G) admixed with glassy carbon (GC) at varying concentrations. The study compares these properties with doped PMMA and investigates the effect of GC grain size (0.4-12 m and 20-50 m). The results reveal for both cements a significant decrease in compression strength when adding 20-50 m GC, resulting most likely from thermal interference in polymerization process. Interestingly, the introduction of 0.4-1.2 m GC in Palamed did not notably affect compressive strength across the tested concentration range. These findings highlight the prospect of improving the mechanical properties of PMMA bone cement through controlled admixture, providing a valuable contribution to improving the outcome of total joint replacement procedures.

Improvement of the mechanical properties of Kagome structures using PUR foam matrices: static and dynamic investigations

abst. 1250
TEODORICO
Tuesday
September 3
15h30

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This study investigates the opportunities of improvement of the stiffness, strength and energy absorption capabilities of metamaterial structures based on Kagome cells using rigid polyurethane (PUR) foam matrices for embedding. The lattices were manufactured through PolyJet 3D printing of an acrylic-based photosensitive resin and three types of structures were considered, corresponding to a relative density of approximately 0.1, 0.15 and 0.2 respectively, while the density of the PUR foam was maintained constant. The quasi-static properties were investigated in compression and dynamic tests were performed using a drop tower, with the structures being incorporated in sandwich panels using

thermoplastic polymer reinforced woven glass fibre faces. Considering the weight added by the PUR matrix, the performance of the investigated structures was evaluated with respect to their density. The mechanical behaviour of the structures was investigated using Finite Element Analysis, accounting for the damage and failure of both the resin and the PUR foam, in order to replicate the experimental results.

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abst. 1278
TEODORICO
Tuesday
September 3
12h30

The influence of controlled delamination areas upon mechanical properties in sandwich composites

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The work focuses on examining the mechanical properties of composites that have been specifically designed with delaminated areas. The aim of the study is to comprehend the delamination mechanisms in composites, develop methods for detecting, controlling, and eliminating these damages, and assess their impact on the mechanical properties of the materials. Experimental investigations constitute the main focus of the study, presenting an analysis of the employed methods for examining mechanical properties, the results of these investigations, and the analysis of these findings. The study primarily centers on three key aspects: flexural strength, Young's modulus, and the impact resistance of the composites. Conclusions drawn from the conducted research provide a better understanding of the influence of delaminated areas on the mechanical endurance of composite materials. The study underscores the significance of investigating delaminated areas in composites as a step towards enhancing the construction of materials with increased strength and durability. The obtained test results regarding the properties of composites with controlled delamination areas were analyzed in detail. They concerned three key parameters: flexural strength, Young's modulus and impact strength, which were considered in the context of various conditions and loads. These three parameters are important indicators of the mechanical properties of composites, which are essential, especially in the aerospace sector, where materials must demonstrate exceptional strength and resistance. The results of bending strength tests show that composites have different properties depending on the presence of delamination. The defect-free composite exhibits relatively stable flexural strength values, indicating its cohesion and ability to withstand loads. However, composites with delamination areas show reduced strength, which is an expected effect of reduced structural integrity due to delamination.

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abst. 1284
TEODORICO
Tuesday
September 3
12h50

Overlap and gap analysis and optimisation in Automated Tape Laying via adaptive finite elements

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Modern techniques in producing composite materials are Automated Tape Laying (ATL) and Fiber Placement, which allow fast and relatively cheap technology to produce large parts, such as wing skins. One of the main problems in this technology is the presence of defects, particularly between the different tapes. To avoid any void or very thin resin layer between the tapes, it is necessary to overlap the various tapes. On the other hand, overlap is detrimental to the material's mechanical properties at ply and laminate levels. Therefore, any optimisation process needs to evaluate the local and global behaviour of the composite material. Research on the influence of the gap and overlap between tapes is usually carried out through an experimental campaign or numerical test. Numerical tests have the more significant advantages of being flexible, cheap, and allowing a priori testing of various geometries and optimisations without particular design limitations. Finite element models are well established in

the numerical field; however, in the proposed problem, they may not be very efficient, needing 3D elements to be able to describe the kinematic behaviour of a multilayer material both to follow the thickness variation (positive for an overlap and negative for a gap). In this work, to prevent these limitations and ensure accuracy in analysis, a recently introduced class of finite elements is proposed: adaptive finite elements. These elements are developed within Carrera's Unified Formulation (CUF) framework. In two-dimensional models, Carrera's unified formulation approximates the kinematic field along the thickness of the plate in a unified manner that is then used to derive the governing equations in a very compact way and makes the method very easy to implement. Therefore, it works as the basis for developing the adaptive finite elements. As demonstrated in previous work, adaptive finite elements allow 2D models to study structures of varying thickness. The adaptivity of the elements is both geometric, on the thickness dimension, and numerical, allowing the accuracy of the expansion along the thickness to be adjusted for more sensitive areas of the laminate. These characteristics make it a powerful tool for studying overlap and gap problems. The numerical development of these elements is possible thanks to the CUF. According to this theory of 2D modelling, the displacement field of a generic plate structure can be described as a generic expansion of the generalised displacements on the mid-surface by employing arbitrary functions of the thickness coordinate. The arbitrary functions (called thickness function) characterise the 2D model. Indeed, depending on the choice of the thickness functions, different classes of 2D theories can be implemented among these classical theories, such as Kirchhoff-Love, Reissner-Mindlin, and so on. A recent integration in the CUF, the Node-Dependent-Kineamtic (NDK), allows the choice of the kinematic model on specific nodes with the possibility of performing a local adaptable refinement of the approximation without any compatibility requirement for the nodal kinematic. In this work, only Lagrange polynomials are considered thickness functions, allowing layer-wise models to be implemented. Thanks to the above formulation, it is possible to expand the use of 2D models to variable thickness plates by combining CUF (the thickness functions) and conventional FEM (the shape functions) into a single non-conventional 3D shape function, thanks to which it is possible to have different orders of polynomial expansion in the several spatial directions. Returning to the original problem, exploiting adaptive finite elements will allow us to study and optimise gap and overlap on composite material produced by ATL, Fiber Placements, or a similar technique in a computationally cheap and accurate way. Moreover, the mesh generation is enormously simplified compared to 3D elements. Practically, from a baseline 2D mesh, in several cases, changing the thickness superposition and the angle due to the overlap (or the same for the gap) can be modelled by variating the expansion on thickness, size and type. The work will present preliminary results on an analysis of overlapping tapes with different geometrical characteristics to evaluate the possible decrease in the composite's mechanical properties. Finally, due to the low computational cost of the elements, the influence of several overlaps and gaps on a composite made by several tapes is investigated. The final aim of this work is to use the adaptive elements as a simple and efficient tool in an optimisation process for this kind of technology.

Investigations on the bond-critical failure of the CFRP-ECC-NC composite interfaces: Experimental study and analytical model

abst. 1354
TEODORICO
Thursday
September 5
12h10

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Externally bonded carbon fiber reinforced polymer (CFRP) is widely recognized and applied in the field of concrete structure reinforcement owing to its advantages of lightweight, high strength, corrosion resistance, and good durability. However, in actual applications, the appearance of bending-shear cracks increases the interfacial stress, leading to the concentration of interfacial stress, which causes the debonding failure of CFRP. Premature debonding reduces CFRP utilization and structural safety performance. Engineered cementitious composites (ECCs) are widely used to reinforce concrete structures owing to their ultra-high toughness, self-healing properties and excellent strain-hardening properties, which improve the ductility and toughness of concrete structures. However, ECC, as a cementitious

material, still has the deficiency of low tensile strength, which limits its applications. To solve the problem of premature debonding (underutilization of CFRP) in reinforced concrete structures strengthened with CFRP and the limited increase in the load-bearing capacity of reinforced concrete structures strengthened with ECCs. In this paper, an ECC layer is introduced between CFRP and normal concrete to form a CFRP-ECC composite reinforcement structure, which can fully utilize CFRP's high tensile strength and the good durability of ECCs with multi-cracking. However, limited literature is available on the interfacial bond-slip model and damage modeling for the CFRP-ECC bond in the CFRP-ECC-NC composite interface. Currently, the existing bond-slip model is mainly for research related to the bonding performance of the interface between carbon fiber-reinforced polymer composites and normal concrete. But there are differences in mechanical properties between ECC and normal concrete, it is not yet known whether the existing bond-slip relationship model is applicable to the CFRP-ECC bond in the CFRP-ECC-NC composite interface. For this reason, some scholars have established a bond-slip model for CFRP-ECC-concrete composite interfaces based on single-shear tests. However, owing to the inherent eccentricity between the constraint imposed and the load by the single-shear test, this behavior will have an impact on the interfacial stress transfer mechanism and the interfacial force, resulting in the established bond-slip model not being able to accurately estimate the state of the force when the interface is subjected to a force perpendicular to the interface stress component. Therefore, the establishment of a bond-slip model for the CFRP-ECC bond in the CFRP-ECC-NC composite interface under a complex stress state has important theoretical significance and engineering application value for the force analysis and design calculation of CFRP-ECC composite reinforced concrete structural components. Therefore, to investigate the bonding behavior at the bond-critical failure of the CFRP-ECC-NC composite interface under bending-shear loads, ten groups of notched beam specimens with various ECC compressive strengths, ECC layer thicknesses, composite interfacial bond lengths, and bond widths were designed and fabricated. The specimens were tested for interfacial bonding performance. Firstly, the interfacial failure mode, shear stress distribution, and the bond-slip curves between materials were analyzed. Secondly, an analytical model for the bond-slip relationship at the CFRP-ECC bond in the CFRP-ECC-NC composite interface was established, and the characteristic parameters of the model were discussed. After that, the influence of the ECC strengths, ECC layer thicknesses, and interfacial bond widths on the interfacial damage model was investigated. Finally, analytical models for predicting interfacial stiffness degradation damage and bond strength depreciation models of the CFRP-ECC bond in the CFRP-ECC-NC composite interface were derived.

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abst. 1362
TEODORICO
Thursday
September 5
12h30

Specimen Optimisation for Compressive Fatigue Testing of Thick Composites

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Determination of fundamental material properties at a coupon level exists to provide relatively fast and low-cost data that supports the design process. However, compressive strength and fatigue data derived from coupon testing are typically applied with significant conservatism owing to large variability in results. Uncertainty in compressive data tends to increase further with laminate thickness. The effect being acute in the marine and wind-energy sectors, where the highly compressed and already large structure sizes can be quickly magnified with over-design. Greater structural redundancy from ill-informed design increases weight and manufacturing costs, mandates alterations to production methods, worsens hydrodynamic and aerodynamic drag, and reduces the advantages of composite use over conventional materials. Prior research to enhance the accuracy, precision and reliability of compression test methods has centred three primary sources of inconsistency: the introduction of strain concentrations, the occurrence of gross column buckling and the strain gradient through the gauge thickness. These efforts have been somewhat successful, with developments in combined loading and sandwich structure coupon testing. However, the partial load-transfer through shear used for combined loading limits its applicability for compression fatigue testing, and the use of sandwich structures becomes quickly impractical as the sample thickness increases beyond a few millimetres. A finite element model of an end-loaded specimen was developed. End-loading allows for a smaller and more practical specimen than a sandwich coupon while also avoiding the complications of shear load transfer experienced by combined loading. As the specimen is to be only end-loaded, the onus for improvement was placed almost entirely on the respective tabbing parameters. Therefore, the tab geometry and material present themselves as the focus of the study, with analysis aiming to develop an understanding of the relationship with the three identified sources of inconsistency. It has been shown that reducing the tab modulus and thickness decreased the strain peak resulting at the tab terminations while, in tandem, reducing the strain gradient across the gauge thickness. Adjustments to the tab taper showed a limit in its effectiveness between removing inefficient material and removing load-carrying material. At approximately 15 degrees, the load was forced to be transferred into the specimen earlier along the length, reducing the strain concentration at the tab termination. Most interestingly, the depth of the concentrations' influence was shown not to change when adjusting the parameters of the tabs nor when changing the specimens' thickness. This presents an opportunity for the testing of thick composites, with the potential for outer ply blocking to negate the effects of the shallow peak while an adequately supported laminate below can be successfully tested. Tab geometry and material properties that positively influence compression testing through a reduction of strain concentrations also cause a reduction of the specimens' effective stiffness, proportionally increasing the specimen's susceptibility to buckling. Numerical techniques were used to develop an understanding of this buckling in relation to the tabbing parameters. Validation of the numerical model was completed through a comparison with experimental full-field strain measurements.

Optimal of honeycomb composite structures for attenuating vibration induced noise radiation in ducts

abst. 1364
TEODORICO
Thursday
September 5
12h50

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Honeycomb structures represent biomimetic configuration characterized by efficient spatial organization using minimal materials, thereby exhibiting superior durability and spatial utilization. - Honeycomb structures utilize structural integrity within composite configurations to enhance material durability. - It also leverages the advantage of excellent space utilization to demonstrate superior damping performance with a high area ratio. - In general, ducts carrying fluid flow often produce vibrations, which can lead to system damage and the emission of noise. - As the duct shape becomes more complex, the flow inside the duct changes irregularly, creating turbulence, and the flow wall impact occurs due to the generated turbulence, which increases vibration and increases the overall level of radiated noise. The radiated noise of the system is caused by modes with high radiation efficiency in the structure, so reducing the primary target modes is a method to decrease noise. In this study, various honeycomb structures were used to design optimization aimed at noise reduction through targeted damping of vibration modes with high radiation efficiency. To verify the radiated noise of the system, flow excitation conditions were implemented using a compressor. Additionally, to identify the causes of noise reduction, the main noise bands were checked by entering the duct, and the relationship with radiated noise was analyzed by checking the mode frequencies through external vibration measurements and excitation components via wall shear stress inside the duct. As a result, the honeycomb structure was optimized and applied to reduce vibration modes with high radiation efficiency.

Comparison of the fire properties of more sustainable resin systems in sandwich and non-sandwich composite structures

abst. 1366
TEODORICO
Tuesday
September 3
16h10

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The FENICE project (upscaling, KAVA9, EIT RawMaterials, www.fenice-composites.eu) is an EU-funded project whose main objective focuses on the development of lighter battery cases with good fire resistance using innovative composites (FML, Fiber Metal Laminates) with advantages in terms of sustainability and safety. To this end, different more sustainable prepregs are being developed using resin systems such as PFA, Elium and Crosspreg® (a system developed by CROSSFIRE, which is one of the project partners). In the following work, the fire properties of these systems in sandwich and monolithic structures are studied using a cone calorimeter in order to observe which of the configurations is more resistant to fire. For these composites, aluminium of different thicknesses of 0.5 and 0.1 respectively will be used, so this is also compared. In addition, the mechanical properties of the materials before and after exposure to fire are studied by means of flexural tests. This way, the residual strength of the materials after a possible fire incident is evaluated.

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abst. 1367
TEODORICO
Thursday
September 5
16h10

Predicting Effective Characteristics and Measuring Dynamic Properties of Mineral Casting for Enhanced Vibration Damping

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Mineral castings are widely used in a variety of industrial applications to reduce vibration in machinery and equipment. To achieve low vibration and vibration robustness, it is important to ensure optimal dynamic and static properties of mineral casting materials and their composition. The overall physical properties of mineral casting composites are influenced by the type and proportion of internal materials, including minerals and epoxy. To develop a configuration that maximizes vibration damping efficiency, it is essential to predict the overall properties based on a given material and its amounts and ratios. Vibration damping is intrinsically linked to the dynamic behavior of composite structures, so it is important to accurately measure the dynamic properties. This is especially important in vibration structures where accurate measurement of dynamic characteristics has a direct impact on performance and reliability. Therefore, this study focuses on developing a model that predicts the overall characteristics of mineral casting based on the characteristics of its constituents. We utilize a variety of materials to cast mineral composites and conduct experiments to measure the dynamic properties of the specimens. By analyzing and comparing trends between different material compositions and experimental results, we aim to identify optimal material combinations and ratios for improved vibration damping.

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abst. 1404
TEODORICO
Thursday
September 5
16h50

Effects of carbon nanomaterials on the interfacial properties of carbon fiber reinforced epoxy resin composite

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The surface of carbon fiber is treated with sizing agent containing hydroxylated carbon nanotubes, fullerenols, and graphene oxide, respectively. The effects of carbon nanomaterials and their structures on the surface properties of carbon fiber, the interfacial properties and the mechanical properties of carbon fiber/epoxy composites are investigated. All three types of carbon nanomaterial can improve the interfacial bonding strength and modulus, thereby enhancing the interlaminar shear strength (ILSS) of composites. Moreover, the ILSS increases with the increase of interfacial bonding strength, duing to the roughness and the number of active groups. Compared with the composite without carbon nanomaterials, the interfacial bonding strength of the three nanoparticle-modified composites increased by 14%, 5% and 4%, the modulus increased by 10%, 26% and 9%, and the ILSS increased by 14%, 8% and 7%, respectively. The interfacial bonding strength has a more significant impact on the ILSS than the interfacial modulus.

Evaluation of Strength Composite Cross Joint Reinforced by I-fiber Stitching

abst. 1411
GALLA PLACID
Friday
September 6
10h20

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Layered composites are widely used in lightweight structures due to their excellent in-plane mechanical properties, but they exhibit vulnerability in the thickness direction as they rely on the properties of the resin. This can lead to interlaminar delamination, which can reduce the durability and stability of the structures. To address these issues, methods such as stitching, braiding, tufting, weaving, and Z-pinning have been developed, and the structural reinforcement effects of these methods have been studied [2-7]. The I-Fiber stitching technique has attracted attention as a method that can effectively prevent interlaminar delamination and increase the strength in the thickness direction of composites. Kim [1], An [2], and Song [3] have applied the I-Fiber stitching technique to T-joints and single lap joints and confirmed that joint strength significantly increased. Jonathan [4-7] analytically studied the strength characteristics of I-Fiber stitched structures using cohesive and solid elements. Most of these studies have compared analyses and experiments on structures with a single I-Fiber inserted. Although some experimental studies have evaluated the strength of structures with multiple I-Fibers inserted, there has been little research on methods to predict the strength of reinforced structures. In this paper, we conducted experiments and analyses on various stitching patterns (3x3, 4x4, 5x5) with multiple I-Fibers inserted into cross-shaped composite joint structures to establish a method for predicting the strength of these structures. Cross-shaped composite structures were fabricated, and specimens were prepared by inserting I-Fibers in each pattern in the thickness direction. Finite element analysis was performed using spring elements to simulate the I-Fibers, and a method to predict the strength of the reinforced structures was established. To evaluate the tensile properties of joint structures with multiple inserted I-fibers, cross-shaped composite structures were fabricated by overlapping two composite beams at right angles. The composite beams were fabricated by stacking prepreg materials, using a jig to achieve a [0/-45/90/45]4S stacking pattern. The material used for the stacking was USN125 from Korea Toray. After laminating the cross-shaped composite beam structure, I-fiber reinforcement fibers were inserted in 3x3, 4x4, and 5x5 stitching patterns in the thickness direction to produce the specimens. The I-fiber reinforcement fibers used were 6K H2550 carbon fibers from Hyosung Corporation. Two types of specimens were created depending on whether a release film was inserted in the overlapping part of the composite beams. In the specimens without the release film, the structure was reinforced by the I-fiber reinforcement fibers and bonded by the excess resin simultaneously.

Crosspreg, the innovative composite system, mass productive, hybrid reactive, thermoplasrtic behaving, to lightweight in circular economy

abst. 1413
GALLA PLACID
Friday
September 6
10h40

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crosspreg is a RT solid, very quick reactive curable, thermoplastic behaving over its Tg, circular recyclable, solvent free, resin/prepreg system to join the thermoset materials thermal stability and fabric saturation, with the thermoplastic like advantages, over its Tg, like thermoforming, thermoplastic overmolding, mass production and easy recyclability. Its RT solid nature, offers further advantages in terms of LCA, without frozen transportation/storage and very long shelf life. Crosspreg offers several ways to recycle, all granting high value to the secondary raw materials obtained, in circular economy way. Crosspreg is already highly compatible with Bio and recycled (not sized) fibers/fabrics. An important quote of the source monomers comes from its circular recycling. Crosspreg is now developing its Graphene added formulations and technology to mass productive automotive components within the giance ec funded project

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Composite structures in civil engineering

abst. 1261
Repository

Comparative analysis of axial compression behaviour in square HST, RCC, and CFST stub columns at elevated temperatures

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Fire is one of the natural hazards that can affect the lifespan of a building or possibly destroy building structures. Columns, being one of the crucial components of the structural frame system responsible for the transfer of loads, must possess the capacity to withstand fire to some degree. Since square columns are widely employed in residential, industrial, and commercial constructions, the primary aim of this research is to assess and compare the post-fire structural capacity of square Reinforced Cement Concrete (RCC) columns, Hollow Steel Tube (HST) columns, and Concrete Filled Steel Tube (CFST) columns under axial compression. In this research, an experiment was conducted to examine and compare the post-fire axial compression characteristics of square RCC, HST, and CFST stub columns having identical dimensions of 91mm $\times$ 91 mm cross-section and 300 mm height. M25 grade of concrete, 10mm diameter of HYSD longitudinal bar, and YST-240 grade of HST with a thickness of 3mm are used in this research. The column specimens were exposed to room temperature to elevated temperatures of 300 degrees Celsius, 450 degrees Celsius, and 600 degrees Celsius with an exposure duration of 45 minutes in a temperature-controlled furnace and then subjected to further axial compression tests using a Universal Testing Machine (UTM). Critical parameters such as load-carrying capacity, ductility, percentage reduction, and failure modes are systematically analysed and compared. The results of the comparative analysis demonstrate that at any given temperature, the axial load-carrying capacity of CFST columns is more than the total load capacity of RCC and HST columns, with RCC columns having the lowest strength. Up to 300 degrees Celsius, the yield segment of the load-deflection curve for CFST columns falls between the yield segments of RCC and HST columns. Beyond 300 degrees Celsius, the yield segment of the CFST columns' load-deflection curve coincides with that of the HST columns. The load-bearing capacity of RCC and HST columns declines as temperature rises. In contrast, it is observed that the axial load-carrying capacity of CFST columns increases marginally (from 4.13 percent at 300 degrees Celsius to 7.42 percent at 600 degrees Celsius) at an average rate of 2.5 percent as temperature rises from ambient temperature to 600 degrees Celsius. The ductility of HST and CFST column specimens increases while that of RCC columns declines as the temperature rises to 600 degrees Celsius. The enhancement in strength of CFST columns up to 600 degrees Celsius can be attributed to the confinement effect of concrete and the temperature difference between the outer surface of the steel tube and the concrete core in CFST. Additionally, the deterioration of steel tubes occurs at a significantly higher temperature compared to that of concrete. In conclusion, the findings of this research contribute to understanding the response of different structures under axial compression after exposure to elevated temperatures, aiding in the choice of fire-resistant structural designs based on the requirements of the structure.

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abst. 1311
GIUSTINIANO
Wednesday
September 4
13h10

Experimental and numerical analysis of shear connection in composite cold-formed steel beam system for modular building application

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Modular building systems offer numerous benefits such as quick erection, improved energy efficiency and less reliant on good weather over conventional construction methods. Cold-Formed Steel (CFS) has been widely used for residential, commercial and light industries due to lightweight and ease to

install. Composite beams comprised of steel sections and concrete slabs, are one of the most widely used beams due to their advantages such as improving stiffness and strength compared to bare steel or reinforced concrete beams. Shear connectors are key elements that ensure integrity in a composite system. The primary purpose of a shear connector is to bring a high degree of interaction between composite elements. A wide variety of connectors is available for hot-rolled composite construction, connected to the beam through welding. However, with CFS members being very thin, welding of shear connectors is not desirable in cold-formed composite constructions. Shear connectors for cold-formed elements are limited in studies as well as in the market. Furthermore, sustainable performance for shear connection of built-up sections in modular constructions is still unknown. To evaluate the ultimate shear strength, failure mode and ductility performance, a few numbers of push-out tests were conducted under static loading. Finite element models using ABAQUS software were validated using test results, and then, further models were developed. The effective parameters include infill position, infill material, mortar strength, number of bolts and different hollow bone shapes. Increasing mortar strength and number of bolts showed good results among all the specimens.

Composites in concrete-based structures

abst. 1011
DANTE
Friday
September 6
11h50

Synergy of steel, polypropylene, basalt and glass fibers in high performance concrete composites

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The addition of fibers is currently one of the most frequently used methods to improve the tensile characteristics of concrete. Fibers improve ductility, energy absorption capacity and reduce cracking of concrete, but on the other hand they can have a negative impact on the workability. The aim of the work is to investigate the influence of various types of fibers, such as steel, polypropylene, basalt and glass fibers, on the fresh properties of high-performance concrete composites (HPCC), as well as the resultant mechanical properties and fiber hybridization. Single- and double-fiber hybrid composites were produced using different fiber types with a 3% volume fraction in two different fiber ratios (1:1 and 2:1). Slump test, compressive strength, splitting tensile strength and flexural strength tests were performed. The flexural test results were analyzed in detail to determine representative fracture parameters and identify synergies associated with different fiber combinations. It has been shown that basalt fibers for a given volume fraction have the most adverse effect on the workability of HPCC. Furthermore, based on selected analysis schemes, fiber combinations were identified that show maximum synergy in terms of flexural toughness.

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abst. 1072
DANTE
Friday
September 6
12h10

The influence of fiber and mesh reinforcement on the mechanical and static properties of high-strength fiberglass concrete composites.

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This contribution describes a selected stages of the development of high-strength fiberglass concrete composites, intended for the production of facade panels and other architectural elements with high useful properties in the form of high tensile strength after bending, low absorption and very good durability. The carried out research works were focused on the development of the production technology of pouring fresh fiberglass concrete mixtures into molds of the required size, but also on the development and optimization of the fiberglass concrete recipes, in which a combination of scattered fiber and mesh reinforcement in their composition was applied. The proposed fiberglass concrete mixtures were characterized by a specific composition, especially from the point of view of the reinforcement used. While common high strength concretes mainly use dispersed steel wire reinforcements in their composition, the developed concrete mixtures contain dispersed fiber reinforcements based on glass fibers of various lengths and glass mesh reinforcement. The aim of this step was to enable the production of future high-strength fiberglass concrete composites, not only with the help of the method of casting fresh mixture into prepared molds, but also with the help of the method for the production of sprayed fiberglass concrete composites, which is currently still a unique method, given the high strength requirement of the composites produced in this way. Prefabricated fiberglass concrete panels were evaluated especially from the point of view of compressive and tensile strength characteristics after 7 and 28 days, bulk density and absorbency. Testing was carried out according to the EN standards. The other significant stage of testing was the evaluation of durability tests and aesthetic parameters of fiberglass concrete composites. Special testing equipment of Research Institute for Building Materials was used, intended for testing the durability and resistance of building composites, especially against the effects of external climatic influences. The last stage of testing was focused on the static assessment of the developed composites in terms of pressure and wind suction on the tested composite facade panels. The result of the load tests of the concrete panels was knowledge about the mechanism of deformation and failure in the loading process even when the objective limit bearing capacity was reached. Also the static assessment was carried out for installation on the facades of buildings in the territory of the Czech Republic in wind zones IV and V, according to ČSN EN 1991-1-4. The static assessment proved the satisfactory load-bearing capacity and usability of these composites up to hight of 30 m in the mentioned wind zones. Using the chosen methods, it was possible to realize the production of composite thin-walled

facade panels with a bending tensile strength exceeding 21 MPa and an absorbency of less than 5 % by weight. The very good resistance of the developed facade panels was confirmed by numerous tests in the form of long-term durability tests and static assessments.

Seismic Performance of RC T-Beams Strengthened in the Negative Moment Region with UHPC Layer

abst. 1128
DANTE
Friday
September 6
11h30

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Ultra high performance concrete (UHPC) demonstrates exceptional compressive strength and toughness as a result of its compact micro-structure and fiber bridging. This study examined how effective a UHPC layer is in improving the seismic performance of the negative moment region in reinforced concrete (RC) T-beams. Three beams were subjected to cyclic loads in a test, one being an RC control beam and the other two being UHPC strengthened beams. The influence of steel bars in UHPC was taken into account. A comparative analysis was conducted on the specimens' failure modes, hysteresis response, skeleton curves, strains of steel bars, stiffness degradation, and energy dissipation. The findings revealed that the proposed UHPC strengthening techniques resulted in a minimum 87% increase in load-carrying capacity and a minimum 29% enhancement in energy dissipation. With increasing diameter of steel bars, the load-carrying capacity of the UHPC strengthened specimens exhibited an improving trend. A design method for predicting the flexural capacity of UHPC strengthened beams was implemented, with the average ratio of predicted values to tested values being 0.99.

Offshore floating wind turbine foundation revolution enabled by FRP reinforced ultra-high-performance concrete structures: development, durability and aero-hydrodynamic analysis

abst. 1223
DANTE
Friday
September 6
12h30

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Offshore floating wind turbines (OFWTs) are becoming increasingly popular due to their high wind energy harnessing capabilities and low visual pollution, while conventional steel supporting foundations for OFWTs are facing severe corrosion and high maintenance costs. In this study, fiber-reinforced polymer (FRP) reinforced ultra-high-performance concrete (UHPC) composites (referred to as FRU composites) are proposed to build the foundation of OFWTs. Extensive experimental studies on mechanical properties of FRU composites and elements are carried out, and results demonstrate that FRU composites and elements have excellent mechanical properties. Durability assessment of FRU plates under simulated marine environment is conducted based on accelerated aging tests and tensile tests of FRU plates. Scanning electron microscope (SEM) analyses are conducted to explore the fracture surface and interface between FRP and UHPC matrix. Strength design methodologies for FRU elements under various loadings are established. Aero-hydrodynamic analyses and comparative studies on FRU

and steel OFWTs are conducted and the results show that FRU OFWTs exhibit a better stability and smaller motion responses under a coupled wind-wave-current loadings. Successful development of FRU composites is expected to revolute the industry of OFWT by introducing durable and low-cost options of foundation.

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abst. 1286
DANTE
Friday
September 6
12h50

The influence of perforated CFRP tubes on the load-bearing capacity of self-compacting concrete

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In the face of the global raw materials crisis, growing environmental concern and need for design solid structures, reinforcement for concrete elements with FRP composite profiles seems to be more and more attractive. The use of this type of reinforcement can take various forms, including ribbed bars and profiles with open or closed sections. Previously, mainly steel tubes were used to reinforce concrete elements with closed sections. Concrete-filled steel tubes (CFST) provided stability and reduced the risk of buckling of slender column elements. The external confinement of the concrete columns creates a triaxial state of stress during compression (which increases the load-bearing capacity of the elements). In addition, the steel tubes in the CFST also functioned as lost formwork. On the other hand, some attempts have been made to use steel closed-section profiles as internal reinforcement. This solution is used to increase the rigidity of the structural element and the possibility of placing installation pipes inside it. This solution is usually implemented with an external profile acting as formwork – and called concrete-filled double tube (CFDT). As a result of combining both ideas, both the outer and inner profiles (mainly steel pipes) could be filled with a concrete mixture. This solution combines the advantages of both closed-section profile reinforcement systems, but it does not provide cooperation between the inner concrete core and the outer jackets. In this case, research was conducted on the authored manner of reinforcing concrete column using perforated CFRP pipes inside solid CFRP pipes. The purpose of using this type of internal reinforcement in the element is to ensure the lateral confinement effect of concrete and maintain cooperation between the concrete core and the outer shell. For research purposes, cylindrical concrete specimens were prepared with usage of CFRP pipes (solid and perforated) and self-compacting concrete (SCC). Different CFRP pipes arrangement relative to concrete (inside the cross section, outside and combined) and different thicknesses of CFRP tubes were considered in this studies. The specimens were subjected to uniaxial compression tests to determine load-bearing capacity and stiffness. During the tests, horizontal and vertical displacements were measured. Based on the obtained research results it has been shown, that usage of CFRP pipes has significant impact on the load bearing capacity, stiffness and energy of destruction of the composite samples, in comparison to plain concrete.

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abst. 1408
DANTE
Friday
September 6
13h10

Modelling of static behavior of FGM concrete beams with the addition of GNPs

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The present experimental and numerical works come from the idea about the possible fabrication of cement and generally civil structures using nano-additives based on uniform and functionally graded (FG) amalgamations to possibly improve mechanical properties. On this matter, one-directional functionality and material grading utilizing a carbon filler through the thickness of the cement beam-like samples have been assumed by means of four-layer mixtures in two different arrangements. The nano-additive has been graphene platelets (GPLs) and the matrix has been Portland cement consisting of sand and

superplasticizer but omitting concrete coarse aggregates. The prepared samples were classified as X-FGM, O-FGM, uniform mixing, and the classic cement specimen excluding the carbon additive. The recipe for samples has been developed at 0.05%, 0.25%, and 0.45% of GPLs for uniform beams, and a combination of 0.05% and 0.45% for FG beams. The essential mechanical properties of the specimens such as Young's modulus and Poisson's ratio have been obtained via the data extracted from the wave frequency method. The three-point bending test exposed to a transverse line load was performed employing a vertical machine test and the displacement results were measured by the Digital Image Correlation (DIC) method. The results given by DIC have been compared with those of the FEM established by Abaqus commercial software and a satisfactory concord has been observed. This work can be shared as a starting point for civil engineers and researchers on the merits and demerits of the construction of cement-based structures via FG compositions.

Composites in innovative applications

abst. 1409
GIUSTINIANO
Wednesday
September 4
12h50

Comparative Analysis of Carbon Fiber Recycling Technologies: Advantages of CURTI's Thermal Recycling Technology in Europe's First Plant by HERA

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The increasing demand for sustainable solutions in materials engineering has propelled advancements in carbon fiber recycling technologies. This paper presents a comparative analysis of the current carbon fiber recycling methods, emphasizing mechanical, chemical, and thermal techniques. A particular focus is given to the innovative thermal recycling technology developed by CURTI, recently implemented by HERA in Europe's first dedicated carbon fiber recycling plant located in Imola, Italy. This technology stands out due to its efficiency, environmental benefits, and economic feasibility. CURTI's thermal recycling process not only ensures high-quality fiber recovery but also significantly reduces the ecological footprint compared to traditional methods. The presentation will delve into the technical aspects of this technology, its operational advantages, and the positive implications for the carbon fiber market and sustainability goals. Through this case study, the potential for broader adoption of advanced recycling technologies in Europe and beyond will be explored, highlighting the pivotal role of CURTI's innovation in shaping a more sustainable future for high-performance materials.

Composites in innovative applications (chaired by L. Solazzi)

Effect of selected ceramic admixtures on mechanical properties of acrylate bone cements

abst. 1152
GIUSTINIANO
Wednesday
September 4
09h40

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Every year, millions of individuals worldwide suffer from joint and bone conditions necessitating orthopedic surgery. Poly methyl-methacrylate (PMMA)-based bone cements, extensively used due to their biocompatibility and bonding capabilities, are primarily employed for fixing orthopedic implants. However, their mechanical properties can result in implant loosening, particularly in the aggressive environment of the human body. To enhance PMMA's mechanical strength, various additives have been explored. Our study investigates the impact of adding different grain size ceramic components to PMMA: tricalcium phosphate alpha and beta (TCP /), as well as hydroxyapatite (HA). Compressive loading tests, simulating post-prosthesis implantation conditions, were conducted on samples containing different concentrations of TCP and HA. Results reveal that TCP maintains PMMA's mechanical properties, whereas TCP leads to a slight decrease in compressive strength beyond a 3% concentration. Similarly, HA exhibits significant effects only at a 2% concentration. These findings provide valuable insights into optimizing PMMA-based bone cements as polymer-ceramic composites for enhanced mechanical performance in orthopedic applications.

Feasibility study of a front underrun protection device using different materials for industrial vehicles

abst. 1168
GIUSTINIANO
Wednesday
September 4
10h00

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This research investigates the utilization of innovative materials for a front under-run protection device (FUPD) for industrial vehicles, a crucial component for ensuring the safety of car drivers in the event of an accident involving such means of transportation. The traditional FUPD component, typically constructed from steel, features a square profile measuring 100x100x1930 mm with thickness of 3 mm and is welded to the supports. As a safety device, its homologation adheres to European standardization, which outlines three load conditions. It has been observed that the most hazardous condition involves an applied force on the external part of the FUPD equivalent to 60 kN. The initial innovative configuration is made using glass fibre reinforced polymer (GFRP), produced via pultrusion, and maintains the same geometry as the traditional component but with thickness of 6.5 mm. Due to the differing material properties of the supports and the FUPD, it was decided to connect these components using bolts. This configuration was employed to compare numerical simulations with experimental tests; such tests have been executed on a test bench specifically realised for a system developed to represent the real vehicle, where a part of the chassis is attached with the aim of simulating a fixed support for the studied assembly. A cylinder applies the load to a plate whose geometry is defined by the cited regulation; the plate is

linked to the cylinder through a hinge, in order to follow the deformation of the analysed components. Strain gauges and load cells have been applied to the FUPD with the aim of collecting the data needed to do the comparison with finite element analysis. Following positive results, then the innovative structure has been optimized with increased thickness to withstand the applied stresses effectively. Subsequently, a second solution utilizing carbon fibre reinforced polymer (CFRP) was investigated, featuring a distinct geometry achieved through filament winding. An elliptical, non-constant section was chosen. To affix the device to new supports, an adhesive epoxy was applied. In both new configurations, the supports were designed in aluminium and adjusted to accommodate the new geometry and joining method. The results indicate a weight reduction of approximately -55% for the CFRP solution and around -18% for the GFRP solution compared to the traditional steel component. Although both solutions entail higher costs than the traditional approach, the investment can be amortized over a few years, leading to reductions in fuel consumption and vehicle pollution emissions.

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abst. 1212
GIUSTINIANO
Wednesday
September 4
10h20

Development of high performance carbon felt composite electrode for vanadium redox flow battery

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Since the electrochemical reaction of vanadium couplings occurs on the surface of the electrode, it significantly affects the energy efficiency of the vanadium redox flow battery (VRFB). Owing to their chemical stability, carbonaceous materials are typically utilized as electrode material. However, the hydrophobic nature and poor electrochemical reaction with vanadium redox couple are the major drawbacks of these materials. In this study, the borophene and carbon felt composite electrode has been synthesized and used as the electrode for the VRFB. Borophene two-dimensional nanosheet, has been identified as a potential electrode material for high-performance VRFB. Morphological and structural analysis has been done to determine the growth of the borophene on the surface of the carbon fibers of carbon felt. The electrochemical performance of borophene-carbon felt specimens is determined by using cyclic voltammetry analysis. The composite electrode has high electrochemical performance as compared to the bare carbon felt. The modified electrode exhibits superior energy efficiency compared to the bare carbon felt. The results indicate that the modified composite electrode exhibits superior electrochemical activity in comparison to the bare carbon felt electrode. This study offers a valuable perspective on the potential of a novel electrode for VRFB.

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abst. 1213
GIUSTINIANO
Wednesday
September 4
10h40

SnO_2 nanoparticles embedded SPEEK membrane for vanadium redox flow battery

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The ion exchange membrane (IEM) is an essential component of the vanadium redox flow battery (VRFB). It facilitates the exchange of protons and sulfate ions to maintain the circuit during the charging and discharging processes. simultaneously, it acts as a barrier, preventing the positive and negative electrolytes from mixing. The study utilizes a composite membrane consisting of sulfonated polyether ether ketone (SPEEK) and tin oxide as the membrane material for the VRFB. Various loadings of tin oxide have been employed and studied in the VRFB. The validation of tin oxide loadings is achieved through the utilization of scanning electron microscopy, water uptake measurements, swelling ratios, and assessment of vanadium ion permeability. The composite membrane containing 2 wt.% of tin oxide exhibits superior performances, such as a low permeability to vanadium ions and good efficiency, which can be attributed to the blocking characteristics of tin oxide. The SPEEK membrane, which is a composite material, has superior characteristics in terms of coulombic efficiency, energy efficiency, and self-charge discharge time when compared to the PFSA. Hence, the composite SPEEK membrane shows potential as a viable alternative to the conventional PFSA membrane owing to its cost-effectiveness and superior performance.

Development of high-performance MXene-rGO carbon felt composite electrodes for vanadium redox flow batteries

abst. 1214
GIUSTINIANO
Wednesday
September 4
12h10

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Vanadium redox flow batteries (VRFBs) have captured considerable attention in the field of energy storage systems due to their safety, affordability, and long cycle life but encounter challenges in widespread adoption due to low energy efficiency. The inability of VRFBs often arises from the comparatively slow reaction kinetics of the V3+/V2+ redox pair. Therefore, creating a superior electrocatalyst to accelerate the negative reaction kinetics is a effective way to increase battery performance. This work investigates MXene-rGO and carbon-felt composite electrodes, made up of rGO and MXene, as electrocatalysts for the V3+/V2+ reaction in VRFBs. The synergistic benefits of MXene, known for its high surface area, hydrophobicity, and electrical conductivity, and rGO, for its significant surface area and exceptional electrochemical capabilities, are used to develop a modified carbon felt electrode composite to improve VRFB performance. The presence of functional groups such as hydroxyl (-OH) and carboxyl (-COOH) improves the kinetics of the V3+/V2+ reaction and increases the number of active sites for redox reactions, which increases the catalytic activity of the electrode. Cyclic voltammetry (CV) and electrochemical impedance spectra (EIS) tests are used to assess the catalytic efficacy of MXene-rGO, and the results shows that the modified electrode enhances reaction kinetics. This study helps to improve the overall efficiency of VRFBs and overcome the problems related to carbon-felt electrodes.

Analysis of thermal development during curing and mechanical characterization of nanomodified adhesives based on in-mould induction heating system

abst. 1298
GIUSTINIANO
Wednesday
September 4
12h30

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The global expansion of wind energy necessitates larger turbine blades, leading to increased production times. This research investigates the use of induction heating nanoparticles to reduce the extensive curing phase in blade assembly and bonding processes. These nanoparticles enhance self-heating chemical reactions in epoxy adhesives, enabling precise placement of reactive precursors for on-site composite joint creation. The study evaluates nanoparticles mixed into commercial thermosetting resins to develop self-heating polymer composites for on-site strengthening of composite structures, focusing on a specific thixotropic bonding paste. Traditional methods such as convection ovens, thermal blankets, and radiant heaters indirectly heat the bondline, which can reduce efficiency due to the additional energy required to heat the entire adherend. In contrast, induction heating utilizes high-frequency electromagnetic fields to heat susceptor materials embedded within the bondline, directly enhancing the curing process. This method allows for localized heating, minimizing the risk of overheating adjacent components and eliminating the need for direct electrical connections. This research also explores the integration of the adhesive susceptors as magnetic powders with Curie temperature-limited heating, offering a controlled heating process tailored to adhesive requirements. The research proposes the development of a finite element model to predict the thermal behavior of the adhesive bond layer during curing, integrating heat transfer equations with curing kinetics. This model aims to optimize curing times and prevent overheating, thus maintaining bond integrity. Further, the study assesses the thermal behavior of selected nanoparticles using Differential Scanning Calorimetry (DSC) analysis and conducts physical and

mechanical characterizations to meet specific production needs. A lab-scale prototype of the induction device and bonding process is developed to evaluate the feasibility of scaling up this technology for industrial use in wind turbine blade manufacturing. This approach aims to enhance the efficiency of blade production by shortening cycle times and ensuring the structural integrity of the blades through improved adhesive technologies.

Delamination, damage, fracture, failure and durability of composites

Mechanism based Paris Law Approaches for Delamination Growth Characteristics of Composite Laminate under Fatigue Loading

abst. 1024
DANTE
Friday
September 6
09h00

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ASTM-D5528 and D6115 are widely used for investigation on mode I delamination of composite laminate since delamination is one of the critical failure modes and major considerations in composite structures design and certification. However, it is important to remind that ASTM-D5528 and D6115 are for static delamination initiation (fracture toughness) and fatigue delamination growth onset respectively. They are vital for supporting the current conservative 'non-growth' principle used in design and certification of composite structures such B787 and A350 composite airframe components. Moving forward to more efficient damage tolerance (DT) design criterion and certification regulation, it is vital to develop reliable fatigue delamination growth methods for composite materials. Since there are no testing and more critically analysis methods specially designed for composite materials, numerous previous studies have been based on the analogy of the methods for metallic materials, in particular the Paris Law which is based on Linear Elastic Fracture Mechanics (LEFM). It is well known that delamination growth behavior of the composite laminate is significantly different to the crack growth behavior of metallic material. The additional fiber bridging generated in the DCB specimen used in the ASTM standard introduces strong non-linear traction force distribution behind the delamination crack tip. Various empirical approaches have been proposed in the literature to modify the Paris Law to consider the nonlinear fiber bridging effect by introducing additional fitting factors. The empirical approaches are potentially violating the similitude principle central to LEFM which the Paris Law is based on and leading to misinterpretation. Furthermore, the empirical approaches are in fact to correlate the consequences based on the consequences, not based on the cause of the consequences. A comprehensive review is carried out in this study to identify the unique characteristics of delamination growth of composite laminates and compared with the applicability of the empirical modified Paris Law. Then a new type of approaches is suggested based on the two distinguishing delamination mechanisms within the two delamination zones associated with mode I delamination growth in composite materials. The new mechanism-based Paris Law (MB-Paris Law) approaches are envisioned to correlate the consequences with the causes which are the physical of the phenomenon. Experiments are carried out to verify the proposed MB-Paris Law approaches. Good agreement between the experimental results and the results based on MB-Paris Law validates the applicability of the new approaches.

Multiscale-based multiaxial fatigue model of short fiber reinforced polymer composites under high-cycle proportional loading

abst. 1030
DANTE
Friday
September 6
10h00

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Due to the inhomogeneity and anisotropy of short fiber-reinforced polymers (SFRP), even uniaxial loading can induce multiaxial stress states inside them, which significantly increases the difficulty of grasping their fatigue behavior. To efficiently predict the fatigue life of SFRP under proportional multiaxial stress, a multiaxial high-cycle fatigue model is proposed, relying upon the multiscale modeling strategy capable of integrating the influence of fiber microstructure. Taking the fiber-matrix interface stress at the critical region as the internal driving factor of fatigue fracture is the core assumption

verified by microscopic observations. Off-axial fatigue tests with different orientations and stress ratios are performed to validate the fatigue model. Results show that the prediction accuracy has reached an acceptable level, and the quadratic polynomial surface can well represent the relationship between fatigue life and multiaxial stresses. This work provides an efficient tool for multiaxial fatigue life prediction and expounds the failure behavior of SFRP from multiscale perspectives.

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abst. 1044

Trustworthy virtual testing beyond coupons: Failure modeling of large-scale composite wind turbine blades

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Rotor blades of modern wind turbines are among the largest single components in the world that are primarily made of fiber polymer composite materials. Advancing beyond the historic feasibility limits deemed by designers, rotor blades have surpassed the 120 m length milestone. The industrial trend is still to pursue even larger blades in the coming years and the time-to-market of the new blades is essential. However, the development and certification of large rotor blades are extremely costly and time-consuming. For example, the full-scale certification test of a 100-meter-long blade typically takes more than 200 days in a test facility. There is a need for virtual testing of these large-scale rotor blades to replace at least some of the physical tests. Although considerable research has been done in the virtual testing of composite materials at the coupon level with a primary focus on damage simulations, the research on the virtual testing of composite structures with a scale order from a few meters to 100 meters is still very limited despite the urgent need from the wind energy industry. This study proposes a new test pyramid, namely the italic capital D, for composite wind turbine blades. With a few case demonstrations, this study identifies the established knowledge, the latest achievements, the topical research fields, and the current challenges for future research and development toward efficient and trustworthy virtual testing as an important replacement for some physical tests of large-scale composite wind turbine blades.

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abst. 1105
Repository

Energy release rate and mode partition solution for an edge-cracked thin circular laminated beam

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Laminated composites in curved configurations are more prone to interface cracking than planar ones. Investigating interface cracking or delamination in laminated composites requires to consider mode mixity-dependent fracture toughness, which is caused by geometric discontinuity, curvature, mixed load scenarios and material properties varying gradually in a predetermined manner. To predict the growth of curved interface cracking in laminated composites with reference to fracture toughness, it is required to accurately evaluate the mixed-mode fracture driving forces. The present work extends Wang-Harvey theories on an interface cracking in straight laminated beam to circular laminated beam. The theoretical formulation is proposed for the total strain energy release rate (ERR) and its pure components in an edge-cracked thin circular laminated beam, employing the doubly orthogonal pure-mode partitioning method and virtual crack closure technique. The mode-I and mode-II ERRs, along with their interaction, which is concerning orthogonal parameters, curvature, extensional stiffness, coupling stiffness and bending

stiffness, are accurately obtained. And the dependence on radius-to-thickness ratios and end-loading ratios is explained. The present work provides insights to predict the mixed-mode dependent fracture toughness in laminated composites with curved configurations and to establish failure criteria.

Interfacial oxidation diffusion-chemical-thermal-mechanical coupling model for thermal barrier coatings

abst. 1110
Repository

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During the high-temperature service of thermal barrier coatings (TBCs), a thermally grown oxide (TGO) layer forms, inducing non-uniform stresses and gradual interface toughness degradation. This phenomenon can ultimately lead to spallation failure of TBCs. Despite experimental observations confirming non-linear TGO growth within wavy interfaces, the comprehensive oxidation diffusion-thermal-chemical-mechanical coupling mechanism remains inadequately understood. This study addresses the knowledge gap by employing chemical potential and chemical reaction processes of major elements as independent variables within a constructed viscoplastic constitutive model. The model aims to evaluate diffusion and reaction processes, shedding light on the nonlinear growth and stress evolution of TGO. The investigation considers full TGO growth stages, including rapid oxidation generating multi-component mixed oxides, stable stages, and complexes oxidation phenomena. Results indicate that the developed multi-field coupling model successfully predicts the non-uniform TGO growth with wavy interfaces, elucidating the aluminum deletion process. Additionally, a kinetic phase diagram is obtained, together with stress evolution within TGO and along wavy interfaces. The theoretical models and numerical simulations are validated by using the experimental results. This research contributes valuable information for potential failures in TBCs after prolonged thermal cycles, aiding in their mechanical performance and reliability assessment during extended thermal service.

STRAIN RATE-DEPENDENT PERFORATION OF WOVEN FIBRE COMPOSITES UNDER IMPACT

abst. 1118
Room DANTE
Friday
September 6
10h40

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In order to reduce costs of development and production of structural components in aeronautical, space, military and automotive industry, development of high-fidelity numerical models suitable for capturing the mechanical behaviour of fibre reinforced polymer (FRP) composites in all loading regimes is inevitable. Furthermore, to accurately predict the load bearing capabilities and to correctly design the structural elements, implementation of the strain rate effects on material response is also imperative, as concluded throughout the literature. Hence, in this study, progressive intralaminar and interlaminar damage models suitable for simulation of impact phenomena in woven FRP composites are introduced. The additional element removal criterion suitable for penetration modelling due to impact loading conditions is introduced in the model. By implementation of this comprehensive mesoscale numerical model in the commercial finite element method (FEM) software package Abaqus/Explicit as a VUMAT user-defined material model subroutine, an effort is made in advancing the current state of available woven FRP material models. Intralaminar failure initiation and damage evolution is based on the Continuum Damage Mechanics (CDM) approach, whereas the interlaminar damage is modelled based on the Fracture Mechanics (FM), i.e., the Cohesive Zone Model (CZM) in the form of the decoupled bilinear

traction-separation law. Inherent oscillations of numerically obtained strain rate values in explicit integration procedures are treated by a low-pass filter-like algorithm. Strain rate dependence is implemented for both failure initiation and damage propagation. Thus, empirical logarithmic functions are utilized to scale both intralaminar and interlaminar material strengths and fracture toughness values based on the reference strain rate value and experimentally obtained data in quasi-static loading conditions. The fitting parameters of the empirical strain rate effect curves were then fitted according to dynamic experimental results. Material degradation is captured by a total of five intralaminar damage variables, and a single interlaminar damage variable. Removal of both cohesive (representing interfaces) and solid (representing FRP plies) finite elements is utilized in order to simulate the complete failure of the material point. Along the vastly used maximum damage criterion for element removal, the effective failure strain (EFS) finite element removal criterion is employed in order to accurately capture the penetration phenomena. Characteristic finite element length is used in the CDM approach in order to overcome the mesh dependency of the solution. The high-velocity perforation phenomenon in laminated woven composite structures was simulated in this work using the described numerical model. The VUMAT is developed for numerical models discretised using solid finite elements (C3D8R in Abaqus). Thus, the laminated structure is modelled using a single element through the ply thickness direction. The effects of different parameters within the numerical model on the perforation phenomena have been investigated in this work.

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abst. 1120
m TEODORICO
Friday
September 6
12h30

Characterisation of Crack Type Damage in Fiber Reinforced Polymer Composites using Digital Image Correlation and Finite Element Updating

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The excellent strength and fatigue properties together with low mass make fiber reinforced polymer composites very popular for structures in the marine, sports and aerospace industries. However, any composite contains some defects, the most common being delaminations and internal cracks. Even a barely visible crack type defect or damage in the composite structure can grow and cause a sudden failure of the material [1]. Recently developed optical measurement methods, such as full field Digital Image Correlation (DIC) [2], open up new possibilities for the non- contact inspection of composite structures in service. There are already studies using composite surface DIC strain measurements to identify defects. For certain defects, in particular cracks [3], the results are successful even under static loading of the analysed structure. However, defect detection by DIC is dependent on the defect parameters: size, especially depth in the structure, loading type of the structure and relative direction to the defect orientation. There have been no studies carried out to analyse the defect detection capabilities of DIC according to defect parameters. The surface strains of the CFRP plate with different crack type defects are measured by DIC and analysed in this study. Parameters such as minimum crack length, maximum depth in the structure from the surface, orientation angle to the loading direction at which cracks can be detected by DIC, are identified. Once the defect is visible in the strain field measured by DIC, the second task is its characterisation. Although the shape of the defect can initially be assessed from the DIC strain field, defect depth remains unknown. To determine the defect depth in the structure a validated finite element model (FEM) is created and FEM updating (FEMU) technique is used by comparing experimental DIC and simulated strain values around the defect. In addition, the growth of defects in the composite structure under various cycling loads is monitored by DIC and characterised by FEMU. Limitations and possible errors of DIC-FEMU composite defect analysis are identified by the X-ray computed tomography. It is believed that this study will be useful for the development of a non-contact defect identification and characterisation method, that can be applied to operating composite structures. References: [1] Hliva, V.; Szebényi, G. Non-Destructive Evaluation and Damage Determination of Fiber-Reinforced Composites by Digital Image Correlation. J Nondestr Eval, 2023, 42, 43. [2] Schreier, H.; Orteu, J.-J.; Sutton, M.A. Image Correlation for Shape, Motion and Deformation Measurements; Springer US: Boston, MA, 2009. [3] Bataxi; Chen, X.; Yu, Z.; Wang, H.; Bil, C. Strain Monitoring on Damaged Composite Laminates Using Digital Image Correlation. Procedia Eng, 2015, 99, 353–360.

Fatigue behavior of cracked steel beams reinforced with CFRP plates using a toughened adhesive

abst. 1123
Room GIUSTINI
Wednesday
September 4
15h30

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The use of externally-bonded Carbon Fibre Reinforced Polymers (CFRP) reinforcements is often seen as an effective technique to strengthen or retrofit steel beams affected by fatigue cracking. However, stress concentration at the crack location may lead to premature failure due to intermediate debonding of the CFRP, especially under fatigue conditions. Recently introduced toughened adhesives, composed of an epoxy matrix enriched with styrene-butadiene rubber particles, have demonstrated higher strain capacity compared to traditional adhesives. This characteristic promises the adhesive's ability to handle adequate to high stress/strain concentrations at the crack tip location, thereby preventing the initiation of debonding phenomena. This paper investigates the intermediate debonding of CFRP plates bonded to notched steel beams using a toughened adhesive. Initially, outcomes from an experimental campaign conducted at the Politecnico di Milano were considered. Steel beams with artificial cracks were reinforced at the bottom side of the tension flange using CFRP pultruded plates and subjected to fatigue loading in a four-point bending configuration, revealing a debonded area between the reinforcement and the steel beam at the crack location. Subsequently, analytical models were developed to assess strain redistribution in the reinforcement strips and the debonding length at a given crack length. The analytical formulation is intended for straightforward application in the design phase of reinforced steel beams under various loading configurations and static schemes. Finally, analytical results were compared to experimental outcomes in terms of both strain redistribution in the CFRP and debonding length.

Numerical Simulations of Embedded Delamination Defects on Damage Mechanisms in Tapered Composite Laminates

abst. 1155
Room GIUSTINI
Wednesday
September 4
16h30

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The escalating traction garnered by fibre-reinforced plastic composites is a testament to their extraordinary mechanical attributes, inherent lightness, versatility in design, and commendable resilience against corrosive and fatigue phenomena [1-3]. These composite materials have risen to prominence within the domain of aircraft engineering, witnessing an increased integration into a plethora of aircraft frameworks. Their application has transcended beyond mere secondary structural components, now encompassing pivotal structural segments such as the wings and fan blades of aircraft. To meet exacting design imperatives, composite constituents are often engineered with a taper in one or several dimensions. Such tapered laminates are instrumental in producing components with variable thicknesses and fibre orientations, thereby conferring requisite robustness and rigidity where most imperative. This methodology paves the way for the refinement of structural mass and operational efficacy, culminating in heightened efficiency and a downturn in expenditure related to operations [4-5]. In the realm of composite structures, tapered laminates are indispensable for the diminution of weight and the amplification of aerodynamic proficiency. However, the design of these laminates may induce localized material and geometric irregularities, precipitating pronounced interlaminar stresses and becoming harbinger sites for the inception of damage. The fatigue damage mechanisms of laminates with different ply-drop groups interactions, designed using the composite laminate design approach, were analysed using high-fidelity finite element modelling techniques and a constitutive equation based on the cyclic cohesive interface

model approach. The delamination defects were inserted into static and weak-link damage position to investigate the quantitative relationship of ply-drop groups interactions on fatigue damage mechanisms. The relations between delamination damage and frequency the laminates with various ply-drop groups interactions were investigated at the first natural frequency under cyclic loading with different stress ratio to discover the fatigue damage mechanisms. In the initial research phase, composite laminates featuring diverse configurations of ply-drop groups were fabricated to investigate the fatigue damage properties inherent to the composite material used in fan blade dovetails. A design methodology tailored for tapered laminate structures was established, taking into account the specific design requirements for the composite material layers. This methodology was implemented using the Fibresim® software. Various methodologies for designing tapers have been comprehensively delineated in prior literature. A critical element to consider is the architecture of the taper itself. In preceding investigations, composite tapered laminates were primarily engineered with three distinct taper angles, including eight layers named "continuous plies" and ten layers named "dropped plies". The second pivotal aspect pertains to the configuration of the layup sequence. Last area of significance is the ply-drop groups' interactions, where three different ply-drop groups are designed to investigate the interactions. The main emphasis of this study was to investigate the delamination behaviour of the composite laminates. To achieve this, a cyclic cohesive interface model approach was employed to formulate a constitutive equation. To analyse the interlaminar fatigue behaviour of the tapered laminate, it was necessary to incorporate properties related to damage initiation and evolution within the constitutive equations. The equation describing the evolution of damage, considering the aforementioned requirements, can be expressed as follows. The damage evolution law utilized in this study incorporates the Heaviside function. To determine the current damage evolution, effective cohesive quantities are employed. The cyclic cohesive interface model, which was outlined in this research, was implemented using the USDFLD subroutine feature in Abaqus® software. This study focuses on the interlaminar fatigue behaviour of laminates with different ply-drop groups interactions under cyclic loading with varying stress ratios. The study introduces a criterion for designing tapered composite material layers, which demonstrates that the laminate structure satisfies the design requirements for composite laminates by incorporating rational dropped plies and smooth transitions. Moreover, the proposed design enhances manufacturability. The study will explore the damage mechanisms of laminates featuring various ply-drop groups. This will be accomplished through a static damage assessment method that utilizes a bi-linear traction-separation cohesive formulation. By employing this method, the study will identify the maximum damage index occurring at the interface of cohesive element plies. In addition, the study presents a dynamic damage assessment method utilizing the classical constant life diagram model to predict the weak-link zone for high-cycle fatigue. The results will reveal a significant influence of different ply-drop groups on the maximum value of the damage index in cohesive element plies. Laminates with multiple ply-drop groups could lead to a significantly wider range of stress distribution and exponentially stronger interaction between adjacent layers on the same taper angle laminates, which could lead to a higher initial value of cumulative damage and ultimately results in earlier fatigue failure. At last, delamination defects were inserted into static and weak-link damage position to investigate the quantitative relationship of ply-drop groups interactions on fatigue damage mechanisms for the first time. References: [1] He K, Hoa SV, Ganesan R. The study of tapered laminated composite structures: a review. Compos Sci Technol 2000; 60: 2643-57. [2] Bing Z, Luiz F, Mike A. An experimental and numerical investigation into damage mechanisms in tapered laminates under tensile loading. Composites Part A: Applied Science and Manufacturing 2020; 133. [3] Mukherjee A, Varughese B. Design guidelines for ply drop-off in laminated composite structures. Composites Part B Engineering 2001; 32(2): 153-164. [4] Brod M, Dean A, Rolfes R. Numerical life prediction of unidirectional fiber composites under block loading conditions using a progressive fatigue damage model. International Journal of Fatigue, 2021, 147: 106159. [5] Zhang B, Allegri G, Yasaee M, Hallett SR, Partridge IK. On the strain and delamination sensing functions of CFRP Z-pins. Compos Sci Technol 2015; Under Revi:1-25. [6] Jin L, Chen Y, Tang X, et al. A numerical study on damage characteristics in composite tapered laminates under cyclic loading with different stress ratios. Composite Structures, 2023, 311: 116777.

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abst. 1224
TEODORICO
Friday
September 6
11h50

Reinforced crack propagation in a prestressed and prepolarized piezoelectric material

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In this paper the problem of an antiplane reinforced crack in prestressed and prepolarized piezoelectric materials is considered. Using the boundary conditions of the reinforced crack we get the homogeneous and a nonhomogeneous Riemann- Hilbert problems. Nonhomogeneous linear complex differential equations having the unknown complex potentials are obtained. For a constant value of the applied incremental forces can be obtained the complex potentials, incremental displacement and stress fields corresponding to the third mode of the classical fracture. Extending Sih's strain energy density failure criterion for prestressed and prepolarized piezoelectric materials we study the antiplane reinforced crack propagation in a PZT type piezoelectric material. Using numerical results and the graphical representation of incremental strain energy density, the direction of antiplane reinforced crack initiation can be predicted versus different values of stiffness constant and for different small values of initial mechanical and electrical fields.

Monitoring the non-linear behaviour of concrete structures using the homogenisation principle

abst. 1240
Repository

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Abstract. The need to describe the behaviour of brittle materials in order to predict the initiation and progression of failure in structures has led to a great deal of work. Starting from the principle that beam theory tends to study the overall behaviour of elements before and after failure, "the appearance of macroscopic cracks without taking into account the initiation of these cracks at the microscopic scale well before failure". Continuous damage mechanics has attracted increasing interest and has become a promising tool for describing material degradation, where damage is represented by internal scalar or tensor state variables, depending on the modelling objective. The quality of a behavioural model is generally assessed according to two criteria, namely its ability to reproduce representative elementary or structural behaviours (tension, compression, bending, shear, etc.), taking into account multiaxial behaviour, the efficiency of its implementation (resolution algorithm, convergence) and the simplicity of calibrating the parameters it uses (or their physical meaning). Based on these criteria, a new model has been developed to monitor the non-linear behaviour of concrete structures [1, 2]. This model is determined by applying the principles of damage and fracture mechanics [3, 4] and by using the current laws of non-linear unidirectional behaviour of concrete that are commonly accepted in the continuous mechanics of materials - Sargin's law [5] for compression and Grelat's law [6] for tension. It should be noted that Sargin's law is defined by two coefficients that adjust the descending and ascending parts of the behaviour law. These coefficients are very representative and are related to the ductility or otherwise of the concrete used. To be able to rely on the theory of continuous mechanics, it is necessary to replace the real material by an equivalent fictive homogeneous material. The combination of these two laws, "Hooke's low generalised" [7] and the theory of damage mechanics, "Theory of isotropy of damage and principle of equivalent deformation" [3], leads us to a law of variation of damage in three directions, applied in two directions and in one direction [1, 2]. This principle is expressed as "The same deformation caused by a stress in a damaged material can be obtained by applying an equivalent stress in the same undamaged material" [3]. In this study, a ductility parameter, an ultimate strain and a compressive yield point for concrete were proposed, which allowed us to monitor the actual behaviour of concrete structures up to failure. The variation of Poisson's ratio is necessarily imposed by the introduction of the hydrostatic effect on the concrete material, indicating a change in the modulus of compressibility [8]. Assuming that this coefficient is related to a change in volume associated with volumetric damage, Young's modulus is more closely related to deviatoric damage.The study by Bouafia et al. (2014)[1] and Smahi et al. (2015)[2] proposes two damage variables and an equation for the variation of the Poisson's ratio, which essentially depends on the state of loading (uniaxial or biaxial). A finite element calculation programme is proposed, based on the fact that each loading step corresponds to a displacement step. The application of the Newton-Raphson algorithm, which consists in calculating the secant stiffness (introduction of the secant modulus of elasticity) at each loading

step and for each iteration, and the application of the weighted residual method, which consists in considering a non-zero residual at each iteration. The application of the relationships adopted (evolution of Poisson's ratio, evolution of unidirectional and bidirectional damage) and the comparison of the calculations with the experimental results (behaviour of concrete in unidirectional and bidirectional compression and tension) made it possible to describe and monitor the real behaviour of concrete structures until failure. Keywords: Concrete, damage, Non linear calculation, Rupture, Static, Poisson's ratio, Hooke's low généralized, finite element, Isotropy, volumetric damage, Deviatoric damage, unidirectional, Bidirectional, Homogenization. REFERENCES [1] Bouafia Y, Smahi R, Dumontet H, Kachi MS. Modeling the Behavior of Concrete by Damage Mechanics with a Poisson's Ratio Variable. Procedia Materials Science. (2014), Volume 3, Pages 714–719. (20th. European Conference on Fracture). https://doi.org/10.1016/j.mspro.2014.06.117 [2] Smahi R, Bouafia Y, Kachi M S. Modeling the Biaxial Behavior of Concrete by Damage Mechanics with Poisson's Ratio Variable. Applied Mechanics and Materials, Vol. 749 pp 391-397, 2015. https://doi.org/10.4028/www.scientific.net/AMM.749.391 [3] Lemaitre J, Chaboche J L, Benallal A, Desmorat R. Mécanique des matériaux solides, Dunod, Paris, ISBN 978- 2 -10- 051623- 0, 2009. [4] Besson J, Cailletaud G, Chaboche J L, Forest S. Mécanique non lineaire des matériaux. Hermès-Lavoisier, 446p, ISBN13 978-2-7462-0268-9, 2001. [5] Sargin M. Stress-Strain Relationships for Concrete and the Analysis of Structural Concrete. Sections, Study No. 4, Solid Mechanics Division, University of Waterloo, Waterloo, Canada, 167 pp, 1971. [6] Grelat A. Comportement non linéaire et stabilité des ossatures en béton armé. Annals of I.T.B.T.P, N° 234, France, (1978). [7] Royis P. Mécanique des milieux continus : cours, exercices et problèmes. Presses universitaires de Lyons, ISBN: 2 - 7297- 0770- 0. ENTPE collection, 1 vol. (349 p), 2005. [8] Chen W F. Plasticity in reinforced concrete. Edited by J. Ross Pub., Fort Lauderdale, Fla. Book published by McGraw-Hil New York, 474 pp. ISBN: 9781932159745, 1932159746, 2007.

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abst. 1254
TEODORICO
Friday
September 6
11h30

Thermal shock resistace and shear performance degradation at intermediate temperature of 2D SiC/SiC

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Thermal shock mechanical properties of SiC/SiC composites is a critical issue for solving the use of aero-engine at extreme temperature. In this paper, a self-built automatic test platform was used to test the thermal shock resistance and shear mechanisms degradation of 2D SiC/SiC, revealing the effect of thermal shock on the degradation of the shear mechansims. The results show that the SiC/SiC matrix oxidised and underwent interfacial debonding after thermal shock, and caused a decreasing trend in the shear properties of SiC/SiC. The shear modulus decreased from 78.5 GPa to 63.6 GPa, which was quantitatively described by the mixing law considering interfacial debonding. The proportional ultimate stress decreased from 128.9 MPa to 99.25 MPa, which was qualitatively analysed by using the matrix cracking stress formula. The shear strength decreased from 205.8MPa to 187.3MPa, which was quantitatively analysed by using the rigid body sliding model, and the error between the theoretical and actual value was less than 10%, proving that the modified sliding model can predict the shear strength well.

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abst. 1262
GIUSTINIANO
Wednesday
September 4
15h50

Axial compression of composite filament-wound tubes: mechanical analysis with acoustic emission technique considering the influence of mosaic pattern

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The filament winding method is developing technique in the production of composite materials, especially components such as pressure vessels, pipelines or tubes. There a few technological and design parameters that are widely investigated: winding angle, fibre tension, layer thickness or stacking sequence. However, there is one less popular, namely, mosaic pattern (also called winding pattern). This parameters is inevitable and must be pointed during every filament winding design and manufacturing process. The mosaic pattern influences the material distribution and the number of interlaces on the structure. In this research, the axial compression test will be used as a mechanical analysis of the influence of mosaic pattern on the strength and stiffness of composite tubes. Three patterns were chosen (1/1, 2/1 and 3/1) and three winding angles (45, 55, 75). As an additional technique the acoustic emission (AE) method was used to examine the damage modes occurring in the structure. The dataset obtained during the AE measurements was then analysed using machine learning techniques such as clustering. The idea is to determine if there are differences in terms of acoustic emission activeness and the type of damage mode occurring in composite tubes with different mosaic patterns.

Numerical assessment of delamination fatigue crack initiation and propagation in composites within a homogenization theory of mixtures

abst. 1269
Repository

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Among the wide range of damages in composite materials, delamination has been considered to be highly critical owing to its significant effect on the stiffness and strength of the structures [1]. However, the numerical simulation of this damage within large structures has been facing some difficulties due to the necessity of incorporating interfacial elements within the whole structure. In this study, a homogenization theory developed recently by the authors [2] has been extended to the cyclic loading regime. To this end, a method based on the progressive decrease of a fatigue reduction factor [3,4] has been merged to the previously-developed one for the monotonic loading [2]. The proposed model is capable of identifying the type of loading and calculating the fatigue-related parameters according to a previous calibration for both modes I and II. To assess the performance of the developed model in simulating the initiation and propagation of damage within a pure cyclic load, three case studies in mode I, mode II and mixed mode have been employed. Two different reversion factors of 0.1 and 0.3 were employed for the calibrations as well as for the numerical simulations. To obtain the whole loading spectrum, different maximum stresses were chosen to feed the model. Results showed that there is a good agreement between experimental and numerical results and the present model could not only accurately predict the number of cycles in which a catastrophic failure in the composite phase happens, but also it is able to predict the rate of fatigue crack propagation. REFERENCES [1] Garg, N., Prusty, B.G., Ooi, E.T., Song, C., Pearce, G. and Phillips, A.W., 2020. Application of scaled boundary finite element method for delamination analysis of composite laminates using cohesive zone modelling. Composite Structures, 253, p.112773. [2] Taherzadeh-Fard, A., Cornejo, A., Jiménez, S. and Barbu, L.G., 2023. A rule of mixtures approach for delamination damage analysis in composite materials. Composites Science and Technology, 242, p.110160. [3] Jiménez, S., Barbu, L.G., Oller, S. and Cornejo, A., 2022. On the numerical study of fatigue process in rail heads by means of an isotropic damage based high-cycle fatigue constitutive law. Engineering Failure Analysis, 131, p.105915. [4] Junior, L.G., Jiménez, S., Cornejo, A., Barbu, L.G., Parareda, S. and Casellas, D., 2023. Numerical simulation of a rapid fatigue test of high Mn-TWIP steel via a high cycle fatigue constitutive law. International Journal of Fatigue, 168, p.107444.

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abst. 1297
GIUSTINIANO
Wednesday
September 4
16h10

MODE I FRACTURE TOUGHNESS EVALUATION OF INTERPLY CARBON/EPOXY - GLASS/EPOXY HYBRID COMPOSITES

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Interply (interlayer) hybrid composites are laminates produced by stacking composite materials with different reinforcement fibers. Hybrid composites are utilized to meet the design requirements of advanced structures by combining distinctive properties of each composite material accordingly. One of the significant applications of interply hybrid composites in aerospace industry is flexbeam spars of bearingless tail rotor blades. Flexbeam spars are designed as interply hybrid tapered laminates to meet compromising structural requirements considering the complex loadings on bearingless rotor blades [1]. Tapered laminates are laminates with thickness variation along their span by dropping off plies at discrete locations, allowing structural tailoring and weight savings. Nevertheless, interlaminar shear and interlaminar normal stresses caused by the material and geometrical discontinuities at ply drop-off locations make the tapered laminates prone to delamination failure [2]. Design process of tapered hybrid laminates involves interlaminar failure analysis of the structure, which requires determination of interlaminar properties of the interfaces with different reinforcement plies. In this study, experimental studies will be performed to evaluate Mode I fracture toughness of unidirectional carbon/epoxy, glass/epoxy and carbon/epoxy - glass/epoxy hybrid interfaces by double cantilever beam tests. Test results will be supported with photographs taken during the tests and with microscope images of the specimens after the tests. Finite Element Analysis of the double cantilever beam specimens will then be performed using Cohesive Zone Method for the delamination modeling. REFERENCES [1] Murri, G. B., O'Brien, T. K., Rousseau, C. Q. (1997). Fatigue life methodology for tapered composite flexbeam laminates. American Helicopter Society 53rd Annual Forum. [2] He, K., Ganesan, R. (2000). The study of tapered laminated composite structures: a review. Composites Science and Technology, 60(14), 2643-2657.

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abst. 1300
m TEODORICO
Friday
September 6
13h10

Non-Deterministic Investigation of Composite Microstructure Effects on Macroscale Properties

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Heterogeneities in the microstructure of composite materials contribute to local deformation and initiation of microcrack formation, directly impacting mechanical behavior at the macroscale. Hence, changes to variables such as fiber volume fraction, fiber size, and void and inclusion distributions, will alter the homogenized response making physical experimental testing time consuming and costly. Furthermore, it has been shown that the stiffness and thickness of the boundary between the matrix and fibers (interphase) also contribute to the homogenized properties. Given that the non-deterministic microstructure of a composite significantly influences its structural performance, probabilistic characterization of the defect distribution and correlation to macroscale properties is essential in predicting progressive failure, damage models, and mechanical properties. For material systems composed of multiple phases, homogenized properties obtained by a micromechanical approach describe bulk scale mechanical behavior and are often determined from a statistical or representative volume element (SVE or RVE). Traditional numerical methods, such as finite element analysis, have been widely demonstrated to predict homogenized macroscale properties based on variable material properties and fiber distributions. However, these methods are typically not capable of simulating progressive damage from a large number of random defects, particularly when considering the massive number of simulations needed for non-deterministic evaluation. Peridynamics offers a computational solution to rapidly generate stochastic models from probabilistic distributions of microstructural features and subsequently simulate progressive damage under loading. Peridynamic theory offers an alternative formulation to describe deformation of bodies which internal forces are expressed as an integral term in contrast to the traditionally used differential form which allows for damage to occur intrinsically by inclusion of a failure parameter in the constitutive relationship. Previous fracture studies displayed the capabilities of peridynamics to model spontaneous crack formation and complex crack patterns. In addition, an initial crack in the material domain is not required for crack propagation to occur in contrast to LEFM. Furthermore, crack propagation occurs freely without a predefined path making fracture modeling more versatile than cohesive elements. The same equation of motion can be applied in the presence of discontinuities, making peridynamics an ideal tool to model mechanical behavior of complex geometries such as composite microstructures. A methodology has been developed to generate probabilistic distributions of defect characteristics from images and to statistically formulate peridynamics models from these distributions. Peridynamics analysis is then performed to simulate progressive damage due to the microstructural defects to correlate microstructure to macroscale behavior. This method will be presented, and demonstrations will include validation of material samples that were imaged to obtain the microstructure prior to testing. These 3D images were directly imported for model creation and peridynamics analysis. Analysis and testing results were compared to validate the peridynamics model. Once validated, statistical analysis was performed to evaluate and quantify microstructural effects on mechanical properties. This analysis consisted of assigning a probabilistic density function to all material and microstructural input parameters, sampling these parameters to create thousands of input parameter combinations, generating peridynamics, and predicting macroscale behavior. The resulting dataset was then used to generate a surrogate model to generate an even larger dataset for global sensitivity analysis. Sobol' Indices were computed for all material and defect input parameters to identify the most influential characteristics on macroscale properties.

Numerical and experimental investigation of non-linear response in Ceramics Matrix Composite for reusable space vehicles

abst. 1301
Room DANTE
Friday
September 6
09h40

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The past decade witnessed a doubling of space launches, fueled by the entering of private companies into the market and by technological advancements aimed to provide affordability. For these reasons, the economic and environmental sustainability are key research areas. Focusing on structural design, the development of fully reusable spacecraft can significantly enhance the cost-effectiveness and minimize the environmental footprint of the space industry. Achieving this goal requires that the material selected is characterized by good structural properties and good damage tolerance combined with the capability to resist to multiple exposure to severe environments. Ceramic Matrix Composites (CMC) are the perfect candidate in this sense, and this research focuses on the usage of C/SiC (Carbon fiber reinforced Silicon Carbide) composite for a hot structure, which provides both thermal protection and structural functions. To verify the material suitability, V-shaped specimens, representative of a supersonic leading edge, were subjected to Plasma Wind Tunnel (PWT) exposure, thus simulating the reentry conditions. The damage tolerance of the material was investigated using a subset of specimens, that was manufactured with artificial delaminations and butt joints. The specimens were then tested mechanically to assess the PWT-induced properties degradation and the internal state was evaluated using CT scans. To perform numerical-experimental correlation, a detailed ply-wise Finite Element model of the test was developed. This model was based on the hybrid biphasic model formulation, where the fiber properties are assigned to shells and the matrix properties are assigned to layers of solid element, which share nodes with the fibers layers. The formulation is paired with a Continuum Damage Mechanics (CDM) approach, thus providing the model with the capability to represent delaminations between every layer, which was considered fundamental to replicate the experimental behavior that was characterized by the development of an extensive crack network. Moreover, the model reproduces the in-plane, matrix dominated, nonlinear response of the CMC and is able to take into account coupling between out of plane and in plane damages. This method provides a numerically effective technique to model both the in plane and the out of plane response of the material, and was calibrated with cross ply, angle ply, and Double Cantilever Beam (DCB) tests. By looking at the CT scans of the specimens it was found that they were characterized by noticeable manufacturing defects, and, to have a good correlation, these defects were replicated in the FE model. The results of the study were found to be encouraging in terms of reusability, with a good damage tolerance and no indicator of degradation for the PWT tests at design conditions. Degradation was noticeable for specimens subjected to off design condition, but the material kept an acceptable load carrying capability. The numerical experimental correlation provided valuable insight into the failure mode of the specimens and proved that a fundamental role in the failure is played by the presence of artificial and manufacturing defects. The activity presented is a part of AM3aC2A project funded by Italian Space Agency (ASI).

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abst. 1319
DANTE
Friday
September 6
10h20

Effect of damage evolution on low-velocity impact simulation of Kevlar-fibre woven composites

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Woven composites exhibit remarkable properties suitable for various high-performance applications in industries such as defense, aerospace, and automotive sectors, which can offer outstanding characteristics including energy absorption, impact resistance and ballistic performance. However, numerically modelling the response of composites under impact conditions currently remains a challenge as damage evolution are difficult to characterize considering the complicated mechanical behaviours of woven composites. Thus, it is significant to analyze the feasibility and applicability of different damage models when exploited to reproduce the mechanical behavior of composites within a wider range of impact energy with damage evolution considered. This research is aimed at comparing two damage models: Enhanced composite damage model (MAT_055) and Pinho laminated fracture model (MAT_261), where former of them considers the empirical damage evolution and the latter controls the damage evolution with fracture mechanism. To assess their predictive capabilities regarding mechanical response and damage in Kevlar-fiber epoxy plain-woven composites, low-velocity impact (LVI) responses at four energy levels, ranging from 27.9 J to 109.5 J, were investigated. The enhanced composite damage model is widely adopted for simulations involving impact and crush of composites. Pinho laminated fracture model is a composite material model with physical failure criteria and has demonstrated capability for unidirectional composites compared to other models. Its application on woven composites for low-velocity impact simulations is less explored. Therefore in this research s the potential of Pinho laminated fracture model to capture the behavior of woven composites under such conditions was evaluated. A finite element model with macro-homogeneous solid element formulation was developed to analyze the response and failure mechanisms of laminates. A rigorous calibration of the various physical and non-physical parameters was conducted (for both material models) to guarantee the accuracy. Low velocity impacts tests were performed in order to have experimental evidence of different failure mechanisms, to be compared with numenrial models. Focus was devoted to the penetration behavior between the impactor and woven composites. The results indicate that, the physically-based model (Pinho laminated fracture model) better fits the experimental data by incorporating physical-parameters. This is particularly evident in high impact energy level, where it demonstrates high accuracy on absorbed energy. Meanwhile, it also overall exhibited slightly lower peak force and more element erosion. In contrast, the empirical-based

model (Enhanced composite damage model) overestimates the damage morphology and delamination at various impact energy levels; however, it requires significantly less computational time. Overall, this study provides an in-depth understanding of the limitations and advantages of the two material models, providing insight for appropriate material model to simulate the impact behavior of woven composites.

The influence of mechanical couplings on the thin-walled composite plates behaviour

abst. 1325
TEODORICO
Friday
September 6
12h10

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Thin-walled structures are widely used in many branches of the industry. Now a days isotropic structures like steel are boldy replaced by orthotropic ones eg. GFRP (Glass Fibre Reinforced Plomer). In case of laminate structures, there exist the possibility of behaviour design under certain load by tailoring i.e. considering the nonzero elements of "coupling stiffness matrix" B as well as elements A16, A26, D16 and D26 from ABD laminate stiffness matrix. Simply supported square plates subjected to uni-axial compression with lowest and highest intensity of particular types of matrix coupling will be analysed using Finite Element Method to examine its behaviour. The intensity of the coupling will be described using coefficients from the literature.

Delamination in step drilling of fiber-reinforced composites: An analytical model considering step structure effects

abst. 1344
Repository

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Fiber-reinforced plastics (FRP) composites drilling is a common scenario in various industries. Substantial efforts have found that step drills can significantly reduce axial drilling forces and delamination damage, thus observably enhancing the mechanical properties of composite components. However, the existing predictive models of critical thrust force (CTF) have been mainly designed for twist drills, and insufficiently described the interaction between step drill structure and delamination. To fill this gap, an analytical model based on the step structure of naval drill bit to predict the CTF was established in the study. The varying tool loads during different stages of the drilling process with a step drill were considered in the purposed model. The effectiveness of the model was validated through delamination tests and cutting force measurements, exhibiting a favorable agreement of predicated and experimental results. By applying the proposed model to various types of FRP composites, the geometric design of step drills was specifically optimized, leading to a significant reduction in exit delamination damage.

Cross-sectional damage of reinforced concrete structure against steel corrosion and axial load

abst. 1352
Room TEODOR
Friday
September 6
12h50

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In the present study, considering the electrochemical relation between the steel corrosion and external loading, the structural limit under the steel corrosion was analyzed. The rust overwhelmingly formed on the steel surface results in stress to the concrete body, which may be buffered by the interfacial gap. Simultaneously, the structural capacity and performance, subjected to both axial load and steel corrosion, were quantitatively determined. Moreover, various compressive strength of concrete was

reflected to the impact on deterioration degree in term of the onset of surface cracking of concrete. To evaluate the impact of cracking of concrete column depending on the steel corrosion and external load, in the current study, finite element model was built up concerning the buffering effect on the development of rust formation on the steel surface. The rust formation-induced cracking at the cross-section of the column is considered to derive from the steel-concrete interface to the surface under corrosive condition. In fact, combination of steel corrosion and axial load is resulted in the yielding, cracking and failure driven by compressive and tensile stress. Thus, the axial load could be a more influential factor on the cross-sectional damage than rust formation in terms of structural margin (i.e. geometric or/and boundary conditions). In this study, a more crucial parameter was examined for the possibility of cross-sectional cracking: (1) geometric condition indicating the location at cross-section (2) boundary conditions including axial load and rust formation of a column. Simultaneously, the cross-sectional cracking was analytically classified into the overwhelmingly influential factor related to the structural margins. The possibility of cross-sectional cracking driven by both rust formation and axial load was evaluated, taking into account the pores at the interface between steel and concrete. The internal cracking, starting at the steel-concrete interface, was produced by compressive stress arising from an overwhelming amount of rust formed on the steel surface. Tensile deformation and damage significantly influence the concrete surface, subsequently developing into the concrete body. Tensile stress and damage significantly influence the concrete surface, subsequently developing into the concrete body. However, with a decrease in the compressive strength of concrete, the higher axial load can lead to a reduction of interfacial cracking. The axial load primarily resulted in cracking from the surface towards the core of the cross-section, whilst rust formation on the steel surface led to interface cracking in the opposite direction compared to surface cracking. The surface cracking on the cover was increased with the further axial load. The propagation of cracking from the interface to the core was restrained by the development of axial load. It is implied that the stress acting on the cross-section was reduced by the axial load. The tensile stress-induced interfacial cracking was crucially affected by the axial load, which had occurred before the surface cracking at the cover area. Moreover, the axial load had much effect on both the pattern and rate of the interfacial cracking originated to the compressive stress and simultaneously dominantly contributed to the tensile cracking compared to rust formation. The further axial load mitigated cracking due to the rust formation at the cross-section, regardless of the compressive and tensile stress. However, the cross-sectional cracking was obviously started at the development of rust exceeding the interfacial gap, which could lower the possibility of cracking by suspension effect on the rust formation-induced stress on the steel surface, suggesting that an enhancement of the structural performance for reinforced concrete structures can be accomplished in terms of chloride-induced steel corrosion.

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abst. 1378
GIUSTINIANO
Wednesday
September 4
15h10

Low, medium, and high-velocity impact and residual tensile strength of aerospace-grade carbon fiber composite laminate

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Understanding and characterizing uni-directional (UD) composite materials has gained significant interest in the scientific community in the last decade due to their exceptional mechanical properties and applications in the automobile and aerospace industry. Although there are many studies on composites in the literature, still further research is needed on out-of-plane impact behavior and the effect of the impact energy on the damage formation and post-impact tensile strength (TS) [1]. In this paper, we investigate the difference in mechanical performance between pristine UD carbon fiber and damaged-by-impact UD carbon fiber specimens. The specimens are made of Xpreg XC130 150g UD carbon fiber prepreg with a consistent stacking sequence of [45/03/-45/90]s. The design of the drop-weight machine and the method followed to impact the specimens comply with guidelines from ASTM D7136/D7136M-12. The tested impact energies are 5.2, 10.5, 14.4, 26.2, 36.0, 55.6 and 75.2 J. Each test (impact and tensile) is repeated at least 5 times to calculate an aggregate and remove any outliers in the data obtained through the mechanical testing process. The mechanical testing machine (MTS) is supplied by MTS Systems Corporation, an MTS Exceed E45.305 with a 300 kN range, along with an extensometer model 634.28-2X to facilitate accurate and precise measurements of the specimen's elongation. The impact loading is recorded using a high-speed camera. To characterize the impact damage, we conduct a detailed study of energy absorbed by the impact/transferred energy, force-time curves, visible damage area, and bending of the specimen. Initial results show that the impact loading decreases the TS of the material exponentially. The residual TS of the material decreases significantly after 26.2 J. Since the main loading plies are near the center, it was observed that, beyond this impact load, the TS decreases much more sharply. Photographic evidence also suggests that the main loading plies were also damaged beyond 26.2 J. This paper is the first of a series where we characterize the TS after impact through experiments to determine the residual TS. The study further aims to develop a numerical model using different damage models, where we can accurately predict the damage and the residual TS of these materials through simulations and then later aim to repair the impact damage using repair patches made out of appropriately selected composite material. Keywords: Tensile after Impact (TAI), impact strength, carbon fiber, uni-directional. References: [1] Mahdi Damghani, Nuri Ersoy, Michal Piorkowski, Adrian Murphy, "Experimental evaluation of residual tensile strength of hybrid composite aerospace materials after low velocity impact", Composites Part B: Engineering, 179 (2019) 107537

On static fracture analysis of brittle micropolar plates

abst. 1414
Room DANTE
Tuesday
September 3
13h10

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Knowledge on the prediction of fracture behavior is crucial for efficient applications of composites due to their heterogeneous character promoting the fracture type failure. As such materials possessing heterogeneities of significant size and texture indicates the presence of scale-effects, the medium is modelled as a two-dimensional (2D) micropolar plate with the intention on demonstrating the effect non-locality on resulting crack paths. For this purpose, an energy-based fracture criterion is proposed, and a parametric study is performed by altering the material parameters and mode mixidity ratios. Through the generalized micropolar/extended finite element method (XFEM), the basic fracture parameters are obtained numerically and substituted into the derived analytical formulation to attain the corresponding crack paths. The results are further checked by the zoom-in methodology, which helps building an accurate numerical model of the region around the vicinity of the crack-tip, in pursuit of detecting the branch orientation satisfying the fracture criterion via repetitive simulations. It is shown that, for Mode-I, a self-similar crack growth, independent of the material parameters is attained same as classical (Cauchy) continuum, whereas the direction of the crack growth is strongly affected by level of non-locality for pure Mode-II and Mode-II dominated mixed mode cases in which the crack trajectory approaches to the crack's axis due to more diffused nature of curvature field. Moreover, the trend of propagation angle and mode mixidity ratio curve deviates from the one in Cauchy continuum as the micropolarity is increased.
Acknowledgement: The Authors acknowledge the support of PRIN 2020, Project 2020F23HZ7_003 (J35F22000640001), PRIN 2022, project: 2022YLNJRY (J53D23002500006) Funded by the European Union - Next Generation EU, and PNRR CN1 – Spoke 6 (B83C22002940006).

Design and applications of composites

abst. 1071
Room GALLA PLACIDIA
Wednesday
September 4
15h10

Addressing Structural Certification Challenges with FEM Analysis in Electric Seaplane Wing Preliminary Design

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This study explores the complex balance between structural certification challenges and business objectives for an electric seaplane, emphasizing the structural trade-offs associated with achieving certification. Sandwich structures and bonded joints offer significant weight reduction and structural efficiency advantages, particularly crucial for electric aircraft seeking optimal performance and sustainability. However, their integration into aircraft design demands meticulous certification procedures due to their complexity and criticality in ensuring airworthiness. EASA CS-23 Level 3 and Level 4 certifications represent distinct categories of aircraft, with Level 3 typically encompassing simpler, less complex designs suited for basic general aviation operations, and Level 4 encompassing larger, more complex aircraft with higher performance capabilities. While both levels of certification present opportunities for integrating sandwich structures and bonded joints into primary structures, there are notable differences in the regulatory requirements and design considerations between the two categories. The integration of sandwich structures and bonded joints in Level 4 aircraft intensifies these challenges, requiring exhaustive testing, analysis, and documentation to meet stringent regulatory standards. Certification complexities are further intensified by the differences in passenger capacity constraints between CS-23 Level 3 and Level 4 aircraft. For this research, some aircraft specifications include a non-pressurized airframe, and the maximum speed is relatively low compared with other aircrafts under Level 4 category. The loads obtained from the aircraft flight envelope (V-n diagram) were used in the Finite Element Analysis (FEM) and it serves as a pivotal tool in validating the structural integrity and performance. To address these challenges, the study conducts a comprehensive FEM validation and comparison of two different structural analyses: one to comply with Level 3 certification using sandwich structures and bonded joints, and the other to comply with Level 4 certification using traditional airframe architecture with metal fasteners. The FEM validation evaluates the structural integrity and performance of both designs under the most critical loading conditions, providing insights into their behavior and guiding further design iterations. The impact on the business case is profound, as achieving Level 4 certification is desirable for market positioning and competitiveness, with larger passenger capacities. However, the structural certification challenges associated with Level 4 certification induce a strategic decision to pursue Level 3 certification, balancing regulatory compliance with operational and business objectives. Recommendations to comply with Level 4 certification include adopting traditional airframe architecture with metal fasteners, despite the increased weight of the overall structure. While metal fasteners streamline the certification process, they introduce weight penalties that may affect the aircraft's performance and range. Manufacturers must carefully evaluate these trade-offs and optimize the structural design to minimize weight while meeting certification requirements. While sandwich structures and bonded joints offer compelling benefits for electric planes in general aviation, their integration poses formidable certification challenges, particularly in Level 4 aircraft. Through rigorous testing, analysis, and validation, engineers can navigate these complexities and implement the advantages of lightweight construction, ultimately advancing the feasibility and sustainability of electric propulsion in seaplane aviation.

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abst. 1107
LLA PLACIDIA
Wednesday
September 4
15h30

Effect of modulus changes of a biodegradable bone plate on early bone healing of tibial fractures

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Conventional metal bone plates which have excessively high Young's modulus relative to bones have been used to treat long-bone fractures. However, several problems have been found in using metal prostheses such as incompatibility with bone stiffness resulting in delayed healing and moreover, the secondary surgery is required to remove the metal bone plate after complete healing. To improve healing performance of metal bone plates biodegradable composite materials are introduced to provide continuously degrading stiffness of prostheses during healing period under body fluid environment, which can provide load-carrying capacity of the damaged bones and finally accelerate bone healing process. However, bone plates made of biodegradable composite materials have the problems of low initial stiffness and high dissolution rates. These problems induce lack of structural integrity in whole period of healing and as a result, the prostheses can lose completely load-carrying capacity before complete healing of the damaged bones. This paper investigate the degradation process of biodegradable bone plates made of Mg wire and Polylactic acid (Mg wire/PLA composites) under the simulated body fluid environment by means of finite element analysis using ABAQUS. To find out the effect of the modulus degradation of the biodegradable composite bone plate on bone healing finite element analysis with a biphasic mechano-regulation algorithm bone healing process was carried out by considering cell diffusion and tissue phenotype activities in calluses and a fusion model that combines the Comiskey algorithm and a swelling model to accurately estimate the shape development of external callus around the fracture site. The callus changes in shape and volume were accurately estimated during healing period and the results from conventional metal plate and the biodegradable composite plate were compared. Consequently, the healing performance of composite bone plate was estimated. Keywords: Bone plates; Finite element analysis (FEA); Biodegradable composite material; Modulus degradation. Acknowledgment: This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government(MSIT) (RS-2023-00208286).

Experiemental study on mechanical performance degradation of a hybrid bone plate under simulated human body environment

abst. 1114
Room GALLA PLACIDIA
Wednesday
September 4
15h50

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In surgical treatment of fractured bones, metal bone plates have been used to fix and support the fractured bone. However, the high material properties of metal bone plates have the disadvantage of lowering treatment efficiency due to inflammation caused by corrosion as well as stress shielding, which deteriorates bone density and causes osteoporosis. In order to overcome the limitations of these materials' shortcoming, related researches are being conducted on biodegradable composite materials in which material properties decrease as fractures regenerate and degraded materials help in healing. In general, materials used as biodegradable materials include PLA (Ploy lactic acid), Mg alloy, and bioglass. Among them, PLA has the disadvantage of having low material properties when used alone and causing inflammation by increasing the surrounding acidity through a hydrolysis reaction. Mg alloy has the disadvantage of having a very fast decomposition rate, so surface treatment using phytic acid affected corrosion resistance. Therefore, when used with surface-treated Mg alloy, it can compensate for low material properties and neutralize acidification, and friction at the interface increases due to the rough interface, so it is being studied in the form of Mg/PLA composites as a biodegradable composite material. However, if a bone plate is completely made of biodegradable composite materials, structural integrity would be the major problem because this material rapidely degrades, as a result, the prostheses made of this material are hard to resist any external load when they are applied to implants which is the critical problem. Consequently, hybrid structures composed of partly degrable material composition would be the solution of the problem. In this study, we have designed a hybrid bone plate using biodegradable composite with biocompatible, non-degradable composite that do not decompose without adverse effects on the body. This study aims to evaluate the fatigue life of a hybrid bone plate through an eccentric fatigue test in a simulated body fluid environment of a hybrid specimen in a PBS buffer environment.

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abst. 1143
Room GALLA PLACIDIA
Wednesday
September 4
16h30

Performance of 3D printed Small UAV Propellers Made of a Carbon Fiber-reinforced Thermoplastic

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Stratasys ABS-CF10 is a carbon fiber-reinforced thermoplastic that combines standard ABS (acrylonitrile butadiene styrene) materials with 10% chopped carbon fiber. In this report, we present a study on the performance of 3D printed unmanned aerial vehicles (UAVs) propellers made of the ABS-CF10. UAVs have gained widespread applications due to their low cost and flexibility. Nevertheless, the design of propellers for small UAVs have been focused on geometry and profile optimization aimed to optimize their aerodynamic efficiency. The sensitivity of the propeller performance on the materials used in the manufacturing, on the other hand, have not been explored sufficiently. ABS-CF10, 50% stiffer and 15% stronger than the standard ABS 3D printing materials, possess a potential to further improve the overall reliability of the propellers. In this work, the performance of 3D printed ABS-CF10 propellers will be evaluated in terms of both structural reliability and aerodynamic efficiency. And their performance will be compared with those built from ABS standard materials and commercially available propellers. Moreover, since ABS-CF10 are inherently anisotropic, the effect of printing process will be investigated, and a comprehensive design guideline for composites based small UAV propellers will be presented.

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abst. 1149
LLA PLACIDIA
Wednesday
September 4
13h10

Transfer learning-based crashworthiness prediction for the composite structure of a subway vehicle

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Due to the lack of load/displacement sensors in a complex and uncertain crash test/accident of rail vehicles (e.g., vehicle-to-vehicle or train-to-train collision), only structural deformation images can be obtained while the crashworthiness indicators (e.g., force, displacement, energy absorption) cannot be measured directly. This paper aims to propose a transfer learning-based inverse method for extracting the structural parameters and crashworthiness characteristics by the deformed pictures of energy-absorbing structures. A finite element model of an energy-absorbing structure was firstly established and calibrated by experiments. Then, a number of deformation images were captured from the numerical design of experiment (DOE) through coding languages, which were saved as TFRecord format to reduce the computational time during the training of transfer learning models (i.e., VGG16, LetNet, AlexNet and ResNet50). The result showed that the transfer learning model, ResNet50, exhibited the best performance with determine coefficients of 0.736 and 0.981, respectively, for predicting the structural parameters and crashworthiness characteristics. In addition, the number of full connection layers should be reasonably selected on the premise of maintaining accuracy and efficiency. A group of deformation pictures were randomly used as samples to validate the prediction of structural parameters and crashworthiness through the trained transfer learning model, where good consistence was observed. The proposed method is expected to bring the image recognition and big data prediction into the design and test of composite energy-absorbing structures; thus, auxiliary improve the crashworthiness of rail vehicles.

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abst. 1216
Room GALLA PLACIDIA
Wednesday
September 4
09h40

Evaluation of the effectiveness of the repair of metal semi-monocoque structures using composite materials and adhesives

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The purpose of the present research was to evaluate the effectiveness of repairs to metal components used in the construction of semi-monocoque aerospace structures made using adhesive bonds and GFRP composites. The evaluation was carried out by subjecting the repair nodes to both static and dynamic loads (fatigue life). Geometric parameters of the repair nodes, including, among others, the patch lengths of the adhesives bonds and the strength and stiffness parameters of the repair patches were defined using the capabilities of modern computational tools (numerical simulations). Multistage calculations and experimental tests were carried out on repaired flat specimens subjected to compression and tension, determining, among other things, that in the case of repair nodes subjected to compression, the stiffness of the repair patch has a significant effect on the adhesive bond strain - a patch that is too stiff can induce the unfavorable phenomenon of repair patch peeling. Static and fatigue tests were also done on plates subjected to shear. For undamaged, damaged and repaired plates, a critical force value was defined, beyond which the phenomenon of loss of stability of the plate occurred. The forms of plate buckling and the initiation and development of fatigue cracks were also observed in experimental studies.

Weight optimization of design parameters of composite structures

abst. 1220
Room GALLA PLACIDIA
Wednesday
September 4
10h20

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The paper deals with the main aspects of the technique for weight optimization of design parameters of composite structures for rocket and space technology. The optimization process was divided into several stages in accordance with the reasonable levels of significance of the parameters included in the objective function, i.e., minimum weight. The results allow us to achieve a deep level of simultaneous optimization of the reinforcement pattern and structure of load-bearing skins, the height of the honeycomb filler, and the geometric parameters of its cell, as well as parameters of the additional structural frame in the regular zone and local reinforcement zones for almost all spectrum of external actions. At the same time, the load-bearing capacity of the structure was provided in all critical areas taking into account the deterioration of the physicomechanical characteristics of materials employed due to thermal effect and fulfilment of additional functional and technological constraints. Decompositions of the general task of parameters' optimization were carried out into a number of types that correspond to the main types of structures of the considered class of technology: interstage compartments of launch vehicles and precision structures of spacecraft. An integrated approach to the optimal design of the interstage compartments of the head block of launch vehicles of various structural and power schemes is proposed. A distinctive feature of the approach is the possibility of multifactor optimization of the parameters for units of the class under consideration while providing regulated load-bearing capacity with simultaneous power and heat loading, taking into account technological restrictions that correspond to the existing level of their production. Results of ground-based strength tests of the interstage compartment at this stage of development confirmed the reliability of the results obtained. A conceptual approach to the synthesis of rational parameters of composite frames of solar panels of various structural and power circuits is proposed, based on the integrated realization of well-known principles implemented by relevant units that are integrated by computer technology into a single optimization complex. An integrated approach has been synthesized to create precision space structures from polymer composite materials, which makes it possible to obtain rational thermo-dimensionally stable composite structures. An algorithm for determining the rational structure of a composite package has been developed and implemented, which provides a compromise combination for the absolute values of the coefficient of linear thermal expansion keeping maximum precision of the product in accordance with the proposed criteria. The results obtained made it possible to provide an increase by more than 20 % in the mass efficiency of the composite aggregates of rocket and space technology produced at the leading enterprises of the industry. The results taken as a whole form are the scientific basis for the rational design of sandwich shell-type systems with the honeycomb filler under simultaneous strength and thermal loadings, taking into account of technological constraints and can be used in designing of the other load-bearing shell-type units for aviation, space, and conversion applications.

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abst. 1228
LLA PLACIDIA
Wednesday
September 4
10h00

Surface-oriented CNTs-PVA composite Electric Double Layer ionogel flexible pressure sensor for wearable applications

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The Electric Double Layer (EDL) flexible capacitance pressure sensor features high sensitivity, fast response, and excellent stability, making it suitable for use in wearable devices and human-computer interaction. Here, we present a polyvinyl alcohol (PVA) ionogel composite with oriented carbon nanotubes (CNTs) on the surface. CNTs function as extended microelectrodes, which enhances the change of EDL capacitance during heavy loading. Additionally, the finite element simulations and experimental data show that the electromechanical properties of this CNTs-PVA composite ionogel depending on CNT distribution direction and gradient concentration. The flexible sensor made of CNTs-PVA composite ionogel performs well in monitoring various human behaviors from breathing to knee bending, covering low and high loading conditions. This research indicates that this composite can overcome the performance limitations of existing EDL sensing materials and has the potential for broader applications.

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abst. 1272
Repository

Comprehensive research on the synthesis, properties and potential applications of vinyl ester resin composites with wood flour

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In recent decades, due to the increasing depletion of resources and global ecological awareness of the Earth, there has been an increased interest in economically and ecologically friendly biomaterials and recycling of raw material waste. Two synthetic vinyl ester resins were used in the presented research, one of which is a commercial VER resin based on bisphenol A (BPA), and the other VPE is synthesized from unsaturated polyester derived from PET recyclate. In both cases, styrene was a diluent and cross-linking agent. Wood flour (WF) was used as a natural filler for the composites. The reinforcement of polymer composites is due to the fact that the biofiller has advantages such as high strength, low cost, low density, biodegradability and low water absorption. A positive effect of using this waste from the wood industry is environmental friendliness. It is known that microorganisms survive for a long time on "touch" surfaces. This can be particularly problematic in healthcare, where a patient's immunity is at greater risk of infection. Touch surfaces in hospital rooms can serve as a source or reservoir for bacterial expansion. Nosocomial infection can occur in various ways, e.g. in hospitals, nursing homes and even diagnostic laboratories. In the case of the tested composites obtained for the food, pharmaceutical and medical industries, it is important that bacterial cells do not adhere to their surface and at the same time are not toxic to eukaryotic cells. The antibacterial study assessed the inoculation of composites with bacteria to create a biofilm on their surface. The antibiofilm effect of the composites was assessed using an in vitro monospecies biofilm model against Gram-negative and Gram-positive strains. The

results of bacterial adhesion to the surface of wood-resin composites were compared with bacterial colonization of clean control materials and assessed using confocal microscopy imaging. Normal human skin fibroblasts (BJ cells) were used to test for indirect cytotoxicity. BJ cell viability was assessed using a colorimetric assay. The influence of WF content on the properties of composite materials was determined. Comprehensive tests of mechanical, thermal and thermomechanical properties, hardness, gloss, wettability and flammability of composites were carried out.

Automatic assembly of tensegrity chain structures based on NURBS curves

abst. 1326
Room GALLA PLACIDIA
Wednesday
September 4
12h10

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Tensegrity chain structures (TCS) refer to chain-like assemblies of simple tensegrity units aligned in a specific direction. They are gaining popularity as an appealing structural form and have attracted significant attention due to their wide range of applications, including beams, columns, towers, and more recently, mechanical or acoustic metamaterials. However, designing large-scale chain-shaped tensegrity structures, especially those with intricate geometric shapes, remains a challenging issue. Existing studies have rarely provided parametric and efficient design methods for such structures. To address this, we propose an automatic modular assembly method for effectively constructing TCS, utilizing non-uniform rational B-spline (NURBS) curves to capture the target structural configurations. By following a NURBS curve, a desired TCS can be obtained by sequentially assembling numerous elementary tensegrity units along their axes into the overall structure. For assembly purposes, some existing simple tensegrities, including both 2D and 3D cases, are exemplarily introduced as elementary units, and their self-equilibrated configurations are respectively discussed. In the assembly process, two viable shape transformation patterns, namely shearing and bending patterns, are also developed for these units, allowing the assembled structures to take on some complex shapes. The proposed design method can be summarized in three main steps: Firstly, create a NURBS describing the shape of desired TCS, specifying its starting and ending points as well as the assembly direction. Segment this curve into multiple sections at predetermined positions using some division points. Secondly, construct all design planes at each division point with given radii and normal vectors in accordance with the unit type and adopted shape transformation pattern. Thus, each packing space can be formed between every pair of adjacent design planes to accommodate an individual tensegrity unit. Lastly, determine the self-equilibrated node positions in each packing space for each unit, sequentially from the starting point to the ending point, and integrate the nodal coordinate matrix of the overall structure in the form of blocks from all assembled units. Within the obtained node sequence, an efficient computational algorithm is proposed to automatically map the topology of each unit into the overall connectivity matrix to directly obtain the topology information of the overall TCS. A parameterized computational algorithm is then provided to determine the initial prestress distribution of the overall structure. In this algorithm, the singular value decomposition (SVD) of the equilibrium matrix is performed for each individual self-equilibrated unit to extract its independent self-stress modes, and these self-stress modes are linearly combined using appropriate coefficients and subsequently integrated into the overall internal force vector for the designed TCS. Finally, several amusing examples of TCS are presented to validate the effectiveness of the proposed method, and the design results demonstrate the versatility of this method in various scenarios. By innovatively introducing NURBS curves to TCS design, the method significantly enhances design flexibility for structural configurations. Combined with the parameterized determinations of nodal coordinates, topology, and prestress, the proposed method exhibits excellent advantages in designing TCS, especially those with complex geometries and high complexity. The proposed method holds promise for acting as a generic and comprehensive optimization framework, in which the configuration, topology, and prestress can be incorporated and considered simultaneously, paving the way for the modular design of such systems. Based on the proposed method, optimizing the structural performance for mechanical or acoustic applications to develop some tensegrity-based metamaterials or metastructures will be an interesting topic.

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abst. 1337
Repository

Fabrication of a Ride Wing using Fiber Composite Materials

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This study focuses on designing, analyzing, and fabricating a "Ride Wing" hydrofoil structure using fiber composite materials. It is applied to high-speed marine vehicles to obtain lift to raise the rear hull and reduce the resistance to motion. The hydrodynamic performance of a hydrofoil structure heavily depends on its hydrodynamic shape and flow patterns at different Reynolds numbers (Re) and angles of attack (AOA). Thus, a proper assumption of 2D and 3D hydrofoil's hydrodynamic behavior is a necessity to obtain a better architecture for hydrofoils. Many researches have been conducted in this regard, for example, to obtain a submerged hydrofoil with better controllability [1] resulting in a shape-memory-alloy actuated bio-mimetic hydrofoil. Another study, to improve hydrofoil performance [2] suggested a shape-adaptive composite hydrofoil utilizing bend-twist coupled composite layups. This project aims at fabricating a lightweight and durable composite hydrofoil structure made using glassfiber reinforced composite materials. It has enhanced the strength and properties of a hydrofoil structure, improved its hydrodynamic efficiency, and offered manufacturing flexibility. To have a better hydrodynamically stable hydrofoil structure, different airfoils (NACA 0015, NACA 2412, NACA 4412, NACA6412 and NACA 63412) were studied to develop a CAD model of the wing-shaped horizontal component of the hydrofoil structures embedded with a common vertical strut structure. The next step was to conduct a CFD analysis on each of these completed CAD models to find out the most optimum design criteria under certain boundary conditions. Later on, two selected hydrofoil structures were built using E-Glass fabric reinforced polyester composite with a unique manufacturing method, and finally, their structural stability was analyzed. The particular hydrofoil structures used in this analysis showed a better hydrodynamic performance after CFD analysis was carried out on the hydrofoil structures fabricated using NACA-0015 and NACA-2412 airfoil structures, and the composite layup technique with a right orientation and distribution of fibre content was highly suitable for the fabrication of the "Ride-Wings". Furthermore, the "Ride-Wing" hydrofoil structures supposedly enhanced the boat's overall performance during practical implementation phase by enhancing the speed, energy efficiency, maneuverability and stability of the host vessel or vehicle. It is also expected to improve the structural integrity and durability of the "Ride-Wing" itself while reducing its environmental impact. Keywords: Ride Wing Hydrofoil, Fiber Composites, E-Glass, Resistance Reduction, Hydrodynamic Efficiency, CFD Analysis, Composite Layup Technique. References: [1] Garner, L. J., Wilson, L. N., Lagoudas, D. C., Rediniotis, O. K. (2000). Development of a shape memory alloy actuated biomimetic vehicle. Smart Materials and Structures, 9(5), 673–683. doi:10.1088/0964- 1726/9/5/312. [2] Herath, M. T., Prusty, B. G., Phillips, A. W., St. John, N. (2017). Structural strength and laminate optimization of self-twisting composite hydrofoils using a genetic algorithm. Composite Structures, 176, 359–378. doi: 10.1016/j.compstruct.2017.05.012

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abst. 1392
Room GALLA PLACIDIA
Wednesday
September 4
10h40

Seismic behavior of RC columns jacketed by textile-reinforced ultrahigh toughness cementitious composite: Experiments and simulations

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Textile-reinforced ultrahigh toughness cementitious composite (UHTCC) jackets, herein referred to as TRU jackets, are an innovative strengthening system for reinforced concrete (RC) structures. In this jacket system, UHTCC with high ductility and excellent crack control capability, exhibits better

deformation compatibility with the textile than brittle mortar does. However, the seismic performance and strengthening mechanism remain unclear for RC columns strengthened with TRU jackets. This paper presents an experimental study of the seismic performance of reinforced concrete (RC) columns strengthened with TRU jackets using cyclic lateral loading tests. The effect of stirrup ratio, number of textile layers, strengthening height and styles were investigated and discussed in detail. The results indicated that the TRU jacket could effectively restrain the development of cracks in the plastic hinge zone, delay stiffness deterioration, and significantly improve ductility and energy dissipation capabilities. Moreover, at a low stirrup ratio of 0.39%, the peak load of the jacketed columns was greatly enhanced compared to the peak load of RC companion columns. With an increased number of textile layers, seismic performance was on the whole improved. When the axial compression ratio was increased from 0.15 to 0.30, ductility and energy dissipation capacity did not drop for TRU-jacketed columns. As the strengthening height decreased from 2h to 1.2h, the seismic performance of jacketed columns remained almost unchanged. A numerical model was developed for seismic simulation of TRU-jacketed columns based on OpenSees platform, and the predicted hysteresis curves agreed well with the test data. These results provided significant references for the application of TRU jackets in strengthening of RC structures.

Design model for FRP-confined circular and rectangular reinforced concrete columns

abst. 1394
Room GALLA PLACIDIA
Wednesday
September 4
12h30

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The vast majority of reinforced concrete buildings in seismic prone countries are built according to older code principles, which did not account for ductile performance. Seismic strengthening of similar buildings is often a more viable solution as compared to demolition and re-construction. Use of fiber reinforced polymer (FRP) external jackets as a retrofit method to upgrade substandard reinforced concrete (RC) columns increasingly gains popularity among other retrofit methods, because of the comparatively easy application combined to the resulting increase in structural performance of the member. Extensive analytical and experimental research on external FRP jackets has been performed in columns with circular section, mostly for plain concrete elements subjected to axial compression. Comparatively less research has been carried out on columns with rectangular section. And less attention has been paid on the behavior of FRP-jacketed RC elements. Objective of this work is to determine a reliable design model aimed at the estimation of the enhanced mechanical characteristics of axially loaded FRP-confined RC columns. FRP jackets offer lateral confinement and are activated when the RC column is subjected to axial compressive stress higher than the unconfined concrete strength. The increase in the axial strength is linked to the lateral confining pressure induced by the FRP jacket, which is maximized for round sections and becomes less effective in rectangular sections, inversely proportionately to the aspect ratio of the section. Given that FRPs are elastic materials, axial confined strength depends on the strain at failure of the FRP jacket. However, the estimation of the FRP strains at failure of the jacket includes considerable uncertainties. Moreover, the presence of internal steel reinforcement in case of RC columns retrofitted by FRP jackets, introduces more uncertainties regarding the estimation of the confined strength. For example, in case of an RC column with sparsely spaced stirrups –typical in older buildings- failure is usually related to buckling of the longitudinal reinforcement bars. The presence of an FRP jacket often postpones such a failure, or even prevents it. On the other hand, it has been pertained that the occurrence of buckling of the longitudinal bars may cause premature rupture of the FRP jacket. This work attempts to address this issue, as well as others involved in the composite contribution of steel- and FRP-confinement to the increase of the confined axial characteristics. To serve this purpose, a broad database of experimental results on axially loaded RC columns wrapped with FRP jackets has been assembled from the literature. The database consists of RC columns with varying ratios of confinement offered by steel stirrups and FRP jacketing, for both circular and rectangular cross-section. The predictive capacity of available design models selected from the literature is assessed based on the models' capacity to predict the respective values of the test results. Finally, a new design model, including the contribution of both steel and FRP, is presented. The proposed model proves to result in better predictions of the confined characteristics of the test specimens of the database, as compared to the other design models considered.

abst. 1407
LLA PLACIDIA
Wednesday
September 4
12h50

Alternative methods for the qualification of composite repair system used in the oil industry

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Composite repair systems for metallic pipelines presenting a through-wall defect must be qualified in accordance with either ISO 24817 or ASME PCC-2 standards. This qualification method requires a number of hydrostatic tests to obtain the failure pressure. In the oil and gas industry, the failure pressure estimation is often performed using a linear fracture mechanics analysis described in both ISO and ASME standards. These standards require the determination of a constant fracture energy, also called the energy release rate. In the case of monotonically increasing loading histories, in the framework of linear fracture mechanics, brutal interfacial debonding occurs when the fracture energy reaches a critical value. This work is an attempt to show that simple tests, such as, shaft-loaded pressurized blister test and Double cantilever beam (DCB) can be employed as an alternative to hydrostatic tests in the qualification of repair systems. The goal is to obtain experimentally the critical fracture energy using such tests. Results show a reasonable similarity between the critical energy values found using all proposed methodologies with the ones obtained with the standard required hydrostatic tests.

Durability and aging of composite materials and structures: Civil, Marine, Automotive, Aeronautical and Aerospace Applications (chaired by M. Gigliotti, F. Ascione)

An innovative ductile connection for fiber reinforced materials

abst. 1134
GALLA PLACID
Friday
September 6
09h40

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The moment connections for Fiber Reinforced Polymer (FRP) structures are deemed to be essential in providing the required load-carrying capacities. Due to both the stress concentration and the manufacturing defects, the premature failure of the connections may lead to the overall brittle failure of the structure, while the utilization ratios of the FRP members are still very low, thus resulting in the inefficient and unsafe use of the material. Therefore, the connections should provide adequate resistance and ductility to guarantee the expected structural behaviour of FRP profiles [1]. The connection technology for FRP members presents numerous challenges due to the brittle and anisotropic nature of the material. They are usually connected via bolting, adopting the design rules for similar steel connections [2-7] but in the last decade the adhesive technique has gained more and more interest [8-16]. The authors recently conducted a comprehensive experimental and numerical program in order to design, test, and patent a ductile moment connection for FRPs elements suitable for structural applications. The proposed junction has been conceived to guarantee the fiber continuity by bonding FRPs to a ductile element, to be easily repaired and/or replaced, where the deformation is concentrated.

The Effect of Thermal Cycling on Degradation and Damage of Ti/C-epoxy Adhesive Joints for Aeroengines Applications

abst. 1136
Room GALLA PLACIDIA
Friday
September 6
09h00

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Three-Dimensional (3D) Woven C-epoxy Composites are increasingly employed for aero-engine fan blades applications. In these structures a titanium plate is bonded to the organic matrix composite (OMC) fan blade with an epoxy adhesive for impact protection. In a realistic environment, both the carbon-epoxy composite material and the Ti/Composite adhesive joint are usually subjected to multi-axial mechanical stresses and to cold/hot thermal cycling. These environmental conditions may promote thermo-oxidative ageing/degradation of polymeric matrices (particularly for thermoset ones, [1-3]) and matrix cracking in both the composite and the adhesive of the Ti/composite joint ([4]). Despite the importance of thermal cycling degradation and damage in the typical aircraft engine environment, there has been limited research into the effects of such phenomena on OMCs and thermoset adhesives. The present research investigates the effect of thermal cycling on ageing/degradation and damage in 3D C-epoxy and Ti/C-epoxy adhesive joints for aero-engine applications. Tri-layer Ti/C-epoxy adhesive joint samples have been subjected to a thermal cycling, between -55°C and 120°C, then

3-point bending tests are carried out and monitored by Markers Tracking (MT), Acoustic Emissions (AE) and µ-Computed Tomography (-CT). During mechanical tests, strain evolution is monitored using MT, while damage occurrence is detected using AE. Additionally, µ-CT is used to obtain 3D material volume scans to visualize damage mechanisms after thermal cycling and mechanical testing. Results show that the preliminary ageing induced by thermal cycling may significantly affect the location and the intensity of degradation and damage. ABAQUS analyses of the tested samples allow for a better understanding of the test results. References: [1] Colin X, Verdu J (2005) Strategy for studying thermal oxidation of organic matrix composites, Composites Science and Technology, 65, 411-419. [2] Gigliotti M, Minervino M, Lafarie-Frenot MC, Grandidier JC (2016) Effect of thermo-oxidation on the local mechanical behaviour of epoxy polymer materials for high temperature applications, Mechanics of Materials, 101, 118-135. [3] Pecora M, Pannier Y, Lafarie-Frenot MC, Gigliotti M, Guigon C (2016), Effect of thermo-oxidation on the failure properties of an epoxy resin, Polymer Testing, 52, 209-217. [4] Zhang C, Binienda WK, Morscher GN, Martin RE, Kohlman LW (2013), Experimental and FEM study of thermal cycling induced microcracking in carbon/epoxy triaxial braided composites, Composites Part A: Applied Science and Manufacturing, 46, 34–44. Acknowledgements: The authors acknowledge SAFRAN Aircraft Engines for providing the material under study. The research subject falls within the research themes of the French Government program "Investissements d'Avenir" (LABEX INTERACTIFS, reference ANR-11-LABX-0017-01, EQUIPEX GAP, reference ANR-11-EQPX-0018).

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abst. 1247
Repository

Study on microcracks and permeability of carbon fiber epoxy composites under ultra-low temperature cycling

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Developing composite material propulsion tanks is an effective approach to reducing the overall weight and increasing the carrying capacity of launch vehicles. However, the tanks of reusable rocket will be subjected to extremely harsh working environments during service, including both ultra-low temperatures and mechanical loads. This exposure may lead to damage such as microcracks within the composite material, which could result in propulsion leakage and catastrophic accidents. Therefore, it is necessary to conduct in-depth research on the behavior of microcracks and leakage in composite materials under the coupled effects of ultra-low temperatures and mechanical loads. This study investigates the initiation and evolution patterns of microcracks in carbon fiber-reinforced epoxy resin composite laminates under the coupled effects of ultra-low temperature cycling (-196°C to 25°C) and pre-stress. First, pre-stress was applied to the composite material specimens using a self-designed pre-stressing apparatus. Subsequently, the specimens underwent ultra-low temperature cycling treatment, and optical microscopy and scanning electron microscopy were employed to characterize the microcracks. The experimental results indicate that microcrack density in inner layers is significantly lower than that in edge layers, but the region with the highest density is observed in the central two 90° stacking layers. Compared to conditions with only low-temperature cycling, introducing pre-stress results in higher microcrack density and a faster growth rate. Additionally, increasing the level of pre-stress further exacerbates the initiation and propagation of microcracks. The growth rate of microcrack density initially accelerates and then saturates with an increase in the number of ultra-low temperature cycles. A cohesive constitutive model considering fatigue damage accumulation was established based on the USDFLD subroutine in ABAQUS. The cohesive elements were globally inserted to simulate the initiation and evolution process of microcracks in composite materials under the combined effects of ultra-low temperature cycling and pre-stress. The simulation results of microcracks are in good agreement with the experiment. Through the integration of experimental characterization and numerical simulation, the mechanisms underlying the initiation and evolution of microcracks in composite materials under the combined effects of ultra-low temperature and mechanical loads are revealed. Further research was conducted on the combined effects of pre-stress and ultra-low temperature cycling on the permeability of composite laminate. Experimental results show that compared to single low-temperature cycling, the permeability of the composite material increases at a faster rate when subjected to pre-stress. Additionally, as the level of pre-stress increases, the permeability also increases accordingly. With an increase in the number of

ultra-low temperature cycles, microcracks and interlayer delamination continue to expand, resulting in a transition of the leakage mode of the composite laminate from diffusion leakage to microcrack leakage. This study provides meaningful insights for the application of composite materials in reusable launch vehicle low-temperature tanks.

Machine learning approach to modelling bond strength retention between Fibre Reinforced Polymer bar and concrete under seawater

abst. 1258
Repository

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The bond between Fibre Reinforced Polymer (FRP) bars and concrete can degrade when exposed to seawater. Accurately modeling the bending behavior between FRP bars and concrete in seawater is essential for maintaining their structural integrity. This study employs an XG-Boost machine learning approach to model how seawater affects the retention of bond strength between different FRP bars and concrete. Various factors such as exposure duration, temperature, bar diameter, surface configuration, mechanical properties of the bar, resin and fiber types, and concrete strength were considered as key parameters influencing bond strength retention. The results demonstrate the accuracy of the developed models in predicting bond strength retention. Investigating the bond strength retention of FRP bars and concrete in seawater facilitates the creation of precise predictive models and design guidelines for their optimal use across industries.

Durability of Pultruded Fiber-polymer Composite Structures Exposed to Different Environmental Conditions

abst. 1304
Room GALLA PLACIDIA
Friday
September 6
10h00

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The durability of three different types of structures composed of glass fiber-polymer composites exposed to various environmental conditions was investigated, i.e., a pedestrian bridge exposed to a harsh Alpine climate and a five-story building subjected to natural weathering both for 25 years, and pultruded unit-deck profiles immersed in water for 8 years. The assessment included a full-scall static loading, investigations of coupons extracted from a bridge beam and deck profiles, and visual inspection. During 25 years, the stiffness of the bridge remained unchanged and no damage was observed in the building. The tensile elastic modulus obtained from coupons remained consistent, however, the tensile strength decreased to approximately 69% and 67% of the initial value for the bridge and deck profiles, respectively. After 8 year-immersion, the bondline in the deck profiles exhibited a 7% reduction and the failure mode was changed from cohesive failure in bondline to the delamination in the profiles, which indicated less degradation in bondline compared to interface properties in profiles. The structural safety and serviceability are still not affected by the strength reduction, however, attention should be directed towards addressing this degradation based on these inspections.

Determination of structural limit arising from steel corrosion-induced rust formation in steel-concrete composite section

abst. 1353
Room GALLA PLACIDIA
Friday
September 6
09h20

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For determination of the structural limit for reinforced concrete structure under corrosive condition, more detailed information on yielding and failure criteria should be accompanied with cracking. Additionally, the interfacial gap impact on the structure has to reflect to quantitatively compute time to structural limits and the corrosion degree. In the current study, the interfacial gap was used as a parameter, ranging from 1/1000 to 10/1000 mm, based on previous experimental observations at the interface between steel and concrete. Subsequently, the rust formation resulting in the structural limit was determined in terms of yielding, cracking and failure of cross-section. To implement the structural limits with the development of steel corrosion, the stress distributed in cross-section was computed and visualized in the vicinity of the steel. (857) The current study deals with modeling the structural capacity of the steel-concrete interface with steel corrosion. The development of rust formation was quantified to start cracking at the steel-concrete interface, unlike the modeling in previous studies that initiated the cracking at the surface of the cover concrete. Simultaneously, gap at the steel-concrete interface was considered to reflect the buffering effect for the rust formation. The quantitative determination of rust formation against cracking would indicate information in specifying the structural limits under the risk of steel corrosion. The cross-section of reinforced concrete was built-up at using a finite element model with the 4-node plane strain element (CPE4). The finite element model simulated the development of rust formation at the interface between the steel and concrete, filling-up the interfacial porosity and subsequently its impact on structural capacity. To simplify the cross-sectional behaviour of reinforced concrete structure, 2-dimensional elements were adopted. It is presumably beneficial for clarifying the possibility of cracking and minimising the unnecessary influential factors in terms of the structural response such as bending moment and shrinkage of steel arising from Poisson's effect, respectively. The time to structural limit due to deteriorate of steel corrosion in concrete was predicted concerning yielding, cracking and failure. It was achieved by quantitatively determining the amount of rust formation on the steel surface using finite element modelling, with a gap at the steel-concrete interface considering to be 1/1000-10/1000 mm. Specifically, the onset of cracking was primarily regarded as the structural criterion for indicating the service life for the reinforced concrete structure exposed to corrosion. The structural limit was determined with factors such as cover depth, steel diameter, and interfacial porosity at the steel-concrete, of which had a significant influence on rust formation up to the structural limit. Yielding and cracking were significantly influenced by porosity at the steel-concrete interface, although its effect on failure was comparatively small. It probably owing to its degree of suspension effect concerning the further development of rust formation on the steel surface, which could generate internal stress on concrete as being a crucial factor in the early performance of the structure. The margin of the steel (i.e., diameter) was more influential than the cover depth in achieving the limit state of the structure. It can be attributed to the expanding area in contact with steel and concrete with an increasing steel diameter, which was presumably resulted in the enhancement of the suspension effect on the concrete concerning the structural limits. Substantially, the cover depth had a very slight effect on the amount of rust formation on structural limits (i.e., yielding and cracking) under given conditions such as constant steel diameter and interfacial gap. However, modification of these parameters can be restricted within a range due to the structural guidelines.

Dynamics of composite structures

Influence of Distinct 3D Printing Layer Patterns on the Dynamic Characteristics of Composite Structures

abst. 1157
Room GIUSTINI
Thursday
September 5
14h30

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In the current work, the fused deposition modelling (FDM) technique was used to manufacture PLA reinforced with continuous carbon fiber composite structures (PLA-CCF) featuring two unique layer patterns: 0°° and 0°0°. The purpose of the study was to investigate the dynamic characteristics of each fabricated composite structure. The Macro Fiber Composite (MFC) was embedded with 0°/0° and 0°/90° structures to investigate the effect of MFC (M8507-P2 type) patch on vibration amplitude suppression under dynamic loading circumstances. First, modal analysis testing was performed using a Polytec laser vibrometer to identify bending mode shapes, natural frequencies, and vibration amplitudes at the corresponding natural frequencies. To determine the stiffness of each structure, several loads were applied at the free end of the structure, and the deformation was recorded using a laser displacement sensor. The findings confirmed that structure with 0°° layers pattern was found to have more stiffness compared to 0°0° structure. Measurement of maximum amplitude suppression in each structure was performed using a laser displacement sensor at the first resonant frequency when applying a control voltage signal with optimal phase to the MFC. Furthermore, stiffer structure was observed to achieve more effective amplitude suppression. Keywords: Carbon fibre composite, MFC,modal analysis,stiffness, amplitude suppression

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Nonlinear flutter analysis of bistable composite shells

abst. 1163
Room GIUSTINI
Thursday
September 5
14h50

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Flutter is a critical aeroelastic phenomenon characterized by self-excited oscillations resulting from the interplay of inertial, elastic, aerodynamic, and thermal forces, particularly crucial in aircraft structural design. Panel flutter, a type of this instability involving skin panels, is of particular interest of the aeronautical community. Nowadays, modern aircraft employ composite fiber-reinforced materials for skin panels due to their exceptional strength-to-weight ratio compared to conventional metal-based materials. These materials offer enhanced mechanical properties and an enlarged range of design choices, permitting the disposition of their fibers in different orientations to optimize structural performance under certain operational loads. Additionally, when fiber-reinforced laminae are stacked in a non-symmetrical way, composite structures can exhibit bistable behavior. This behavior can facilitate their application as morphing structures. Such composites are known as bistable composites. This characteristic has attracted considerable interest in research and has shown promising outcomes for morphing applications. While bistable composites have been extensively studied concerning their room-temperature shape, static and dynamic snap-through response, and triggering methods, investigations into their response to aerodynamic loading, particularly flutter instability, have not yet been addressed. Thus, this paper aims to address this gap by investigating the flutter instability of skin panels using geometrically nonlinear finite element shell models in conjunction with first-order piston theory for aerodynamic loading. By integrating these approaches, we aim to analyze the behavior of composite skin panels under flutter conditions for different boundary conditions and loading conditions, offering insights for advancing the design and performance of morphing aircraft structures.

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abst. 1164
GIUSTINIANO
Thursday
September 5
15h30

Design of dynamic properties for an-isotropic rubber bushings based on contact theory.

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Rubber bushings are used to enhance the driving quality and ride comfort in the lower arm of the suspension or engine mounts. As deformation increases, the elastic characteristics of rubber components lead to an increase in restoring force, preventing excessive deformation. On one hand, the high inherent restoring force in the bushing can lead to durability damage in scenarios with minimal deformation. Geometric variables of rubber bushings can be adjusted to change the correlation between force and displacement, with the resulting area under the force-displacement curve serving as an indicator for evaluating vehicle ride comfort and durability. The dynamic stiffness and loss factor of the probabilistic fastener were derived from the vibration interaction with mechanical structure. This allowed determination of energy dissipation due to the friction in hook and loop from the wave propagation analysis. As the vibration amplitude increased, the loss factor of the fastener gradually increased because the friction of multiple stems increased. With the probabilistic fastener applied, the vibration transmission was reduced compared to bolted joint due to the frictional properties generated in the fastener. With this unique advantage, the probabilistic fastener has potential applications when large damping is required with additional benefit on the reduced weight.

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abst. 1172
GIUSTINIANO
Thursday
September 5
15h10

Failure analysis of the fuel storage compartment of a hydrogen powered vehicle made in composite materials.

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Emilia 4 is a four-seater lightweight solar vehicle made in CFRP (Carbon Fiber Reinforced Plastic) which participated several competitions in the previous years. The latest version of the vehicle features the addition of a hydrogen fuel cell module to supply the electric motors along with the solar panels and a new tail which contains the hydrogen module. This study investigates two possible case scenarios related to the hydrogen storage compartment failure of the vehicle, by carrying out simulations with the finite element explicit software LS-Dyna. The simulation environment includes the vehicle tail, made of fiberglass and kevlar, consisting of a fixed part, in which the tank (a cylinder of hydrogen at 20MPa of pressure) is housed, and a removable hood connected to the fixed part by an innovative system based on 4 elastic material screws. In case of cylinder failure, the gas pressure inside the tail allows to create a gap between the hood and the fixed part of the tail, allowing to make the gas flow out along with the air grills integrated in the tail. The first case scenario involves the detachment of the valve that connects the cylinder to the hydrogen supply pipes: following the gas pressure, the valve undergoes an acceleration that causes it to impact against the inner wall of the tail. In this case, the crashworthiness of the wall is investigated. In the second case scenario, the cylinder yields, resulting in the sudden release of hydrogen inside the vehicle tail. The event is modelled as a FSI (Fluid-Structure Interaction) problem where the hydrogen, represented by a Eulerian ALE (Arbitrary Lagrangian Eulerian) domain, interacts with the vehicle's tail represented with Lagrangian elements. The capacity of the tail to withstand the pressure wave of the gas and to dispose of the flow through the air grills and the gap generated by the elongation of the elastic screws is evaluated. The study also investigates the forces between the tail and the chassis to which it is bolted, in order to determine the accelerations to which the vehicle is subjected.

Analysis of Compressed Helical Spring Dynamic Characteristics: Exploring the Effects of Boundary Conditions using Camera Vision Technology

abst. 1173
Room GIUSTINI
Thursday
September 5
15h50

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With advancements in vehicle technology, ride comfort has become a crucial factor influencing vehicle purchase decisions. Suspension systems play a pivotal role in determining ride comfort by absorbing and transmitting road-induced shocks to the vehicle body. Among suspension components, compression springs are particularly influential in mitigating noise, vibration, and harshness (NVH) characteristics. Therefore, analyzing the vibration propagation characteristics of compression springs is imperative for enhancing NVH performance in vehicles. In this study, finite element analysis was employed to model and analyze the dynamic characteristics of compression springs. While previous research has extensively focused on factors such as spring geometry and material properties, investigations regarding boundary conditions have been relatively scarce. Thus, the Dynamic Stiffness Method was applied to analyze vibration responses of compression springs considering boundary conditions. Furthermore, to streamline the measurement process, camera vision technology was adopted, enabling comprehensive assessment of dynamic characteristics, including vibration mode shapes, with a single measurement session. Through the application of the Dynamic Stiffness Method based on wave equations, the vibration characteristics of compression springs were efficiently analyzed. Comparative analysis between vision measurement data and analytical models validated the accuracy of the approach. By elucidating the impact of boundary conditions on dynamic characteristics, solutions to address vehicle interior noise and vibration issues were proposed.

Tunable composite metamaterials for vibration and impact mitigation

abst. 1180
Room GIUSTINI
Thursday
September 5
16h30

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We present a tunable elastic composite metamaterial designed for vibration suppression and impact mitigation. Elastic metamaterials are typically classified into granular and continuum structures. In granular structures, composed of particles, waves propagate through contacts among particles. The nonlinear contact mechanism within the structure facilitates a diverse range of wave dynamics, spanning from highly nonlinear to nearly linear waves. This observation underscores the utility of contact in adjusting the stiffness of a structure, offering valuable insights into its potential for tuning structural properties. However, they often lack stability, necessitating additional support systems for practical use. Conversely, continuum structures are stable but challenging to adjust in stiffness. In this study, we propose a highly tunable continuum metamaterial by incorporating a contact mechanism within its internal structure. When compressed, two curved surfaces within the metamaterial make contact, substantially increasing its compressive stiffness. The stiffness can be easily adjusted by varying the gap between these surfaces. We fabricated two types of metamaterials; one was fabricated using the 3D printing technique with various plastic materials, and the other was made with carbon fiber reinforced plastic (CFRP), which was carefully assembled by hand. Through comparative analysis of their compression behaviors, we validated that CFRP, known for its high stiffness, presents advantages in terms of fatigue performance, affirming its suitability for designing robust structures. Experimental and numerical investigations demonstrated the tunability of the metamaterial's frequency band structure, showcasing efficient control over frequency band adjustments through small displacements. Furthermore, the designed metamaterials effectively dispersed impact waves by leveraging sudden stiffness changes due to contact. Our proposed tunable composite metamaterials offer broad applicability in various fields, including vibration suppression and impact mitigation.

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abst. 1203
GIUSTINIANO
Thursday
September 5
16h10

Dynamic response analysis of delaminated composite plates using a Finite Element based Reduced Order Model

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Thin-walled laminated composite structures are main structural components in mechanical, aerospace and maritime engineering. The buckling and post-buckling behavior of composite plates and panels under static and dynamic loading is an important topic in the design of thin-walled structures. Delamination is a common form of damage in laminated composite structures. Calculation models for the dynamic analysis of composite structure that include the effect of delamination are important for the failure analysis of these structures and for structural health monitoring purposes. Analytical models to assess the vibration behavior of delaminated structures usually employ certain assumptions, in particular the "free mode" assumption or the "constrained mode" assumption [1], in order to make an analytical treatment viable. An approach to analyze the nonlinear dynamic behavior of thin-walled structures through a Finite Element based reduced order model has been presented in earlier work [2]. This approach is an extension of a perturbation method for initial post-buckling analysis, implemented within a Finite Element framework. In the present contribution, the nonlinear dynamic response of a specific composite plate with a delamination is investigated through the reduced order modelling approach presented in [2]. A specific flat composite plate with a specified delamination under dynamic in-plane compressive loading is analyzed. The static buckling modes of the delaminated structure are used in the perturbation approach to construct a reduced order model for the nonlinear dynamic response analysis. A coupled mode dynamic analysis is carried out to assess the dynamic response behavior of the delaminated plate for cases in which either the "free mode" assumption or the "constrained mode" assumption is applicable. The results of the reduced order model analysis are compared with full model transient Finite Element analysis. REFERENCES [1] C.N. Della and D. Shu. Vibration of Delaminated Composite Laminates: A Review. Applied Mechanics Reviews, Vol. 60(1), 1 -20, 2007. [2] E.L. Jansen, T. Rahman, R. Rolfes. Finite Element Integrated Fast Buckling Analysis Tools using a Perturbation Approach. In: Buckling and Postbuckling Structures II: Experimental, Analytical and Numerical Studies, World Scientific, Editors: B.G. Falzon, M.H. Aliabadi, 2018.

Experimental and Numerical Study on the Buckling of Cylindrical CFRP Shells under Multiaxial Loading

abst. 1057
Room GALLA PLACIDIA
Thursday
September 5
12h30

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Thin-walled cylindrical composite shells exhibit sudden structural failure by buckling under critical load cases, such as axial compression, torsion and bending as well as combinations of those [1]. While buckling of cylindrical CFRP shells in axial compression has been thoroughly investigated in numerous studies and test campaigns, only few experiments with combinations of buckling critical load cases are found in literature. Most of these publications consider combined axial and torsion loads, e.g. [2, 3]. Hence, existing design approaches for cylindrical shells under multiaxial loading such as NASA SP-8007 cite the lack of available test data as cause to rely on very conservative assumptions [1]. There are some studies analysing the buckling behaviour of composite shells under combined loads numerically, e.g. [4]. However, finite element (FE) models employed in those investigations are not validated on test data and usually use eigenmode shape geometric imperfections instead of measured ones while leaving out other influencing factors, such as load imperfections or effects of boundary conditions [4]. In this contribution, the results of an experimental campaign on multiaxial buckling with a set of four cylindrical CFRP shells under various load combinations carried out on the hexapod test rig of TUHH are presented. The shells are nominally identical with an R/t-ratio of 146 and a laminate layup of [90,-30,30,-30,30,90] fabricated in two batches. Repeated buckling tests were performed with each shell in various combinations of axial compression, torsion and bending in different directions at varying ratios. In total, more than 30 different load cases are applied to all shells with each test being repeated six times. The reproducibility of buckling loads with comparably low scatter under each load combination allows to conclude that no significant degradation occurred over the course of testing. Analyses of test data show highly nonlinear load interaction curves and direction-dependent behaviour of the buckling load under combinations including torsion. In contrast, combination of bending and axial load yields almost linear interaction curves which vary depending on the bending direction, thus providing data on the strength of directional effects. A FE model is implemented according to the test set up and using measured geometric imperfections as well as recorded load imperfections. Parameter studies are carried out regarding effects of other potentially occurring imperfections, such as eccentricities or imperfect application of bending loads. It is shown that the influence of geometric imperfections decreases with growing torsion load, while increase in bending increases directional scatter. Furthermore, the chosen procedure to implement bending in tests is proven to yield a good approximation of true bending and a load interaction surface for all load combinations is generated using the validated model. Finally, test results are compared with the existing design guideline NASA SP-8007 and it is shown that design loads supplied are very conservative for all load cases and only yield acceptable interaction curves for pure compression-bending interaction. This research was funded by the German Research Foundation (DFG) via project No. 463883313. References: [1] Hilburger, M. W.: Buckling of Thin-Walled Circular Cylinders, NASA/SP-8007-2020/REV2, National Aeronautics and Space Administration, 2020. [2] Meyer-Piening, H.-R. et al.: Buckling Loads of CFRP Composite Cylinders under Combined Axial and Torsion Loading - Experiments and Computations, Composite Structures, 53, 2001, pp. 427-435. [3] Bisagni, C.; Cordisco, P.: An Experimental Investigation into the Buckling and Post-buckling of CFRP Shells under Combined Axial and Torsion Loading, Composite Structures, 60, 2003, pp. 391-402. [4] Tafreshi, A.; Bailey, C. G.: Instability of imperfect composite cylindrical shells under combined loading, Composite Structures, 80, 2007, pp. 49-64.

abst. 1138
Room GALLA PLACIDIA
Thursday
September 5
12h10

A new experimental method for determining the interlaminar failure envelope of thick-section composites

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As the application of composite materials expands from secondary load-bearing structures to primary load-bearing structures, the thickness of composite laminate structures also continues to increase. Predicting and analyzing the deformation, damage, and failure behavior of thick-section composite structures is closely related to their three-dimensional stress states. However, there is still a lack of an efficient and reliable experimental method to characterize the mechanical behavior of composite materials under out-of-plane multiaxial loading. This work is based on the improved Arcan experimental fixture combined with digital image correlation methods. By changing the installation angle of the specimen in the fixture, multi-axial loading conditions such as out-of-plane tension, compression, shear, out-of-plane tension-shear, and compression-shear can be achieved. The stress-strain relationship and failure behavior under several multi-axial loads can be obtained using the digital image correlation method by measuring the specimen's full-field strain. The results show that under tension-shear loads, the nonlinear characteristics and fracture strain decrease as the off-axis angle increases, whereas under compression-shear loads, the nonlinear characteristics and fracture strain increase from 0° to 45°. It increases as the off-axis angle increases, while the opposite occurs when the off-axis angle exceeds 45°. It suggests that the shear stress component in the compression-shear stress state is critical to the nonlinear response, as compression along the thickness direction might lead to an increase in interlaminar shear strength. Furthermore, by considering the coupling effect between out-of-plane tensile/compressive loading and shear, the authors proposed a new failure criterion for predicting the failure strength of materials under out-of-plane multiaxial loading, which is consistent with experimental results. This method demonstrates the advantages of new experimental methods for characterizing material behavior under out-of-plane tension-shear and compression-shear multiaxial loading.

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abst. 1218
Room GALLA PLACIDIA
Thursday
September 5
12h50

Experimental Study of failures of air conditioners system tram in desert areas by applying preventive maintenance (Using reliability lows)

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Preventive maintenance is considered the health record of industrial machines and transport vehicles in the world of industry because of its contribution to always protecting these machines and vehicles. Therefore, a tight preventive maintenance plan must always be developed to ensure reliability stability. This article aims to solve the problem of complete failure of the air conditioning (AC) system in trams in the desert region of Algeria, in the context of high temperatures, which resulted in the loss of many passengers and a significant drop in company income. Reliability laws will be applied to the way being obstructed as a result of an error applied in the welding process, which led to the ACHAPS shutdown of the air conditioning system, since the average reliability percentage was 59.01% before fixing the problem and became 81.73% after fixing the problem.

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abst. 1355
Room GALLA PLACIDIA
Thursday
September 5
13h10

Chloride removing in cement-based composite by electrochemical chloride extraction (ECE)

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To remove chloride ions form reinforced concrete structure under corrosive environment, the electrochemical chloride extraction (ECE) was implemented, which could mitigate the risk of corrosion by leaching the chloride ions. In the current study, the chloride extraction was assessed against to removal rate of free, bound and total chloride concerning the ECE treatment, respectively, during 2, 4 and 8 weeks with respect to conditions for 1000 of the current density. It may inform the maximum efficiency of the ECE to extract chloride. Additionally, the pH concentration of the cement was measured in terms of its depth, which may be assumed to contribute to the decomposition of bound chloride and its mobility under electric charge Two types of concrete specimen contaminated chloride ion were employed. To simulate the real condition, chloride ions were penetrated into the specimen from a salt reservoir, while chloride mixed water was used as the mixing water to accelerate the steel corrosion. adopted as a binder to mitigate the impact of binder on ECE. The chloride concentration was measured by diluting in acid solution and in still water for total and free chlorides, respectively, in terms of profiling the chloride ingress at each depth. After completion of the ECE, the effect of chloride ion removal from concrete was measured. Specifically, chloride contamination in concrete was quantified at 20 mm increments and categorized into free and bound chlorides to determine their mobility under electric charge. Moreover, the alkalinity in concrete was investigated by measuring the variation of pH against depth to evaluate its impact on the mobility of chloride ions during ECE treatment. An increased duration of the treatment at constant current density led to be further extracted chloride in concrete. The residual total chlorides in concrete specimens were 60%, 40%, and 25% with respect to the treatment duration of 2, 4, and 8 weeks, respectively, amounting to current densities of 336, 672, and 1344 Ah per square meter. After the completion of ECE, After the completion of ECE, free chlorides were mostly extracted in the area around of the steel at the increased electron supply to the specimen, whilst bound ones were quite extracted at all depths. At all depths of the specimen, free chloride was mostly extracted with an increase in electron supply; residual free chloride amounts were almost reduced to zero after the completion of the ECE treatment. However, the amount of bound chloride ions in the concrete was almost constant at all depths after treatment, although different from the initial amount in the specimen before ECE treatment. The ECE treatment resulted in lowering the alkali concentration. In particular, the pH in the specimen was significantly decreased adjacent to the steel-concrete interface under higher charging conditions. The pH degradation may arise from the decomposition of hydration process and trandportation of ions with electron supply; hydroxyl ions are produced at the adjacent depth to the steel-concrete interface then to acidify the cement. Simultaneously, decomposition of the hydration phases (i.e. Calcium ions from C-S-H gel and Calcium hydroxide precipitation) may decrease the alkali concentration and moreover hydroxyl ions produced in the decomposition process can further contribute to the reduction. The bound chlorides were quite removed due to a reduction of alkalinity in the concrete. It resulted in the degradation of the bond chloride ions-hydrations, as indicated in the profile of degraded alkalinity in the concrete matrix. Otherwise, the driving forces, which can be induced by the electric charge, drive the chlorides adsorbed on the surface of hydrations to be mobile in the cement matrix. In turn, the remaining bound chloride in the matrix could become similar to Friedel's salt.

Modifying Stiffness Degradation Model and Validation Using Non-Destructive Modal Analysis in Glass Fiber-Reinforced Composites Under Fatigue Loading

abst. 1412
Room GALLA PLACIDIA
Friday
September 6
16h10

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Residual strength and stiffness models are widely employed for predicting the remaining life of composite structures, particularly in wind turbine blades. However, time-consuming, destructive, and costly residual strength tests present significant challenges for improving these models using experimental data. In this study, first, the correlation between the degredated E-Modoulous tensile strength and modal analysis parameter (the first mode of natural frequency) of the cross-ply glass eposy laminat [0/90]7 was calculated experimentally. Next, the Shokrieh and Lessard's stiffness degradation model was modifyed using experimental test results, with particular focus on lower fatigue life percentages. Subsequently, the updated progressive fatigue damage stiffness degradation model was implemented using the UMAT subroutine in the ABAQUS finite element software. An analytical model, mimicking the composite specimen under tensile-tensile longitudinal fatigue loading, was created at stress levels similar to those in the experimental tests. The first mode natural frequency was analytically calculated at fatigue life percentages of 5%, 10%, 35%, 50%, and 70%. The results showed a good agreement between the analytical and experimental findings.

FRP reinforced structures

Strength predictions of near-surface-mounted fibre-reinforced polymer shear-strengthened RC beams using machine learning approaches

abst. 1001
Repository

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The shear strengthening of reinforced concrete (RC) beams using near-surface-mounted (NSM) fibre-reinforced polymer (FRP) bars/strips is one of the most prevalent applications of NSM FRP. However, due to the complex failure mechanisms and many influencing parameters, the shear capacities of NSM FRP shear-strengthened beams are difficult to predict. Accordingly, this study adopted machine learning approaches to predict the shear capacities of strengthened beams. An experimental database consisting of 130 rectangular/T-shaped beams and their 15 parameters collected from the existing literature was first constructed. Subsequently, a genetic-algorithm-improved back propagation neural network (GA-BPNN) trained with a Bayesian regularisation (BR) algorithm was employed, which was capable of giving accurate predictions on shear capacities of strengthened beams and own good generalisation ability. Furthermore, the GA-BPNN was used for parametric analyses to investigate the parameter effects on the contributions of concrete, steel stirrups, and NSM FRP to the shear capacity. Finally, with reference to the GA-BPNN parametric analyses and existing models, a design-oriented strength model for calculating the shear capacities of NSM FRP shear-strengthened beams was proposed and optimised using the genetic algorithm. A comparison with existing models proved the higher prediction accuracy of the proposed strength model.

ECCENTRIC LOADING TESTS ON STEEL-FREE CONCRETE COLUMNS REINFORCED LONGITUDINALLY WITH HYBRID BARS

abst. 1002
Repository

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Fibre-reinforced polymer (FRP) composites have become increasingly popular as a durable construction material in civil engineering applications. However, the use of FRP bars as longitudinal reinforcement in reinforced concrete (RC) columns has been rather limited due to their substantially inferior performance in compression than in tension (Afifi et al. 2014; Mohamed et al. 2014; Hadi et al. 2016; Hales et al. 2017). Existing design guidelines generally recommend that the compressive resistance of FRP reinforcement be ignored in evaluating the load carrying capacity of the member (e.g. CSA S806 2012), or do not recommend the employment of FRP bars as compressive reinforcement (e.g. ACI 2015). In order to effectively utilize the FRP material in compression, Teng et al. (2018) recently developed the so-called steel-free hybrid bar, which consists of an outer FRP confining tube, a central FRP bar and a layer of high-strength cementitious material in the annular space between them. In such a hybrid bar, fibre micro-buckling and overall buckling of the central FRP bar are both constrained by the surrounding cementitious material and the outer FRP tube so that the compressive capacity of the FRP bar can be properly exploited. This paper presents a pilot experimental study on concrete columns reinforced longitudinally with such hybrid bars under eccentric loading (Fig. 1). The columns are herein termed hybrid bar reinforced concrete columns or HBRCCs. A total of 12 RC columns longitudinally reinforced with either hybrid bars or glass FRP (GFRP) bars were prepared and tested. The main test variables included the type of longitudinal reinforcement (i.e., hybrid rebar or GFRP rebar), the pitch (centre-to-centre spacing) of GFRP spiral (i.e., 40, 80 or 160 mm), the load eccentricity (i.e., 0, 30 or 60 mm), and the external confining system of the column (i.e., GFRP spiral or PET FRP wraps, see Fig. 1). The test results demonstrated that under both concentric and eccentric compression, the hybrid rebar-reinforced concrete columns are superior to the corresponding GFRP bar-reinforced concrete columns (FBRCCs) in terms of load carrying capacity. The bending moment capacity and ductility of HBRCCs under eccentric loading is much better than that of corresponding FBRCCs. As expected, the load carrying and ductility of both the HBRCCs and FBRCCs increase with a decrease in the pitch of GFRP spiral.

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abst. 1018
Repository

Flexural behaviour of FRP-RC beams with FRP-UHPC hybrid rebars in compression zone

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On account of the good corrosion resistance ability of fiber-reinforced polymer (FRP), the FRP-reinforced concrete (FRP-RC) beams have attracted increasing attention and research in the last two decades. However, these FRP-RC beams were found to be lack of ductility due to the brittle manner of FRP material, resulting in their limited application in practical engineering. In the present study, strong FRP tensile reinforcement was adopted to control the failure of FRP-RC beams in compression zone, and novel hybrid rebars made of FRP and ultra-high performance concrete (UHPC) were used as the reinforcement in the compression zone to improve the flexural strength and ductilities of beams. An experimental program was carried out to investigate the flexural behaviour of FRP-RC beams enhanced with such FRP-UHPC hybrid rebars. The test results not only proved the effectiveness of FRP-UHPC hybrid rebars on improving the flexural strength and ductilities of FRP-RC beams, but also revealed the parameter effects on the beam behaviour.

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abst. 1027
Repository

Study on compressive properties of GFRP confined concrete under coupled high temperature and lateral impact

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In order to investigate the combined effects of high temperature and lateral impact on the compressive properties of GFRP confined concrete, a series of 63 short column specimens were meticulously designed and fabricated. These specimens were subjected to varying high temperature conditions ranging from 100°C to 400°C, in addition to a lateral impact energy of 30 kJ. Comprehensive test parameters were considered, including different temperature grades, GFRP tube wall thicknesses, and exposure durations to high temperature. The primary objective of this study was to analyze the resulting modifications in the compressive properties of the specimens under the dual action scenario. The research encompassed an examination of the axial compressive failure mode, load-strain relationship, and load-displacement relationship of the specimens under the combined influence of high temperature and lateral impact. Key indicators of compressive performance were thoroughly analyzed, including ultimate bearing capacity, initial compressive stiffness, and ductility. Furthermore, the study revealed the underlying axial compressive failure mechanism of GFRP confined concrete after experiencing damage. Moreover, a calculation method was proposed to determine the axial compressive capacity of GFRP confined concrete under the dual action of high temperature and lateral impact.

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abst. 1108
Room GALLA PLACIDIA
Thursday
September 5
09h40

Effect of Fiber Orientation in Chopped Prepregs on Stabilization of In-Plane Tensile Properties in Discontinuous Carbon Fiber Composites

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Chopped prepregs, which are cut from unidirectional continuous fiber prepregs into small pieces ranging from a few millimeters to several tens of millimeters, are a type of discontinuous fiber-reinforced plastic intermediate material. Offering significant potential for achieving complex shapes with thickness gradients, chopped prepregs provide excellent mechanical properties due to their high-volume fiber content. They are anticipated to be used in lightweight components such as transportation equipment. In our previous studies, we revealed that the initial arrangement of these chopped prepregs in the molding die significantly impacts the internal structure of the molded CFRPs. An uneven charge distribution can result in material flow during molding, leading to inhomogeneous internal structures such as out-of-plane waviness. This reduces the mechanical properties and increases the variability of these properties in the molded products. Conversely, a uniform charge distribution minimizes material flow, thereby preserving the initial arrangement of the chopped prepregs and maintaining the fiber orientation distribution of the molded product. Therefore, it may be beneficial to initially arrange chopped prepregs with an in-plane fiber orientation that is not biased in a specific direction for producing a molded product with stable in-plane isotropic mechanical properties. This could be achieved by, for example, controlling the initial arrangement of the chopped prepregs in the mold using mechanical devices. However, despite the importance of balancing mechanical properties and cost for practical applications, this approach presents challenges such as the increased cost of implementing mechanical devices and the extended cycle time for charging materials, rendering it impractical. Thus, in this study, we focused on the fiber orientation of the chopped prepregs to easily achieve an initial arrangement with random fiber orientation by hand charging. Flat plates were formed using combinations of two types of chopped prepreg fiber orientations in three different chopped prepreg sizes, followed by tensile testing and internal structure observation. The objective of this study was to evaluate the relationships between the fiber orientation of chopped prepreg and the in-plane tensile strength and elastic modulus. Experimental results suggested that combining multiple types of fiber orientations in the chopped prepreg potentially suppressed variability in tensile properties. For instance, although the average tensile strength of the molded products was found to be lower when a mixture of chopped prepregs with two types of fiber orientations was used, the variability was less compared to when only chopped prepregs with a single type of fiber orientation were used.

Experimental study of GFRP spiral-confined concrete under concentric and eccentric compression

abst. 1306
Repository

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Application of Fiber-reinforced polymer (FRP) reinforcement as internal lateral confinement has been an extensively employed technique in FRP-reinforced concrete (RC) structures. A thorough understanding and accurate estimation of the compressive behavior of the pure FRP spiral-confined concrete (FSCC) is essential in the analysis and design of FRP-RC structures. However, limited studies have investigated the confinement mechanism of concentrically loaded FSCC specimens. Moreover, there appears to be no research available on the compressive behavior of such FSCC under eccentric loading. This paper presents a systematic experimental study on the compressive behavior of GFRP (glass FRP) spiral-confined concrete (GSCC) under concentric and eccentric loading. The investigated key variables included the eccentricity-to-diameter ratio and the volumetric ratio of GFRP spiral. The test results showed that the load eccentricity could lead to a significant degradation in the ultimate axial stress, compressive strength and stiffness, and axial displacement at the loading position but an evident increase in the ultimate axial strain on the compressive side and the ultimate section curvature. The degradation in the compressive behavior of the eccentric GSCC specimens can be offset by increasing the volumetric ratio of GFRP spiral.

The Reinforcement of Glulam Beam-to-Column Joints using FRP

abst. 1315
Room GALLA PLACIDIA
Thursday
September 5
10h00

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Glulam, i.e. glued laminated timber in which individual glulam components are fixed together to form composite members, is widely used as a building material to make up lightweight and large-span structures. The basic concept behind this material is to join many layers of dimensioned wood together using structural adhesives, which increases the strength and stiffness of the component and makes it possible to build enduring structures with attractive aesthetics. Steel and aluminium plates, or even just wooden components, are commonly employed at joints of wood constructions. Aluminium plates are not heat resistant, and steel components that are often utilized as joints are vulnerable to corrosion. Because of this, one issue that has received a lot of attention recently is the use of non-metallic fasteners, such as glue or epoxy resins, to adhere sheets onto a wooden beam. The present study aims to determine the rotational behaviour of glulam beam-to-column joints reinforced with different types and the number of layers of Fiber Reinforced Polymers (FRPs). In this context, the beams and columns with cross-section dimensions of 120x120-120x240 are connected using steel fasteners. The connected beam-to-column joints are reinforced with a glass fiber reinforced polymer (GFRP) and carbon fiber reinforced polymer (CFRP) fabric, 1, 2 and 3 times. Reference beam-to-column joints and reinforced beam-to-column joints are subjected to load-displacement tests under cyclic loadings. Experiments are performed to examine the mechanical features, including stiffness value, energy consumption capacity, and maximum load-bearing capacity. It has been observed that the stiffness, load-bearing, and energy-consumption characteristics of beam-to-column joints have been found to be considerably improved by the reinforcement. It has also been observed that the number of windings increases the load-bearing capacity of the beam-to-column joints. Lastly, it has been determined that, as compared to GFRP, the rotational behaviour of beams reinforced with CFRP is superior.

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abst. 1333
Room GALLA PLACIDIA
Thursday
September 5
10h20

Detection of Porosity across CFRP Layers using Machine Learning Techniques Applied to Theoretical and Experimental Ultrasound Data

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There is an increasing use of Fibre-Reinforced Polymer composites as a replacement for metallic components in the transport applications such as aircraft and automobile. These structures are known to depict interesting and superior mechanical properties. However, these structures are often subjected to defects that alter their efficiency. Porosity such as voids inclusion, is among the most common of these defects. Since, porosity reduces the mechanical performance of such composite structures, it is important to detect and characterise its level and location across the layers. This study deals with the detection of porosity across CFRP layers using Machine Learning (ML) techniques Applied to theoretical and experimental ultrasound data. Different samples of CFRP composites with various levels of porosity are fabricated and tested for this study. The experimental data is acquired using an ultrasound immersion tank. The theoretical study for this work is built around both analytical and numerical approaches accounting for realistic conditions of the composites testing. Both simulated and measured data are used to apply a ML technique, mainly the Convolutional Neural Networks (CNN), to detect and characterise the porosity within the CFRP layers. C-scan and B-scan results are analysed and presented to demonstrate the potentials of the CNN technique to characterise such defects. It is

observed that CNN technique has some interesting potentials for extracting defects such as porosity from complex ultrasound data.

Enhancing the accuracy of composite material simulation with new optimization techniques

abst. 1369
Repository

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Growing demand for advanced composite materials in the aerospace and automotive industries and other fields has led to efforts to address their weaknesses. This study introduces a new method to optimize the performance of composite materials, thereby reducing the discrepancies between experimental and numerical results. By refining Hashin's damage parameters and using an improved artificial neural network (IANN), the approach improves the accuracy and reliability of the model, thereby improving the simulation efficiency of GFRP and BFRP composite materials.

A nonlocal damage-plasticity constitutive model for concrete in compression

abst. 1382
GALLA PLACID
Thursday
September 5
10h40

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This paper presents a nonlocal damage-plasticity constitutive model for compressive concrete, implemented within the Abaqus software environment. The model is based on a previously established plasticity constitutive model for concrete under multiaxial compression, incorporating the Menetrey-Willam strength surface, an evolutionary potential surface with triangular deviatoric traces, and a comprehensive hardening rule. The local compressive damage variable is transferred into its nonlocal counterpart through the implicit gradient-enhanced averaging formulations. By using the coupling thermal-displacement analysis, the nonlocal damage is regarded as the pseudo temperature and can be readily integrated into the existing plasticity framework. The advantages of the nonlocal model are demonstrated through the simulations of several concentric compressive loading cases. In the finite element models of unconfined concrete and FRP-confined rectangular columns, the nonlocal model exhibited excellent mesh objectivity compared to the previous local version of the constitutive model. In the simulation of concrete-filled steel tubes (CFSTs), the nonlocal model can correctly capture the buckling mode of the steel, and thus can provide precise simulation compared to the experimental data. In the Future work, the Rankine fracture surface would be integrated into the present constitutive model to facilitate simulations of concrete under both tensile and compressive conditions.

Functionally graded and porous materials and structures

abst. 1075
TEODORICO
Tuesday
September 3
17h10

Influence of processing parameters on aluminum foam produced using TiH2 as a foaming agent.

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Metal foams, particularly aluminum foam, have gained popularity due to their low density and advantageous mechanical properties, such as remarkable energy absorption capacity. These materials find diverse applications in the aerospace, automotive, and construction sectors. Improving manufacturing methods aims to achieve an ideal balance between desired properties and production parameters. However, production processes are difficult to control and often result in inhomogeneous foam structures. This study aims to assess the influence of production parameters (temperature, stirring speed, holding time, and melt viscosity) on the foaming process of aluminum melt using TiH2 as a foaming agent and to optimize these parameters to attain a homogeneous structure. Many experiments were carried out to achieve this, varying the parameters in question while fixing the other parameters. The samples' morphology was then analyzed and compared, density was measured, and pore size and distribution were studied using two-dimensional analysis. Next, a summary of the optimal parameter ranges governing the foaming process is presented. Finally, mechanical tests were conducted to investigate the material's mechanical response under quasi-static and dynamic compressive loads. The experimental findings revealed that sample density significantly affects plateau stress and energy absorption capacity.

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abst. 1116
TEODORICO
Friday
September 6
15h50

Free Vibration Analysis of Porous Beams Via Numerical and Artificial Neural Network Approach

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The main purpose of this study is to analyze a porous beam, whose nodes are formed with a certain conditioned random function, with the numerical solution and Artificial Neural Network (ANN) approach. The free vibration frequencies of the porous beam were first calculated numerically. Then, the data of randomly generated beams were used to train the artificial intelligence module. In this context, the free vibration frequencies for any porous beam whose data is entered were predicted with the help of ANN and the obtained results were compared with numerical results. The truth is that this type of approach is thought to significantly reduce the processing load in determining the mechanical behavior of such structural elements, which we encounter in the most important fields of engineering such as mechanical engineering, civil engineering, and aviation industries. All results were visualized and explained with the help of 2D and 3D graphics.

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abst. 1151
m TEODORICO
Friday
September 6
14h30

FE thermal buckling analysis of FG porous thin-walled beams

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This work presents a finite element model for thermal buckling analysis of thin-walled porous functionally graded (FG) beam type structures. A model is based on 1D beam finite element able to describe behaviour in the geometrically non-linear regime. The Euler-Bernoulli theory for bending and the Vlasov theory for torsion are supposed. Nonlinear analysis is performed according to UL (updated Lagrangian)

incremental formulation. The cross-sectional displacement field accounts for warping torsion and large rotations. The structural material is treated as functionally graded assuming to vary continuously through the wall thickness according to power-law. Numerical results are obtained as critical buckling temperatures and post-buckling temperature vs displacement curves for different boundary conditions as well as for set of material distributions, FG skin-core-skin ratios, and material porosity coefficient. The results are validated comparing to those obtained by shell FE models.

Stress concentration optimization for functionally graded plates with various holes and cutouts

abst. 1170
Room TEODOR
Friday
September 6
15h10

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The study of the stress concentration in plates with circular holes has received a wide attention in the literature. For homogeneous, linearly elastic and isotropic infinite plates under different far-field in-plane loading conditions, the displacement, strain and stress fields can be evaluated in a closed-form fashion. Historically, Kirsch [1] first evaluated the stress concentration factor (SCF) in plates subject to a uniaxial tension. Following a superposition reasoning, he found that the SCF is identically 3 at the rim of the hole. Since then, the interest in reducing this factor by abandoning one or more of the aforementioned assumptions has been considerably increasing. The resulting research output relied on analytical and numerical approaches for both infinite and finite plates. In a parallel context, the increasing use of particulate composites with spatially varying properties has propounded their application, albeit conceptually, to several models in mechanics, including plates with various geometrical discontinuities. Among all, the stress analysis of the plates with circular holes and made of the so-called functionally graded materials (FGMs) has been remarkably investigated. In fact, it is not difficult to realize the amount of works that aim at reducing the stress concentration by taking advantage of the inhomogeneity of these materials, see e.g. [2-6]. Despite of the promising implications arising from the relaxation of the homogeneity assumption, only few works dealt with the optimization of the material distribution to enhance the elastic stress performance along the plate. In fact, most of these works prefix the spatial variation of the mechanical properties by means of prescribed functional forms endowed with various parameters. Although this approach successfully yielded enhanced stress fields in terms of lower SCF at the boundary of the hole, it does not fully exploit, at best, the inhomogeneity concept associated with FGMs. A more general approach may, in fact, led to better results, as shown in a recent work [7], where an infinite FGM plate with a circular hole and subjected to uniaxial traction is considered. Under the assumption of radially varying Young's modulus, an optimization problem aiming to determine the best Young's modulus law without prefixing its functional form has been numerically solved by embedding the finite difference method within the optimization algorithm. The optimal Young's modulus revealed to obey a sigmoid-like function. that led to a uniform hoop stress along the direction normal to the applied load, and therefore made the stress concentration surprisingly vanish. Motivated by this result, the consideration of a broader class of geometrical discontinuities (noncircular holes and cutouts) may represent a challenging task. However, unlike [7], the finite element method results most appropriate for the transcription procedure due to the nature of the more complex shapes of the boundary conditions in comparison with the circular hole. In this talk, after a brief review of the governing equations, the statement and mathematical formulation of the optimization problems are presented. Consequently, numerical optimal solutions for the Young's modulus distribution as well as the associated stress behavior and SCFs are shown in graphical forms for different stiffness ratios of the constituents. References: [1] E.G. Kirsch (1898) VDI 42, 797-807. [2] D.V. Kubair B. Bhanu-Chandar (2008) Int J Mech Sci 50, 732-742. [3] M. Mohammadi et al. (2011) Int J Solids Struct 48, 483-491. [4] G.J. Nie et al. (2018) Compos Struct 205, 49-57. [5] R. Sburlati (2013) Int J Solids Struct 50, 3649-3658. [6] R. Sburlati et al. (2014) Compos. B Eng. 61, 99-109. [7] H.M.A. Abdalla et al. (2024) Under review in Compos Struct.

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abst. 1207 **Repository**

Tolerance modelling of vibrations of thin functionally graded cylindrical shells

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The objects of considerations are thin linearly elastic Kirchhoff-Love-type open circular cylindrical shells having a functionally graded macrostructure and a tolerance-periodic microstructure in circumferential direction. At the same time, the shells have constant geometrical, elastic and inertial properties in axial direction. The aim of this contribution is to investigate the effect of a microstructure size on the transversal free vibration frequencies of such shells. Moreover, the influence of differences between elastic and inertial properties of the constituent materials on these frequencies will be studied. Many functions describing the distribution of material properties will be taken into account. This dynamic problem will be analysed in the framework of a certain mathematical averaged non-asymptotic model derived by means of the tolerance modelling procedure. Contrary to the starting exact shell equations with highly oscillating, non-continuous and tolerance-periodic coefficients, governing equations of the tolerance model have continuous and slowly varying coefficients depending also on a microstructure size. It will be shown that in the framework of the tolerance model not only the fundamental, cell-independent, but also the new additional, cell-dependent free vibration frequencies can be derived and analysed. The results obtained from the tolerance non-asymptotic model will be compared with those derived from the mathematical averaged asymptotic model formulated by applying the consistent asymptotic modelling technique.

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abst. 1229 **Repository**

A modified discrete shear quadrilateral element with assumed orthogonality bending energy and mixed transverse shear strains for isotropic and FGM sandwich plates

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A simple and efficient quadratic incompatible quadrilateral element called DSQK, which was developed based on the first-order shear deformation theory of Reissner-Mindlin and considered transverse shear effects, is presented to analyse isotropic plates and FGM sandwich plates. This quadrilateral element has one displacement and two rotations at four corner nodes and four temporary DOFs at the element's mid-sides. The assumed orthogonality bending energy of Bergan's free formulation approach is used; that is, the zero coupling between lower-order and higher-order bending energy is assumed to fulfil the constant bending patch test. The kinematic transverse shear strains on each side of the element are expressed as quadratic functions. The discrete shear constraint is applied to obtain the constant kinematic transverse shear strains on the element sides. The combination of curvatures, shear strains, the constitutive law of bending and shear, and equilibrium equations leads to the mixed transverse shear strains in the second derivative of the rotations. The relationship between the temporary DOFs and the final DOFs at the corner nodes is established by equalising the constant kinematic and mixed transverse shear strains in the direction cosines of each side of the element. The DSQK's performance is validated using kinematic patch tests and error in energy norm for isotropic plates and convergence tests, which analyse the convergence of deflections, stresses, frequencies, and thermal bucklings of symmetrical and non-symmetrical FGM sandwich plates. The DSKQ element provides accurate results for plates with various geometries, power-law indexes and length-to-thickness ratios, regardless of their thickness.

THERMAL EFFECTS ON MIXED-MODE FRACTURE IN FUNCTIONALLY GRADED MATERIALS USING AN ADAPTIVE PHASE FIELD APPROACH

abst. 1238
Room TEODOR
Friday
September 6
15h30

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In this study, we systematically study the mixed-mode fracture propagation in functionally graded material (FGM) under the influence of thermal loading. Our approach utilizes an adaptive mixed-mode phase-field method for fracture simulation, employing the phase-field variable threshold as an error indicator for adaptivity. The adaptive strategy incorporates quadtree decomposition for spatial discretization, and the element with hanging nodes is treated as an arbitrary polygonal element. A linear function describes the gradient material characteristics of functionally graded materials. In the present work, a hybrid formulation is utilized and the coupled thermo-elastic phase-field equations are solved using a staggered solution scheme. The studies show that the adaptive framework yields accurate results without compromising accuracy and improves computational efficiency. The numerical simulations shed light on the thermal field's impact on mixed-mode fracture behavior in functionally graded material under different gradient profiles, energy release rates, and temperature variations. The results under mixed-mode loading conditions show that the crack path retains consistency despite variations in the critical energy release rate, whereas the reaction peak force on the load-displacement graph changes noticeably, highlighting the interaction between energy release rate and load response. Notably, variations in crack paths are observed by varying thermal conditions, providing valuable insights into the material's response. Moreover, this work demonstrates the potential of the adaptive approach for solving multi-physics problems and is helpful while designing FGMs in applications where thermal effects play a significant role.

Investigating crack behavior in porous functionally graded materials through a thermo-mechanically coupled peridynamic model

abst. 1274
Room TEODOR
Friday
September 6
16h30

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This study advances a bond-based peridynamic model to explore crack propagation in porous functionally graded materials (FGMs) under thermo-mechanical loads. FGMs are engineered with spatial gradients in material properties, challenging traditional modeling techniques, particularly under complex loading. Our model incorporates a power-law distribution for material properties and considers three distinct porosity profiles, enhancing its applicability to real-world conditions. Our approach simulates discontinuities and complex interactions within the material by leveraging the peridynamic method's inherent advantages, such as its non-local and mesh-less formulation. Numerical simulations, supported by parametric studies, examine the effects of material heterogeneity and external loads, illustrating the intricate mechanisms of fracture in FGMs. Results confirm the model's advantage over standard techniques, particularly in situations characterized by fractures caused by concurrent thermal and mechanical strains.

Modelling Porous Plates with In-Plane Functionally Graded Porosity Distribution Using Classical and Non-Classical Theories: Application to Dental GBR Meshes

abst. 1310
Room TEODOR
Friday
September 6
14h50

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Porous materials have emerged as pivotal components in diverse engineering applications, such as biomedical, aerospace, and civil, due to their light weight, high surface area, and customisable properties. Functionally graded (FG) porous structures represent an intriguing subset, offering tailored mechanical properties across spatial gradients. In this study, non-classical micropolar and Cauchy continua are used to model porous plates with functionally graded porosities that are in the same plane. First, a homogenisation scheme is utilised based on strain energy equivalence to find the equivalent material properties. The established homogenised model provides an efficient framework for investigating the mechanical response of porous plates with diverse porosity distributions, including 'V', 'A', 'X', and 'O' patterns, and for a broad range of aspect ratios. Results show that for aspect ratios less than approximately 1.5, the mechanical response of the FG porous structure depends highly on the functional porosity pattern. In this range, micropolar theory outperforms Cauchy theory in predicting the stiffness and displacement distribution of the FG porous structures. This method is used to study a type of dental implant called guided bone regeneration (GBR) mesh. The central part of the mesh has mechanical properties similar to trabecular bone, and the fixing areas are as close to cortical bone as possible to provide the needed load-bearing capacities while ensuring proper occlusivity. Keywords: Functionally Graded Porosity; Micropolar and Cauchy continua; Finite Element Analysis; Equivalent Porous-Cellular Materials.

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abst. 1410
m TEODORICO
Friday
September 6
16h10

Fatigue behavior of 316L steel structural lattice beams under four-points-bending symmetric cyclic loading

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In the last decades the employment of additive manufacturing (AM) to build metal lattice structures has been spreading across many technical research fields and several technological applications, from the design for lightweight load-bearing structures to functional and smart materials. Lattices have been early classified as cellular solids by Ashby, being the first who ever developed an interest in porous and repetitive cellular materials, given their promising characteristics. The later advent of AM provided a strong topology design freedom, allowing the development of customizable lattice geometries based on the property to be enhanced. The excellent specific mechanical properties of these structures make them exploitable in different engineering sectors: in the biomedical field, lattices can be used for customizing the design of bone implants, employing Ti6Al4V as core material. Thermally insulating and heat exchanging applications found lattices as excellent candidate for their purposes, in particular among shell lattices. The aerospace industry is also becoming more interested in both AM and functional porous materials. Fertile ground can be found in both energy absorption components, for instance hit boxes and wing leading edge and in other components subjected to strict impact resistance and lightweight requirements, such as panels for spacecrafts. The increase of the research interest on lattices for these applications also generated the necessity to investigate their fatigue behavior and failure modes, preferably by developing computational tools able to predict the failure locations and timing in terms of number of loading cycles. This study reports the fatigue behavior of structural lattice beams subjected to four-points-bending load cycles by means of the same methodology already developed and presented by the authors for lattice cantilever beams [1]. Here, the method, based on the strain energy computation at the meso-scale cellular level, is extended to the 4-points-bending configuration. The modeling is supported with experimental validation of samples made with 316L steel and symmetric loading (R = -1). Then, the peculiar effect of the tensile-compressive load in the volume regions of the samples has a specific effect in the fatigue damaging process. The modeling method composes by some steps: firstly, in relation to the cell geometry (in this work, the all-face-centered-cubic shape), the lattice is subjected to homogenization process. This operation, frequently adopted in lattice design and for particles or fibers reinforced materials, allows to compute the macroscopic material equivalent properties of Young's and shear moduli and of Poisson's ratio along three dimensions from a single representative volume element (RVE). This process, performed through the finite element method (FEM) software Ansys Mechanical APDL, makes dramatically faster and computationally lighter the following lattice simulations. The second step of the fatigue modeling consists in the static stress-strain simulation on the homogenized geometry, by using the real amplitude of the load as input force or torque. After that, the most critical RVE (identifying one cell) of the lattice component is identified by means of a strain-based criterion. As last step, solely the most critical cell is subjected to de-homogenization and its three-dimensional strain configuration is computed. The same strain field is applied to the real shape of the cell through a separate FEM simulation that returns the correspondent material stress distribution. The stress at the most loaded material point of the cell identifies the highest actual stress amplitude of the cyclic loading in the entire component. This stress is multi-axial and, by means of dedicated fatigue assessment criteria (e.g. Sines, Crossland, etc.), the failure can be estimated. The experimental validation of the model applied to the samples described above allows to compare the results for the 316L material and the four-points-bending configuration. This experimental setup introduces the effect, not investigated before, of the extension-compression strain on the RVE and the potential effects on the fatigue behavior and failure mode. References: [1] A. Coluccia G. De Pasquale, Scientific Reports 13, Article number: 22775 (2023).

Graphene-based composites

abst. 1056
m TEODORICO
Thursday
September 5
09h40

Elastodynamics of graphene with nonlinear second strain gradient effects

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In this research, a numerical investigation is conducted into wave propagation in defect-free single-layer graphene, considering its geometrically nonlinear behavior through second strain gradient elasticity. The weak and strong forms, which incorporate nonlinear strain-displacement relations, are established. The eigenvalue problem is solved for 2D wave propagation based on periodic structures theory. The results indicate that a significant portion of the energy is confined to a single direction at high frequencies. The wave propagation range in the nonlinear model is wider compared to that in the linear model. The findings presented in this study can enhance the comprehension of the dynamic response of graphene, with potential implications for engineering applications involving graphene-based nanostructures.

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abst. 1181
TEODORICO
Thursday
September 5
10h00

Development of Highly Conductive Untwisted CNT Yarn by -bridging and Analytical Evaluation of Electrical Properties using First Principles Calculation.

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In recent years, carbon nanotubes (CNTs) have been attracting attention as an alternative material to copper and aluminum alloys for miniaturization and weight reduction of electronic devices in the age of high-speed communications and high-frequency currents for large data capacity. Due to the strong covalent bonds derived from sp2 hybrid orbitals, CNTs exhibit excellent electrical properties such as conductivity of 108 S/m, current capacity of 1012 A/m2, ballistic conduction and lack of skin effect. In addition, its low density compared to existing wiring materials and low-cost mass production are expected to make it suitable for various applications, including aircraft and space elevators. The growth limit of CNTs alone is as short as several centimeters, and CNT yarn spinning has been investigated as a method to extend the length of CNTs to the order of several meters. In addition to the wet spinning method and the floating catalyst method, a dry spinning method has been developed as a simple CNT yarn spinning method, in which a CNT yarn is spun by drawing a web horizontally from a CNT array of multilayer CNTs grown vertically on a substrate by the chemical vapor deposition (CVD) method. Compared to other spinning methods, the dry spinning method has attracted attention because of its ease of use and industrial potential, CNTs formed into fibers by this method are expected to be used on a macro scale. However, the excellent electrical properties of CNTs have not been realized due to their low crystallinity caused by structural defects such as five-membered ring structures and impurities such as amorphous carbon, as well as the voids and contact resistance between CNT bundles. Control of the length and number of layers of CNTs, chirality research, and post-synthesis treatment are currently underway as means of achieving more excellent electrical properties in CNT yarns. Typical post-spinning treatments are acid treatment to remove impurities and complexation with metals such as copper, densification to reduce the proportion of voids, graphitization, and doping, each of which has been confirmed to have a certain effect. Although improvements have been made in the removal

of impurities and carbonaceous impurities including amorphous carbon by catalysts and in the purity of CNT fibers, there is insufficient discussion on the reduction of contact resistance between CNT bundles, which is one of the main factors in the degradation of electrical properties of CNT yarns. The effect of such post-treatment is considered to be greatly affected by the crystallinity of CNTs and the physical properties of the CNT bundle interface, but few papers discuss the mechanism, and a detailed investigation would enable the development of an optimal post-treatment method for the practical application of CNT interconnects. In this study, we investigated a method to reduce contact resistance between CNT bundles. The method is to insert molecules with a six-membered ring structure between CNT bundles. We also aim to improve the conductivity of CNT yarns. We achieved this by combining contact resistance reduction treatment, doping treatment, and graphitization treatment. Experiments and first-principles calculations show that graphitization treatment enhances the doping treatment effect by reducing impurities with sp3 bonds. In addition, graphitization enhances the effect of PSE-AP treatment by facilitating the introduction of PSE-AP molecules. Furthermore, it was found that the enhancement of carrier mobility by PSE-AP treatment and the enhancement of carrier density by doping treatment create a synergistic effect of the two treatments and contribute to the improvement of conductivity. By combining the above treatments, we obtained CNT yarns with conductivity on the order of 106S/m. As far as the author knows, this is the world's highest value for dry-spun CNT yarn.

Exfoliation and self-healing agent functionalization of graphene for tailoring healing behavior in CFRP laminated composites

abst. 1316
TEODORICO
Thursday
September 5
10h20

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2D nanostructure, high surface energy and aspect ratio, high surface area and superior mechanical properties of graphene make it an effective filler to tailor mechanical, thermal and electrical properties when reinforced in polymer composites. In this research, we have developed Diels-Alder (DA) based self-healing technique in CFRP composites by reinforcing surface functionalized graphene in the polymer matrix. Graphene was first oxidized through acid treatment to exfoliate and activate followed by functionalization with DA adducts, i.e. bismaleimide and furfurylamine. The successful functionalization of the graphene was confirmed from morphological, chemical, structural and thermal characterization. The DA adduct functionalized graphene showed 57% improvement in tensile strength, 79% in tensile modulus and 11% in interlaminar shear strength when reinforced in CFRP composites. Most interestingly, we found 87% in healing efficiency when tested with double cantilever beam with several times healing capabilities. Till date, it has been found that introduction of healing behavior in CFRP composites reduces the mechanical properties which is successfully overcome in this research. This study thus offers an emerging technology for self-healing of CFRP composites with functionalized graphene and can be a new threshold for future research in development of self-healing polymeric composites.

Use of Carbon- and Graphene-Nanomaterials for Multi-Functional Polymer-Nano-Composites

abst. 1328
TEODORICO
Thursday
September 5
10h40

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Polymeric materials have been modified by nano-materials in order to improve their mechanical, physical and materials properties so that the use of them would be increased in the main engineering applications. Specifically, elemental carbon based nanofillers have been under attention due to possibility of having carbon structures in different geometries. CQDs (Carbon-based Quantum Dots), CNT (Carbon Nanotubes) and GNP/GO/rGO (Graphene nanoplatelets/Graphene Oxide/Reduced Graphene Oxide)

are just some of the carbon structures available with 0-D (Zero-dimensional), 1-D (One-dimensional) and 2-D (Two-dimensional). The use of different carbon based nanofillers in the polyurethane (PU) foams, polydimethylsiloxane (PDMS), recycled polyethylene terephthalate (rPET) will be given in the talk. Moreover, use of different dimensional carbon nanofillers in those polymers will also be discussed to further understand synergistic effect of using more than one nano-fillers on the properties of fabricated materials. The multifunctionality of polymer-nano-composites based on aforementioned approach will be presented in field of mechanical, thermal, acoustic, electrical and reverse osmosis membrane applications.

Advancing Structural Health Monitoring in Adhesively Bonded Repairs: A Novel In-Situ Acoustic Emission-Based Methodology

abst. 1035
GALLA PLACID
Tuesday
September 3
16h50

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Addressing a significant challenge in adhesively bonded repair procedures within the industry involves overcoming the lack of a dependable structural health monitoring technique to ensure the integrity of the repaired region during service. This study introduces an innovative, in-situ acoustic emission-based methodology designed to detect, identify damages, and predict failure modes at early loading stages. The study involves the production of two tapered-scarf repaired plates using different patch materials. The first patch comprises neat carbon fiber prepregs, while the second utilizes thermally exfoliated graphene oxide integrated carbon fiber prepregs. By individually testing the constituents of the repair system and monitoring their acoustic activity, it becomes possible to precisely differentiate each damage type. Consequently, when testing the specimens of the repaired panel, detailed information emerges regarding the current structural status and potential failure scenarios. The effectiveness and robustness of the proposed methodology in detecting and identifying damages of varying severity and predicting failure scenarios in composite panels repaired are verified via both pristine and graphene-integrated patches.

Investigation of damage detection efficiency of PZT sensors based on full guided wavefield measurements of glass-fiber reinforced epoxy laminates

abst. 1097
Room GALLA PLACIDIA
Tuesday
September 3
13h10

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Application of PZT sensors are one of the most universal approaches to structural health monitoring. Elastic guided waves, which can be excited and received by such sensors can interact with many types of structure discontinuities, e.g. which can occur due to low velocity impacts, such as delaminations or matrix cracking. The sensitivity of PZT sensors to damage in composites is dependent on many factors, most significantly on its relative location with respect to the elastic waves source, but can also depend on structure geometry as well as particular signal features and wave modes which are used for structure assessment. In the presentation, results of structure evaluation based on guided waves excited by PZT transducers and full wavefield measurements obtained by laser scanning vibrometer will be presented. The measurements were acquired for pristine state of test structure and with introduced damage, therefore it is possible to calculate spatial distribution of various signal characteristics and estimate effective range of PZT sensors for damage detection based on a given signal feature. Various parameters affecting the damage detection range will be compared, in particular: type and the extent of damage, type of signal characteristic used, parameters of the excitation signal (e.g. frequency, duration), as well time interval used for damage index calculation. The obtained results may be useful for selection of signal features used for composite structures monitoring as well as for refining algorithms for sensor placement optimization and damage localization techniques, e.g. based on RAPID imaging algorithm.

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abst. 1117
LLA PLACIDIA
Tuesday
September 3
16h30

Nonlinear Analysis of Wave-Propagation Through a Delaminated Composite Strip Using the Variational Asymptotic Method

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In the present study, a nonlinear analysis of wave propagation in a delaminated composite strip is carried out. The variational asymptotic method (VAM) is used for structural modeling and the finite element method (FEM) is used for obtaining solutions. The VAM is used as a mathematical tool to simplify the 3D problem to 1 D problem. Further simplification is achieved by adopting a sub-laminate approach to model the delaminated structure. The 1D governing elastodynamic equations of the strip model, so obtained, are solved using the FEM wherein the structure is considered as a waveguide. The investigation focuses on the propagation of guided waves in a geometrically nonlinear strip. An illustrative case study reveals the existence of higher-order harmonics originating due to this nonlinearity. The present study shows the usefulness of the framework in simplifying the structural model for a complex wave-propagation problem and its capability to use geometrical nonlinear characteristics of the strip to reveal details of the delamination.

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abst. 1133
Room GALLA PLACIDIA
Tuesday
September 3
12h10

Analyzing the influence of delamination on composite structures using modal analysis and statistical indices

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Composite materials are increasingly utilized in industries like aerospace and automotive, serving as essential structural components. Consequently, comprehending the behavior of these materials over their lifecycle becomes extremely important. Structural Health Monitoring (SHM) systems have been developed for this purpose, aiming to detect, locate, and quantify damage while estimating the remaining life of the structure, all in real-time. These systems employ various techniques compatible with potential damages that may occur in laminated structures. In this particular study, vibrational techniques, specifically modal analysis, were employed to detect delamination damage in a CFRP structure. Modal analysis involves obtaining the Frequency Response Functions (FRF) of the structure, which depict its behavior under specific excitation frequencies. This response is contingent upon the geometry, stiffness, and dampening of the structure, with damage altering these parameters, thereby facilitating analysis for detection purposes. The beams under investigation were afflicted with delamination at two locations, the fourth and eighth layers, each varying in three different sizes, yielding a total of nine beam configurations. Three laminate configurations ([0]12, [0/45/90/0]12, and [0/45/30/-45]12) were analyzed. Computational analysis was conducted by creating a model with free-free boundary conditions, simulating a laboratory test. Amplitude and phase parameters were extracted from the FRFs

and subsequently applied to damage indices sourced from literature, along with statistical indices. The behavior of these indices concerning the imposed damage on the structure was then analyzed, revealing the advantages and disadvantages of utilizing each index for damage detection, as well as the influence of delamination on the structure's behavior. Both types of indices proved effective in quantifying damage. However, upon analyzing their sensitivity, literature indices demonstrated a more stable and superior response compared to statistical indices. Additionally, the symmetry of the laminate emerged as a significant variable in the study, as the indices returned consistent values even with a change in the position of delamination when symmetry was present. Conversely, without symmetry, a variation in value based on the position of delamination was observed. With this foundational information, a Design of Experiment (DOE) analysis was applied to the geometry to obtain further insights into the influence of delamination. To enhance the efficiency of both types of indices, a filter for lower values in the FRF was applied. This refinement ensured that the indices received only the points extracted in the proximity of the modal frequency, which represents the critical range affected by the frequency difference induced by damage.

Residual strength prediction of composites after fatigue loading

abst. 1150
Room GALLA PLACIDIA
Tuesday
September 3
12h30

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Under fatigue loading conditions, the static strength of composite materials progressively decreases until failure occurs. Knowledge of the residual strength is critical not only for preventing catastrophic failures but also for enhancing the efficiency of maintenance planning. This research proposes a novel approach to estimate the residual strength of glass epoxy composites subjected to fatigue loading. The technique utilizes a piezo-resistivity-based structural health monitoring (SHM) system to collect signals during fatigue loading. These data are subsequently used to predict residual strength through machine learning algorithms. Despite collecting extensive electrical resistance (ER) data, direct analysis failed to identify clear patterns linking ER changes to residual strength, highlighting the data's complexity and the necessity of applying machine learning techniques to uncover hidden patterns. The study involved embedding carbon nanotubes into glass/epoxy samples to make them conductive and subjecting these samples to fatigue testing while continuously monitoring their electrical resistance. Key electrical characteristics, such as total and relative change in ER indicative of residual strength, were extracted from the data and used as potential input features for various machine learning algorithms to predict residual strength. The findings suggest that the proposed method can accurately predict the residual strength with an exceptionally low average error of less than five percent during the testing phase. Figure 1 illustrates the performance of various machine learning models in predicting the residual strength of new, unseen samples in the test set using the change in ER during fatigue loading.

Multifunctional nanocomposite assessment using carbon nanotube fiber sensors

abst. 1219
Room GALLA PLACIDIA
Tuesday
September 3
12h50

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We report on the novel application of carbon nanotube fibers (CNTFs) for the one-step, dual-stage, non-destructive monitoring of multifunctional conductive nanocomposites. Hierarchical nanocomposites were created by embedding CNTFs into carbon nanotube (CNT) - modified matrices during their manufacturing to assess production variables. CNTFs are then left embedded in the structure for monitoring during nanocomposite application. We investigated the dependence of detection sensitivity and reliability on the CNTF diameter (~40-700 μm), electrical conductivity ($\sim 10^2$-$10^4 S/m$), and the choice of measurement technique (2- and 4-point) for single-walled and multiwalled CNT fillers at different concentrations. The sensors showed promising sensitivity to CNT type and concentration, the results were independent of CNTF diameter and contact resistance, and showed low noise. For application monitoring, nanocomposites electrical and mechanical (tensile and cyclic) properties were tested to determine sensitivity to static and dynamic conditions. CNTFs did not cause any reduction in mechanical properties, unlike the losses observed for metallic electrodes (up to 60% reduction in ultimate tensile strength). CNTF-based evaluation of the electrical resistivity (between 10^2 - 10^6 Ohm · cm) and dynamic electrical response (gauge factor between ~2 - 12) matched values from a standard electrode material. Microstructural analysis proved that this unique performance was due to the surface and internal volume infiltration of the nanocomposite matrices into the CNTFs, causing interconnection of the CNTs of the matrix and CNTFs. These findings show that CNTFs may be used to accurately monitor nanocomposite multifunctional properties both during manufacturing and application using one-step integration, regardless of the sample size and manufacturing technology.

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abst. 1248
Room GALLA PLACIDIA
Tuesday
September 3
15h10

Mechanism failure analysis of unidirectional hybrid pultruded rebars under static and fatigue loading condition using acoustic emission

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Determination of failure mechanisms and their development in the structure is an important aspect to provide the understanding of material behavior under loading conditions and safety exploration of designed construction. The inspection of the loaded elements is used to predict the time of the failure and stage of the structural lifetime, which could reduce the maintenance cost in the future. The acoustic emission system is one of the major techniques for the Structural Health Monitoring (SHM) structures. Analysis of the elastic waves generated by the events during damage development was conducted using machine learning techniques. Applied clustering methods like K-means, fuzzy C-means provide to group achieved data to various mechanisms such as matrix cracking, fiber breaking or delamination. Changes in content of each degradation mechanism during different stages of structural lifetime could be used for evaluation of material integrity. The advantage of the acoustic system is the localization algorithm based on time difference of arrivals (TDOAs) of the same event by the different piezoelectric sensors. Accuracy of localization in anisotropy materials like composite could be insufficient due to gradient of elastic wave velocity in the structure caused by fiber orientation in laminate. For unidirectional reinforcement polymers, which is characteristic to pultruded profiles, the distribution of localization results was improved. The experimental campaign was conducted on smooth circular rebars made by a pultrusion process with thermoset epoxy resin and glass, basalt fibers or hybrid glass-basalt reinforcement in the structure. Several issues were under investigation during the experimental campaign. First of all the material behavior was compared at two loading conditions: static and fatigue. The data from acoustic emission have been compared to the results from testing machines and strain measurement techniques such as strain gauges or digital image correlation. The distribution of the event localization, type of damage mechanisms and region of the final damage were verified. Second main field of the studies is the impact of the hybridization techniques on the development of damage mechanisms verified by achieved data from the acoustic emission sensors. The outcome from the experimental campaign will be methodology of acoustic emission data processing and impact of hybridization techniques on material behavior. The work was supported by the project Minigrants for doctoral students of the Wroclaw University of Science and Technology.

Machine Learning-based Defect Detection for a Closed-Loop Quality Assurance System in the Automated Tape Laying Process

abst. 1346
Room GALLA PLACIDIA
Tuesday
September 3
15h30

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Carbon fibre composite parts are increasingly used in lightweight applications, such as aerospace, due to their superior strength-to-weight ratio. Automated tape laying is one of the most advanced manufacturing methods and is widely applied in the industry. However, quality assurance is mostly performed manually, which increases the production time significantly. Gaps and overlaps between the tapes are common defects and have detrimental effects on the tensile and compressive properties of the final material. Therefore, these defects must be detected early in the manufacturing process to allow instant corrective action. This research investigates the use of machine vision techniques for detecting defects in laser line triangulation scans of dry fibre tape layups. The layup is scanned online with the production process, generating dozens of cross-section profiles per second that require evaluation. Existing evaluation methods based on static expert system designs are too slow to realize an online evaluation on edge-computing devices. We propose a convolutional neural network based on the U-Net design to predict the class, position, and size of defects. The network is pre-trained using a novel benchmark dataset of synthetic data based on a geometrical model. Subsequently, the parameters are fine-tuned using a smaller data set of real measurements from the manufacturing line. This transfer learning approach in the training phase allows the model to benefit from domain knowledge while still learning the complex features straight from the data. After deployment, the machine learning-based evaluation proves to be significantly faster and more accurate in detecting defects than the existing expert systems. Using this neuronal network, instant results can be fed back into the production line to perform corrective actions. Implementing the system leads to reliable defect detection in the manufacturing process and, ultimately, higher part quality.

Flexural performance of concrete beam under electrochemical chloride extraction against corrosive conditions

abst. 1358
Room GALLA PLACIDIA
Tuesday
September 3
15h50

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Steel corrosion in concrete inevitably influence the performance of reinforced concrete structure, due to its adjustment of the interface between the steel and as a result concrete properties. Once the steel corrosion starts, the interfacial gap can be filled up with the rust formed on the steel surface. The traction forces along the steel surface may increase, which could decrease after excessive rust formation as the corrosion progresses. Additionally, the internal concrete can be subjected to stress due to corrosion of steel, leading to the initiation of cracking, which could substantially degrade the structural performance. In this study, the flexural performance of a reinforced concrete beam was investigated in terms of its rigidity and strength following the completion of the electrochemical chloride extraction (ECE) treatment. After the completion of corrosion procedure and ECE treatment, the 3-point bending test was conducted for the reinforced concrete beams with two strain gauges attached

underneath the central line of the beam (i.e., the tensile dominant zone). To evaluate the degraded or/and enhanced flexibility of the beam after the ECE, axial load-strain distribution with respect to its depth was determined. Additionally, the flexural rigidity of concrete beam was evaluated by measuring the relation between the bending moment in terms of the curvature and displacement. Simultaneously, a degradation of the moment of inertia was calculated to assess the flexibility and tensile cracking resistance. Finally, a degradation of the moment of inertia and the maximum load-displacement relation were determined to assess the resistance to tensile cracking and ensure the effect of the ECE, respectively. The structural performance was mainly addressed in the current study, including the relationship between the maximum bending moment and mid-span displacement (i.e., flexural rigidity and strength) and the strain-effective moment of inertia. These relationships significantly contribute to the serviceability and durability of concrete structures, reflecting the strength of concrete beams. Before the 3-point bending test, the equipment used for the ECE (i.e., the salt reservoir, titanium mesh, and electric circuit) was removed. Subsequently, the outer concrete beams were washed and dried for 24 hours using a water gun. ECE treatment duration of the 8-weeks can improve the ductility of the RC beam penetrated by chloride from a salt reservoir. Once the steel corrosion starts in concrete beam, both the rigidity and ductility are reduced. However, ductility could be improved by the ECE treatment, which can subsequently increase the resistance against to cracking due to tensile deformation of the beam. Corrosion of the steel further increased the maximum bending moment against the mid-span displacement, which was always higher than the control, although the bending moment decreased with increasing duration of treatment. It means that the ECE treatment reduced the flexural rigidity but enhanced the flexural strength of the RC beam. The mid-span deformation for untreated and for the ECE specimen was always greater than for the Control, particularly, with a further duration of ECE leading to an increase in the mid-span deformation. The ECE treatment can improve the flexibility of the RC beam. In addition, the treatment delayed the degradation rate of the moment of inertia, thus improving the crack resistance despite the higher risk of deflection. The flexural strength (i.e. maximum bending moment) of the RC beam was significantly enhanced by steel corrosion, which may be attributed to improving the traction force at the interface between steel and concrete. However, this enhancement was subsequently reduced by the ECE treatment. Except for the 8-week ECE treatment, the flexural strength was mostly higher compared to the control.

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abst. 1385
Room GALLA PLACIDIA
Tuesday
September 3
16h10

Development of a Carbon Nanotube Sensor Using 3D Photocuring Printing for Strain Monitoring of CFRP Structures

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Carbon fiber reinforced polymer (CFRP) structures are widely used in fields such as aerospace, but they face complex strain environments, requiring the use of strain sensors for structural health monitoring (SHM). This study has developed a novel piezoresistive sensor whose sensing core and electrodes are made from carbon nanotubes (CNTs) and epoxy resin (EP) can be directly integrated into the CFRP surface, thus providing better peel resistance and higher fabrication quality. Specifically, the sensor employs the composite of multi-walled CNTs (MWCNTs) and photosensitive EP as the sensing core and highly aligned MWCNT film as the electrode, utilizing liquid crystal display (LCD) 3D photocuring printing technology. During this process, an embedded electrode printing method was proposed, ensuring the tight integration of the electrodes with the MWCNT-formed micro-nanoscale three-dimensional resistive network. A feedback-regulated dispersion process was introduced, which involves real-time monitoring of the macroscopic conductivity of the printing material to uniformly disperse MWCNTs in EP. Additionally, an optimal set of printing parameters, including layer exposure time and post-curing conditions, was determined to achieve high-quality fabrication. These methods can develop advanced strain sensors that demonstrate excellent performance and potential in the SHM of CFRP structures.

Hybrid composites: Material, Processes and durability (chaired by A. Makradi, S. Belouettar, J. Barkanovs)

Processing of inverse fibre-reinforced thermoplastic/metal laminates

abst. 1026
Repository

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Thermoplastic-Fibre Metal Laminates (TP-FMLs) offer the ability to be thermoformed to produce complex shape composites components . The thermoforming-based production technique is able to produce composite parts faster than any other existing thermoset-based fabrication techniques . However, TP-FML systems exhibit different forming behavior compared to metals and hence structural defaults induced by thermoforming are the leading process damage in these hybrid composites. Thermoforming process of flat blank TP-FMLs is widely experimentally studied towards process optimization considering effects of the process parameters on thermomechanical behavior of different hybrid composite components to reduce defects such as fibre disorientation, fibers wrinkling, delamination and spring-back. Experimental investigations show that a successful thermo-formability of semi-crystalline based TP-FMLs is limited to a narrow process temperature window around the thermoplastic recrystallization. The present work focuses on the manufacturing process optimization of inverse TP-FML, where the metal sheet layer is sandwiched between two fibre-reinforced thermoplastic-based layers. Within this investigation the metal core layer used is the aluminum alloy EN AW-6082-T6 with a thickness of 0.5 and 0.8 mm. The reinforcement of the hybrid structure is obtained by glass fiber reinforced prepregs (PA6 GF60) with a thickness of 0.30 mm. The forming process is in terms of processing temperature, Press force and time optimized. Pre-trials on rectangular benchmark parts using variothermal pressing process were carried out. Derived insights from pre-tests on rectangular benchmark have been adopted to prove the feasibility and reproducibility of manufacturing of Channel benchmark parts. Press trials using isothermal pressing technique were applied on channel benchmarks and found to be saving about 70% of processing time in comparison to variothermal technique. The metal/TP composite adhesion quality was investigated using Interlaminar Shear Strength tests and microscopic imaging.

Intelligent tool design for a closed-loop injection molding process of polymer-based hybrid composites

abst. 1050
Room GIUSTINI
Thursday
September 5
16h50

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For future injection molding processes, the demand of intelligent machine management operations will increase significantly. Not only progressively complex material and composite structures but also the extensive use of recycling materials challenges the process stability of conventional injection molding processes. Consequently, using in-mold sensors to establish a closed-loop process control is beneficial in this regard. In this contribution, the concept of an advanced injection molding tool with integrated sensors and optimized mold flow is presented to mold a locally reinforced injection molded part potentially based on recycled materials. The research aims on a closed-loop production in line with an AI-based network allowing for the analysis of the acquired sensor data. The study thereby centers around the development of a hybrid process which uses the in-mold shaping of a non-woven fabric in combination with the over-molding of a stabilizing rib structure. This results in an established demonstrator component, which allows for the analysis of its mechanical performance. The non-woven fabric shaping, and

the injection molding are the essential parts of this research to control the fluctuating input variables. These two processes are initially considered separately and are combined at a later stage after the process specific sensor technology and the conversion into a controllable system operated by an AI-based method are integrated into the production line. The injection molding tool also serves as a forming tool for the non-woven fabric shaping and must be taken into consideration for the tool design. Through the sensor optimization of the injection molding process the AI is able to counteract inhomogeneities in the material and thermal fluctuations, which leads to a uniform quality distribution. With the help of sensors in the injection molding tool, industrial production difficulties such as delamination, vacuum holes, warping, flash, jetting, burns, sink marks and others can be prevented. The correct sensor placement within the injection molding tool plays thereby a key role for the entire process. The aim of this study is the realization of an injection molding tool which combines the properties mentioned above and presented on a poster on ICCS27.

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abst. 1052
Room GALLA PLACIDIA
Friday
September 6
14h30

Thermoforming Process of Thermoplastic-Fibre Metal Laminate Composites: Modelling, Simulation and Experimentation.

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The use of sustainable and lightweight structures has become mandatory given the ever-rising demand for resource efficiency and sustainability. Structural weight reduction without reducing safety and resistance and increasing costs requires a system-engineering design optimization that combines material properties/functionality and manufacturing processes to meet product and sustainability requirements at the lowest mass and/or cost. With this regard, Thermoplastic Metal Fibre Laminate (TP-FML) composite systems hold a great potential. TP-FMLs offer the ability to be thermoformed to produce complex shape composites components from flat sheet , . TP-FML systems exhibit different forming behaviour compared to metals and hence structural defaults induced thermoforming are the leading process damage in these hybrid composites. Thermoforming process of flat blank TP-FMLs is widely experimentally studied towards process optimization considering effects of the process parameters on thermomechanical behaviour and microstructure evolution of the different hybrid composite components to reduce defects such as fibre migration, fibres wrinkling, delamination and spring-back . However, most existing predictive tools for design of these class of hybrid composites are focused on durability while modelling and simulation of the thermoforming process are based mainly on empirical constitutive equations calibrated on experimental stress-strain curves conducted on individual TP-FMLs components , . Their simulations show that frictionless interfacial behaviour results in no wrinkling, metal tearing and more accurate topological representation of the final stamped parts while introducing friction reproduced the real wrinkling observed experimentally. Therefore, predictive models for TP-FMLs thermoforming process should not take into account only the behaviour and variability of the hybrid composite components but also the variability of the process parameters for better thermoforming process control and optimization. The present work focuses on the development of models taking into account deformation of the thermoplastic composite and anisotropy induced by fibres orientation. The model is validated on a U-benchmark experimental tests. Within this investigation the metal core layer used is the aluminum alloy EN AW-6082-T6 with a thickness of 0.5 and 0.8 mm. The reinforcement of the hybrid structure is obtained by glass fiber reinforced prepregs (CELSTRAN® CFR-TP PA6 GF60-03) with a thickness of 0.30 mm.

Characterization of Thermoplastic Lamina Properties from Vibration Tests of Hybrid Composite Panels

abst. 1073
Room GALLA PLACIDIA
Friday
September 6
14h50

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Thermoplastic fiber-metal laminates (TP-FML) belong to the hybrid material systems combining advantages of both metal and fiber-reinforced thermoplastic layers and considerably reducing the weight of structural parts. The TP-FML hybrid panels of complex geometry can be obtained by using stamp forming technologies providing their high-volume production. To define performance, reliability and safety requirements of such innovative products, their material properties of separate components should be known. If the determination of material properties of metallic layers does not present any particular difficulties, characterization of mechanical parameters of thermoplastic layers is complicated due to their dependence on features of technological process applied for the production. This problem could be solved by an application of the inverse technique based on vibration tests and allowing to characterize the material properties of separate layers from the dynamic analysis of full structural components. The general idea of each inverse technique is the error functional minimization between some numerically and experimentally determined structural integrated parameters, in our case – between natural frequencies. For this reason, the presented inverse technique consists of experimental set-up, numerical model and material identification procedure itself. To avoid any influence of exciting and measuring devices on the vibrating object, the loudspeaker and POLYTEC laser vibrometer operating on the Doppler principle are used. The modal analysis is applied to extract natural frequencies and corresponding mode shapes from the velocity and displacement of vibration sample. Completely free boundary conditions are practically realized by a panel vertical suspension on a frame by thin threads. The commercial finite element code ANSYS Mechanical 2023 R1 is used for the modelling and dynamic analysis of structural parts, where an eigenvalue problem for the undamped free vibrations is solved with the block Lanczos mode extraction method. In a basement of the material identification procedure lies non-direct optimization methodology based on the planning of experiments and response surface technique to decrease considerably computational efforts. In this case simple mathematical models (response surfaces) are determined only by the finite element solutions in the reference points of experimental design. To characterize thermoplastic lamina properties from vibration tests, two hybrid panels with a location of metallic layer between fiber reinforced thermoplastic layers have been prepared by using stamp forming technology. In the first panel with the lay-up structure of 0/90/0/AL/0/90/0 the thermoplastic layers of thickness 0.3 mm are made of polyamide PA6 and glass fibers GF60 with a volume content of 40 % and aluminum AL 6082 T6 layer has a thickness of 0.5 mm. The second panel, where the thickness of aluminum layer is 0.8 mm, has the following lay-up structure 06/PA62/AL/PA62/06. The thickness of each thermoplastic layer is approximately 0.13 mm, and it is made of polyamide PA6 and carbon fibers CF60 with a volume content of 48.5 %. For identification and results validation, two plates of 240x160 mm and some beams have been cut from the hybrid panels. The plans of experiments with regular distribution of the points of experiments in the domain of factors for both samples have been formulated for 4 design parameters and 30 experiments. Different finite element modelling approaches and different order polynomial functions have been estimated in their applicability to approximate accurately the numerical results and bring them as much as possible closer to the results of physical experiments. The identified elastic material properties have been successfully validated by comparison of numerical and experimental resonant frequencies and additionally verified by the three-point bending tests using beam type samples.

abst. 1089
Room GALLA PLACIDIA
Friday
September 6
15h10

Finite Element Modelling of Stamp Forming Processes for Thermoplastic Fiber Metal Laminates

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Thermoplastic fibre metal laminate composites due to their high strength- and stiffness-to-weight ratios, good fatigue and impact resistances, high specific energy absorption, show great promise as lightweight structural materials in transportation industry. Manufacturing process of products made of this material consists of the following steps: preheating of the components, stamping, consolidation during cooling and releasing of the punch. Quality and properties of the final product highly depend on parameters of the technological process. For the development and analysis of the technological process, its numerical modelling by finite element method could be considered as effective and cheap approach. In this case, developing of the accurate and adequate FE model is the most important task. Stamp forming of aluminium-composite-aluminium (layup AL/02/902/02/AL) and composite-aluminium-composite (layup 0/90/0/AL/0/90/0) deep hat-profile (high of cross-section 50 mm width of flange 40 mm, slope of webs 7.4 °, profile length 100 mm) from plate with dimensions of 100 x 200 mm was analysed. Thickness of aluminium Al 6082 T6 plate was 0.5 mm. The composite material was 0.3 mm thick prepregs made of PA6 matrix reinforced by UD glass fiber with volume content of 40 %. It was assumed in this work that blank is uniformly preheated to the desired temperature, therefore preheating process was not considered in the numerical study. It was focused on the high-velocity stamping, simulated by explicit dynamic solver of Ls-Dyna 2023 R1, and following cooling and releasing, analysed by implicit solver of the same software. The reinforced thermoplastic was modelled using 3 different approaches. In the 1st approach the components of composite material (fiber and matrix) are modelled separately with two coincidental shell elements. These two shell elements can be regarded as separate parts and are connected by identical nodes. The thickness of each finite element is equal to the total thickness of composite layer multiplied by a volume fraction of modelled material (matrix or fiber). This means that thickness of modelled composite blank is smaller than the original one. In the 2nd and 3rd approaches matrix and fiber are also decoupled, but they are represented by one layered finite element. In the 2nd approach matrix layers are spaced from both sides of reinforced layer located in the centre of composite blank. In the 3rd modelling approach matrix is uniformly distributed between fiber layers. Reinforced thermoplastic material model (MAT249) was used for representation of fiber and matrix. Aluminium layers were modelled by separate layers of shell finite elements. Material was represented by Johnson-Cook model (MAT015). Components of tool (die and punch) were assumed as rigid bodies and modelled by MAT020 material. Forming surface-to-surface contact was used to model interaction between rigid die and deformable blank. Interaction between deformable components of blank was described by surface-to-surface contact type. Parametric study of the stamp forming process was performed. Process temperature was varied from 180 °C to 260 °C, stamping time from 0.01 s to 0.5 s, friction between aluminium and steel from 0.1 (corresponds to lubricated surfaces) to 0.7 (clean and dry surfaces). Slight dependence of blank stress state on process temperature and friction coefficient was detected. The influence of stamping time is more interesting, since in general, if it increases, the stresses in the blank also increase, however, with a very short time, the impact of the punch can cause extremely undesirable dynamic behaviour (vibrations) of the blank components. This time threshold depends both on the structure of the hybrid composite and on the layup of reinforced thermoplastic.

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abst. 1104
Room GALLA PLACIDIA
Friday
September 6
15h30

Comparative studies on aluminium alloys / CFRP hybrids: Influence of surface modification, joining processes and climatic as well as corrosive stresses on the mechanical properties

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Hybrid compounds made of metal and fiber reinforced plastics, e.g. carbon-based, are used today across all industries. That is why innovative joining processes are being researched to produce hybrid structures which contribute significantly to resource efficiency in various sectors such as the automotive and aircraft industries by reducing weight. For such innovative multi-material designs the assembling of the different materials is critical because each of the different material combinations requires a specially adapted and efficient joining technology. State-of-the-art joining technologies, such as mechanical joining by screws or rivets, have specific restrictions like the use of additional material, limitations in the geometric flexibility or comparably long bonding times. For mobile applications, the long-term resistance of hybrid multi-material systems is a decisive criterion for ruling out premature failure under operating conditions. Within our talk we will present results from several experimental studies in which we investigated the effect of the pre-treatment ad joining process as well as the ambient conditions on the mechanicals strength of different Al-CFRP-combinations. To do so, we followed the technological chain of surface pre-treatment and characterization of the materials used, joining processes and mechanical tests under quasi-static conditions and subsequent post-mortem analysis of samples in their original condition and after the application of climatic and corrosive stresses. Prior to joining, the bonding surfaces were acetone-cleaned or laser-pretreated by near-infrared (N-IR) laser radiation. The different surface topographies were examined using optical microscopes, roughness measurements, and infiltration tests. The surface conditions achieved were correlated with the mechanical properties of the single-lap joints produced. The results indicate that by usage of a specific range of N-IR-laser parameters the shear strength under tensile load can be increased up to a maximum value corresponding to the interlaminar shear strength of the CFR-PA12 applied in the thermo-mechanical direct joining or the cohesion strength of the applied epoxide based adhesive. In addition, hybrid compounds produced by both joining strategies were exposed to artificial ageing regimes such as temperature conditioning at T = 40 °C and relative humidity > 95 %. It can be shown that high strength in the initial state of the thermally direct joined probes of approx. 14 MPa can be maintained over a long period of up to 1,500 h.[1] In contrast, the adhesively joined specimens of acetone-cleaned as well as laser pre-treated surfaces lose a maximum 20 % of their initial average shear strength of 22 MPa after aging up to 1440 h. A critical influence is shown for all samples during the neutral salt spray test according to DIN EN ISO 9227, which leads to a decrease of the bond strength depending on the particular pre-treatment strategy. The fracture patterns of the laser-pretreated samples show corrosive degradation after 720 h, indicating galvanic coupling and crevice corrosion.[2] To summarize, the manufactured hybrid compounds have a strength that corresponds to the material strength of the thermoplast CFRP used for the direct thermo-mechanical joining and on the other side to the cohesion strength of the applied adhesive. Secondly, these hybrid compounds have shown significant but varying degrees of strength degradation under varying climatic and corrosive stresses. References: [1] D. Meinhard, S. Nester, J. Schanz, T. Pott, H. Riegel, V. Knoblauch, Materials Corrosion 2023, 74, 887. [2] J. Schanz, S. Nester, D. Meinhard, T. Pott, H. Riegel, A. K. M. de Silva, D. K. Harrison, V. Knoblauch, Materials Corrosion 2022, 73, 158.

Study on adhesively joined steel-CFRP hybrids for the digitisation of material data: Influence of surface pre-treatment on mechanical strength and fracture mechanics

abst. 1124
Room GALLA PLACIDIA
Friday
September 6
15h50

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Hybrid materials, also known as multi material combinations, are increasingly being used in mechanical engineering, aerospace and the automotive sector. The challenging demands for novel material combinations and associated new property profiles can only be met by the selection of the adequate joining technology. Both adhesive bonding and mechanical fastening are widespread bonding methods. However, they bring different property profiles into the final hybrid component. The properties depend not only on the joining technology, but rather on the joining process and the its parameters. Although there are some isolated data sets on specific material properties, these have seldomly been systematically saved, collated and made available. As a result, the development of new hybrid structures is often related to time-consuming and resource-intensive trial-and-error tests in order to check the validity of joining process and to capture the necessary data for part design. The project HybridDigital aims to make a significant contribution to the digitalization and sustainable development of hybrid structures for lightweight construction. A digital twin for hybrids may in future allow for a resource-optimized and robust development of hybrid structures based on individualized joining processes. The research project focuses on the determination, systematisation, structurisation as well as on the semantic modelling and finally the ontological description of the process-dependent characteristic values. The target is to make these data available in a decentralised platform called MaterialDigital (PMD). The data collection is based on the detailed description of the joining process and a multi-scale characterisation of the hybrid structures on both experimental numerical levels. The multi-material combination selected for principle investigation is steel-carbon fibre-reinforced polymer composite, (abbrev. Steel-CFRP). The approach involves the production of samples by both mechanical fastening and adhesive bonding and the systematic characterisation of the mechanical properties under quasi-static and cyclic loading . Furthermore, the experiments are accompanied by acoustic emission analyses, both in the preparation phase (e.g. when cutting or drilling the CFRP) as well as during the mechanical tests. This allows the detection of damage in the material at a micro level, which can then be correlated with the failure behaviour in the hybrid at a macro level. This study presents the correlative effect of pre-treatment process parameters on the final mechanical performance, considering the entire technological chain, i.e. starting with the material preparation and surface treatment, through the joining process to the mechanical, acoustic and imaging characterization and post-mortem analyses. Single-lap shear samples of DP 700 steel and CFRP based on Fiberpreg C210 UD 24K EP4.2 40 60 were fabricated by adhesive bonding, using Scotch-Weld AF163-2K-.06 as the adhesive. Surface treatment by laser, sandblasting and peel-ply or acetone cleaning was varied systematically. It was observed that the surface treatment has a crucial influence on the mechanical performance of the hybrid samples produced by adhesive bonding. Sandblasted samples showed the best mechanical performance under quasi-static test conditions. These results will be further investigated in cyclic tests as well as in double cantilever beam tests.

Impact problems

Landing simulation of vertical take-off aircraft using spring mass model

abst. 1020
GIUSTINIANO
Thursday
September 5
09h40

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The proposed simulation model for landing analysis consists of a mass and stiffness model. The tire is modeled by spring elements and connected to the ground. Generally, in the landing simulation, the aircraft structure such as the wing and fuselage is modeled by concentrated lumped mass. In this study, the stiffness effects of aircraft on the impact load will be investigated using spring mass model. In this model, the stiffness of entire aircraft structures is considered to simulate the impact landing load accurately. The drop tests are performed to validate the numerical model. The predicted impact landing load was compared with test results.

IMPACT BIRD STRIKE SIMULATION ON A COMPOSITE LEADING EDGE

abst. 1047
GIUSTINIANO
Thursday
September 5
10h40

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Lightweight metal, such as aluminum, has been used in the aerospace industry for decades. The material behavior is therefore well known when subjected to impact and bird collision rarely leads to complications with these types of aircraft. Because all major companies in the aeronautical and automotive industry increasingly utilize composite materials, the impact properties of these kinds of materials need further investigation. Composites are used in aeronautic applications, amongst other things, because they have superior weight to stiffness ratio when compared to other materials. This leads to lightweight structures that consume less fuel than previous generations without loss in security or comfort. There are also new manufacturing possibilities with composites that enable novel ideas in aircraft design. In this paper, the impact behavior of a composite leading edge wing structure is analyzed with respect to residual stresses that can weaken the structure. A first comparison was made between aluminum leading edge obtained in Nastran and c software, respectively. Then, the same component in Radioss® has been studied in aluminum and self-reinforcement propylene material, using a solid and a SPH method to modelling the bird impact.

The use of a different top layer to increase the puncture resistance of a carbon fibre-reinforced polymer

abst. 1139
Room GIUSTIN
Thursday
September 5
10h00

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The article examines the possibility of increasing puncture resistance of a composite with carbon fibre reinforcement by using a different top layer of the composite. The examination focuses on carbon composites made of GG600T carbon fabric laid out in a matrix of MGS L285 epoxy resin, cross-linked with MGS H286 hardener. Epoxy resin (L285, H286), polyurethane paint and Herex foam C.70.55 were used as external layer materials. An Instron CEAST 9340 drop hammer was used to perform the puncture resistance tests. The samples were subjected to impacts with ener-gies of 25 J, 30 J and 40 J. The extent of the damage area was analysed in terms of the applied surface layer per sample surface (impacted/top and bottom). The peak energy, peak displacement and puncture resistance were compared in relation to force and peak energy. In addition, the course of force and energy during the impact were analysed. The results obtained during the examinations demonstrated that the puncture

resistance of the composite can be increased through an appropriate choice of the surface layer material. Among the tested materials, it appeared that the resin composition made it possible to improve this particular property in the tested composite. Furthermore, the transferred load is dependent on the impact energy. In case of higher impact energy, the force transferred by the examined material is significantly higher for composites with an additional surface layer. The ability to use the surface layer to locate the impact site also proved to be a highly desirable feature.

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abst. 1190
GIUSTINIANO
Thursday
September 5
10h20

Influence of preloading on damage in CFRP composite material subjected to low-energy impact loads

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A significant challenge in the operation of aerospace structures made of Carbon Fiber Reinforced Polymers (CFRP) composite materials is their vulnerability to damage from impact loads. The problem is even more complex when one considers that damage to the aeronautical structure occurs typically in preloaded material. Therefore, an effective assessment of impact damage occurring in CFRP-type composite should take into account the occurrence of coupled loads in the material, i.e. not only caused by dynamic loading, but also by static preloading. The purpose of this research was to determine the effect of preloading on the magnitude of damage occurring in an impact-loaded composite material. The composite material CFRP made by autoclave technique from GG 204T g/m2 IMP 503 ZHT carbon prepreg was tested. Preloading was realized as four-point bending of the composite specimen in two variants of the strain in the impact zone. Experimental testing was carried out, using a drop hammer, and the type and extent of damage was estimated using two non-destructive testing (NDT) methods: the ultrasonic method (UT) and the computed tomography (CT) method. Finite Element Method (FEM) analysis was also performed to evaluate the effect of preloading. It was found that low-energy impact loads are more dangerous if they affect the compression layer of the composite.

Joints

Investigating the Combined Effects of Geometrical and Material Properties on Fatigue Performance of Adhesively Bonded Composite and Steel Joints

abst. 1042
Repository

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Adhesive joints provide a better fatigue performance than more conventional joining techniques. However, they present complex failure mechanisms and are greatly affected by the geometry adopted and materials used, particularly when composite materials considered. Accordingly, this study intends to experimentally evaluate the influence of such parameters on the S-N fatigue behaviour of adhesive joints. To achieve this, single lap joints with different substrate materials (glass, and carbon reinforced polymer (GFRP and CFRP), and steel), adhesives (epoxy and methacrylate) and joint geometry (overlap length and adhesive thickness) were tested under fatigue loading. Additionally, in order to identify the parameters that most affect the fatigue performance, a parametric analysis was performed. Results showed that, the ductile methacrylate adhesive, despite presenting a lower fatigue strength, in terms of the ratio between the maximum fatigue load and the ultimate failure load, significantly outperforms the epoxy adhesive, particularly for higher fatigue lives. Regarding the influence of the substrate material, in a similar configuration (where both substrates are of the same material), joints with GFRP substrates presented a fatigue life more than 10 times lower than those made of steel, for the same load. However, in a dissimilar configuration (Steel-GFRP), an enhancement of the fatigue performance was observed. Based on an elasto-plastic finite element analysis, this behaviour was associated to the high ductility of the adhesive and its effect on the maximum stress and stress triaxiality distributions. In the case of joints bonded by the epoxy adhesive with different substrate materials, reduction in fatigue life due to a change in failure mode from cohesive in steel joints to adhesive in CFRP joints was observed. In relation to the geometric factors, joints with thicker adhesive layers presented a lower fatigue performance than thinner ones. Furthermore, increasing the overlap length was also seen to decrease up to 30% the nominal shear stress for the same fatigue life. This parameter, as suggested by the parametric analysis, is the one that mostly affected the fatigue behaviour of the joints.

The Synergy of Mechanical Surface Treatment and -Zirconium Phosphate Nanosheets on Interface Strength in Metallic-Polyurethane Adhesive Joints

abst. 1111
Room GIUSTINI
Tuesday
September 3
12h10

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The interface strength between dissimilar materials such as polymeric adhesive and metallic surfaces plays a pivotal role on the overall performance and reliability of structures. Delamination failure is the main damage mode in adhesively bonded composites such as fiber metal laminates (FMLs). The surface treatment of metals has significant impact on the adhesion of polymers to metallic surface [1, 2]. Employing nanomaterials is reported to positively influence interfacial strength [3, 4]. However, the synergetic effect between surface texture and nanomaterial remains relatively underexplored. This study investigates the impact of mechanical surface treatment of Al-2024 T3 alloy and addition of -ZrP nanosheets to polyurethane adhesive on the strength of aluminum-polyurethane (Al/PU) joints. -Zirconium phosphate (-ZrP), an inorganic layered nanosized compound that offers unique physiochemical properties [5, 6]. -ZrP, ranging from 0 to 2 wt.% with 0.5% increments, were incorporated into

PU to enhance adhesive strength. Results indicate that the optimal content of -ZrP is 1 wt.%, as further increments led to less strength due to the nanomaterial agglomeration. Concurrently, mechanical treatments using sandpaper abrasion with 60, 80, and 100 grit sizes were applied to the aluminum substrate. The lap shear strength of Al/PU joints post-mechanical treatment was assessed, revealing significant improvements. SEM and AFM measurements were employed to study surface morphology before and after mechanical treatment; failure mode was investigated by a high-resolution digital camera and SEM micrographing. Furthermore, the synergetic effect of nanomaterials and mechanical treatment was investigated by evaluating different grit sizes of sandpaper abrasion in conjunction with 1 wt.% of -ZrP. The results conclude that adding nanomaterials reinforces the adhesives and interfacial strength with Al alloy. The interfacial strength is further improved upon the mechanical treatment showing synergistic effect. This synergy is attributed to mechanical treatment creating surface irregularities facilitating enhanced polymer adhesion, complemented by nanomaterials in the polymer matrix providing additional mechanical interlocking. Keywords: Polyurethane adhesive joints; Aluminum surface treatment; -Zirconium Phosphate (-ZrP); Interface strength. Funding: This research is funded by Nazarbayev University under Collaborative Research Program Grant № 20122022CRP1613, S.A; G.K. References: [1] M.E. Mehr, H. Aghamohammadi, S.H. Abbandanak, G.R. Aghamirzadeh, R. Eslami-Farsani, S. Siadati, Effects of applying a combination of surface treatments on the mechanical behavior of basalt fiber metal laminates, International Journal of Adhesion and Adhesives 92 (2019) 133-141. [2] H. Aghamohammadi, S.N.H. Abbandanak, R. Eslami-Farsani, S.H. Siadati, Effects of various aluminum surface treatments on the basalt fiber metal laminates interlaminar adhesion, International Journal of Adhesion and Adhesives 84 (2018) 184-193. [3] S. Wang, B. Zhao, F. Cong, H. Xue, M. Cao, F. Teng, W. Su, X. Cui, Study on the synergistic effect of carbon nanofillers on the interlaminar toughness of fibre metal laminates, Materials Today Communications 33 (2022). [4] A.A. Khurram, R. Hussain, H. Afzal, A. Akram, T. Subhanni, Carbon nanotubes for enhanced interface of fiber metal laminate, International Journal of Adhesion and Adhesives 86 (2018) 29-34. [5] X. Zhu, Q. Yan, Y. Yu, H. Zhao, Q. Xue, L. Wang, Orientation of Ultrathin -ZrP Nanosheets in Aqueous Epoxy Resin for Anticorrosive Coatings, ACS Applied Nano Materials 4(5) (2021) 5413-5424. [6] S. Han, F. Yang, Q. Li, G. Sui, G. Kalimuldina, S. Araby, Synergetic Effect of -ZrP Nanosheets and Nitrogen-Based Flame Retardants on Thermoplastic Polyurethane, ACS Applied Materials Interfaces 15(13) (2023) 17054-17069.

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abst. 1167
GIUSTINIANO
Tuesday
September 3
16h50

Strength prediction of a composite adhesive single lap joint under impact using the ISSF criterion

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The development of numerical tools to predict their behaviour under several types of loading is essential given that adhesive joints are increasingly used in several industries. Currently there is a significant amount of works dedicated to analysing joints under quasi-static loadings. Numerical works devoted to predicting the strength of adhesive joints under impact are scarcer. Furthermore, many of these works use Cohesive Zone Models (CZM) to predict the joint strength. CZM are usually very accurate in their strength predictions, but they have a major disadvantage in that some cohesive properties are dependent on the adhesive layer thickness. As such, it is important to explore different strength prediction criteria, so this work explores the possibly of using a criterion based on the Intensity of Singular Stress Fields (ISSF) to predict the strength of an adhesive joint under impact. This criterion is considered a fracture mechanics criterion, but it does not require an initial crack and it is discretization independent, since it predicts failure based on the stress singularity present at the adhesive/adherent interface corner of adhesive joints.

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abst. 1189
GIUSTINIANO
Tuesday
September 3
12h50

Influence of bearing stresses caused by mechanical fasteners on the joints strength of quasi-isotropic composites

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Achieving high joints strength is possible through the use of mechanical fasteners, which in the case of joining composite structures are mainly Hi-lok or Jo-bolt fasteners. The use of these fasteners requires a wide assortment of them, which is due to the need to match the size of the fastener very precisely to the thickness of the elements to be joined. This poses a unique difficulty in the situation of sudden damage to the composite covering of the aircraft and the need to carry out an efficient, here-and-now repair. Therefore, the aim of the research was to determine the suitability of using solid rivets and conventional threaded bolts to join composite materials. The object of the experimental investigations was a quasi-isotropic CFRP composite produced on the basis of 160 g/m2 carbon fabric and epoxy resin using the vacuum bag method. Riveted and bolted composite-aluminum alloy joints were tested. During the tests, the values of assembly pressures were determined in the direction of the x3 axis (the direction of laying the laminate layers and assembling the mechanical fasteners) and x1 (the direction of reinforcement fibers arrangement and loading the joints). The study showed that a better solution for joining composite structures is the use of bolted joints primarily due to the possibility of adjusting the torque used to tighten the bolts. Indeed, a positive effect of increasing the torque on the load capacity of the joints was found - an increase of about 10%. A similar increase in load capacity was observed as a result of the application of a rare adhesive between the threaded bolt shank and the hole, since this procedure nullifies the phenomenon of cutting the thread crests into the composite material. In addition, tomographic studies were carried out, whereby the values of bearing stresses causing permanent damages to the tested composite in the x1 direction were determined.

Fast Computation of Stress Concentrations in the Bondline of Stepped Lap Joints

abst. 1204
GIUSTINIANO
Tuesday
September 3
15h10

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The fast and valid dimensioning of carbon fibre reinforced plastic (CFRP) repairs requires that stress concentrations in the adhesive layer can be determined with a low computational effort, in particular in order to be able to carry out extensive parameter studies or optimisations. Using the example of a single lap shear joint, bonded joints exhibit localised stress peaks at the outermost edges of the adhesive layer [BS09]. In order to determine these stress concentrations in the adhesive layer with a high degree of accuracy using the Finite Element Method (FEM) a high number of degrees of freedom must be used due to very short rise and decay lengths, which makes a fast and reliable design of the bonded CFRP repair difficult. A computationally efficient finite element technology for the analysis of such stress concentrations in two-dimensional single lap shear joints is described in [LS22]. The finite element technology enables the computation of the decay behaviour of the stress concentrations over very short distances in the adhesive layer with a very low number of elements, partially with only one element. The approach is based on a semi-analytical solution of the underlying differential equations where the material properties of the adhesive layer in the load transfer direction of the joint are neglected (see justification for the neglect of material properties according to [Ban73]). The approach of neglecting material properties at the component level is commonly used to describe honeycomb cores in sandwich structures. In [NZRL+23], standard elements of the commercial FEM programme ABAQUS (Dassault Systemes SA, Paris, France) are used to investigate the extent to which the described neglect of material properties in single lap shear joints can be extended to the calculation of stress concentrations in stepped CFRP repairs. The study shows that the approach enables the calculation of the stress concentrations at the outermost edges of the adhesive layer but does not achieve high accuracy at the steps between the

joint edges. This paper investigates the extent to which the simplifications according to [LS22] can also be applied to stepped lap joints without significant deviations occurring in the stress curve at the steps. The adhesive layer of a stepped bondline is divided into three different areas: Steps, overlaps and the transition areas between steps and overlaps. It is shown that only a small part of the bondline, c.g. the vertical step and the transition area, have to be modelled differently in contrast to the overlap area where negligible in-plane stiffnesses of the adhesive are introduced. And furthermore, the size of it represents only a small percentage of the total length of the overlap, so that a significant reduction in the calculation effort when computing the stress concentrations can still be expected when applying the simplification of negligible in-plane properties of the adhesive. Consequently, extensive parameter studies or optimisations can be carried out considering a precise computation of the stress peaks in the bondline which is in particular relevant for dimensioning. References [LS22] Linke, M.; Savaliya, L. (2022): Fast Semi-Analytical Finite Element for Bonded Joints to describe Bonding Stress Concentrations, Proceedings of 2nd International Conference on Computations for Science and Engineering (ICCSE2), Rimini/Italy, 30th August - 02nd September 2022, pp. 22-23 [Ban73] Bansemir, H. (1973): Krafteinleitung in versteifte orthotrope Scheiben. In: Ingenieur-Archiv 42 (1973), pp. 127–140 [NZRL+23] Nzeke Zedom, A.; Rachmat, M.A.; Linke, M.; García-Manrique, J.A. (2023): Ansätze zur schnellen Berechnung von CFK-Reparaturen, In Linke, M. (Ed.): Innovative CFK-Reparatur-Ansätze in der Luftfahrt, Joachim Herz Stiftung Hamburg, Hamburg/Deutschland, 13.-14. September 2023, pp. 21-22 [BS09] Banea, D. M.; da Silva, L.F.M. (2009): Adhesively bonded joints in composite materials: An overview. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications. 2009; Volume 223, Issue 1, pp. 1-18. doi:10.1243/14644207JMDA219

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abst. 1244
GIUSTINIANO
Tuesday
September 3
15h50

Elastic-plastic semi-analytical method and optimization for curved scarf bonding repairs of composite structures

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For the semi-analytical method, Hart-Smith[1] first derived a two-dimensional analysis model for scarf repaired and step repaired isotropic materials. Basing on this method, Harman and Wang[2] introduced average reduction method of composite section elastic modulus, and derived a method for calculating stress distribution of two-dimensional scarf repaired composites. Additionally, they proposed an optimization method to minimize the peak shear stress of adhesive layer by optimizing the bonding angle distribution controlled by first order equation. To restore the stress concentration caused by the change of angles of fiber orientation accurately, Liu[3] improved the method with stiffness-distribution principle and provided a modified analytical method(MAM), which has achieved a more precise and believable result in calculating stress distribution on flat adhesive surfaces. MAM and the application of stiffness-distribution principle has been proven concise effective by Yan[4] with experiments. In this paper, a semi-analytical stress distribution calculating method that is applicable to arbitrary shape surfaces of scarf repaired composites are proposed. To take not only the cohesive failure caused by shear stress, but also the yield of adhesive under consideration, the adhesive is regarded as an elastic-plastic material. Furthermore, an optimization algorithm basing on this method which could significantly improve the carrying capability of scarf repaired composite laminates is developed. Several examples have revealed high universality and accuracy of this method, and the optimization algorithm developed from which has achieved an excellent effect on reducing peak shear stress. Although it would be difficult to manufacture the optimized surface, this paper still provides a simple but efficient way to evaluate designs of scarf repair and reliable schemes for advancing carrying capacity of scarf repaired composites.

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abst. 1246
GIUSTINIANO
Tuesday
September 3
12h30

Experimental investigation on the effect of forced assembly on fatigue behavior of single-lap, countersunk composite bolted joints

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Forced assembly is a common countermeasure adopted to eliminate the interface gap during composite airframe assembly, which will change the bolt-hole bearing behavior and bring failure risks. In this study, an experimental investigation on the effect of forced assembly on fatigue behavior of single-lap, countersunk composite bolted joints is presented. The joints consisted of two carbon fiber/epoxy laminates (T800/X850) and a Titanium alloy bolt (HST11 AG6-9). The hole elongation and dynamic stiffness were obtained based on ASTM standard D6873. The S-N curves were fitted according to ASTM standard E739. The fatigue damage was observed through microscopy, and the residual strength was acquired by static tensile tests. Results indicated that forced assembly significantly shortens the fatigue life of joints. After forced assembly, the hole elongation evolves faster and reaches the fatigue failure threshold earlier, the stiffness presents lower and degrades earlier. Besides the designed hole bearing failure, the bolt head cracking is observed under low fatigue load level (70% of 2% offset bearing static strength) and makes fatigue property degrade more rapidly. With equal hole elongation (4% of the hole diameter), the joints with forced assembly display severe hole bearing damage, and visible shearing cracks are observed, which results in lower residual strength.

Pathways to optimize mechanical properties of C/SiC bolts: preform design and process optimization

abst. 1255
Room GIUSTIN
Tuesday
September 3
13h10

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Integrated manufacturing techniques have been extensively utilized to assemble thermal structural components made of continuous fiber reinforced silicon carbide composites (C/SiC) to fabricate large and complex components. The mechanical joint, always in terms of C/SiC bolts, become the weakest link in the components. Laminated C/SiC bolts have been invented to meet the requirements of the high temperature applications. Due to the low shear strengths of C/SiC, the threads are prone to be damaged. Therefore, two ways, including preform design and process optimization, are proposed to improve the mechanical property of C/SiC bolts. From the preform design perspective, in order to fully employ the high tensile strength of carbon fibers, core-shell C/SiC bolt is proposed with the shell prepared by woven fiber architecture. Uniform circumferential microstructure of the threaded teeth has been obtained and the corresponding strength has been improved through fiber bridging mechanism. The results shows that the thread pull-off strength is 17.96% greater than that of the laminated thread tooth, and the stud tensile strength is slightly improved up to 2.96%. The stud shear strength is enhanced by 45.29% and 46.88% with unidirectional C/SiC rod and ZrO2 ceramic rod, respectively. From the process optimization perspective, the adoption of SiC whiskers (SiCw) as the high-toughness phase improves thread strength and thus bolts tensile properties. Based on chemical vapor infiltration (CVI), SiCw are generated inside 3DN C/SiC countersunk bolts. The toughening of SiC matrix by SiCw is more conducive to the main load-bearing role of carbon fiber in order to improve the tensile properties of bolts. The experimental results show that the tensile strength of SiCw toughened bolts is 7% higher than that of pure CVI bolts. Development of C/SiC bolts with high mechanical properties provides an application basis for promoting the advancement of C/SiC combined assembly and integrated manufacturing technology.

abst. 1256
GIUSTINIANO
Tuesday
September 3
16h10

Review of preparation processes and joining property of ceramic matrix composite fasteners

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Thermal structural components made of continuous fiber-reinforced silicon carbide ceramic matrix composites (CMC-SiC) have been widely employed in aerospace and aeronautical fields. Integrated manufacturing techniques have been also extensively utilized to assembly CMC-SiC parts together to form large and complex components. The development of novel high-performance CMC-SiC fasteners has become critical manufacturing technology. Based on unique demands in terms of component preparation, CMC-SiC fasteners are reviewed from its preform structure, preparation methods, and microstructural characteristics. It is demonstrated that the strength limit of CMC-SiC bolts is the in-plane shear strength of CMC-SiC composites. Tensile-shear behaviors, load distribution, oxidation damages, and failure mechanisms of CMC-SiC bolted/pinned joints are summarized. Furthermore, vibration relaxation mechanism and related anti-loosening effect are discussed. Accordingly, two ways are proposed to optimize mechanical properties of CMC-SiC fasteners: preform design and process optimization.

abst. 1349
GIUSTINIANO
Tuesday
September 3
15h30

Multi-Failure Coupling Mechanism of Hybrid Steel/GFRP Adhesive Joints

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The damage of a hybrid Steel/GFRP adhesive joint in different loading conditions generally involves multiple failure modes, such as the fracture in the structural adhesive and the delamination on the interface between the structural adhesive and the base material. The various combinations of these multiple failure modes generate different macro strengths and fracture toughnesses of the joint, so the numerical model based on a single failure mode can hardly predict the damage precisely. Therefore, it's necessary to investigate the all possible failure modes of a hybrid Steel/GFRP adhesive joint in different loading conditions. It's also needed to explore the coupling mechanism of these possible failure modes for precisely identifying and predicting the macro strengths and fracture toughnesses. To achieve the above two goals, in this work, the following aspects have been done: 1) Two kinds of materials – uniform thickness steel plates (UT) and orthogonal woven glass fibre reinforced plastics (OW-GFRP) were used to prepare four types of adhesive joint specimens – the butt joint specimen for the tension strength, the single lap specimen for the shear strength, the double cantilever beam (DCB) specimen for the fracture toughness in mode I, and the end notch flexure (ENF) specimen for the fracture toughness in mode II. To generate various failure modes, in each of the above specimen types, two combinations of adhesive joints – UT/UT and OW-GFRP/OW-GFRP were prepared with different pre-crack positions. Besides, another combination of UT/OW-GFRP in the lap shear test was prepared for the coupling mechanism exploration and validation. 2) With the above-mentioned four types of specimens, three kinds of failure modes were found to be involved in the UT/UT, OW-GFRP/OW-GFRP and UT/OW-GFRP adhesive joints: the fracture in the structural adhesive, the delamination on the interface between the UT surface and the adhesive, and the delamination on the interface between the GFRP surface and the adhesive. The strengths and fracture toughnesses of the above three failure modes were identified and found to be different, which indicates the existence and dissimilarity of the multiple failure modes in a hybrid Steel/GFRP adhesive joint. 3) In the lap shear test, the failure mode of the UT/OW-GFRP adhesive joint was found to be a combination of the fracture in the structural adhesive and the delamination on the interface between the GFRP surface and the adhesive. The relationship between the combination of these two failure modes and the macro shear strength of the UT/OW-GFRP adhesive joint was identified quantitatively, which reveals the multi-failure coupling mechanism. 4) Finally, a numerical adhesive joint model with multi-failure modes was proposed and verified by the lap shear test on the UT/OW-GFRP adhesive joint.

The Application Research of DIC Technology in the Rehabilitation Evaluation of Knee Joint Movement Deformation

abst. 1389
Room GIUSTINI
Tuesday
September 3
16h30

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The knee joint, as an important structure of the lower body, plays a crucial role in human movement, but knee joint damage has become a very common disease. After knee joint damage, postoperative exercise therapy and physical therapy are combined with magnetic resonance imaging or CT scans. These commonly used detection methods are either expensive or complex, which brings great inconvenience to patients.This project will use Matlab to design a GUI mini program that can perform DIC visualization. The mini program can process the images captured by the shooting device on the human knee joint motion on the computer. By transforming the coordinates from a matrix to a two-dimensional array during the motion process, the knee flexion angle of the human body during motion will be calculated. The force (torque) will be calculated based on the relationship between the motion changes before and after and time, and then the knee flexion angle of the patient during the recovery period and the knee joint overload caused by the knee exceeding the toe will be alarmed to evaluate the rehabilitation effect. This article combines the relationship between the movement status and angle changes at different times during human movement, and adopts non-contact optical measurement to effectively measure patients in rehabilitation after knee joint injury.

Keynote Lecture

abst. 1014
Room DANTE
Tuesday
September 3
10h40

Data-based micromechanical modelling of the dynamic response of interpenetrated composites

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Pietras, Daniel (pietras140t@gmail.com), Lublin University of Technology, Poland
Guhathakurta, Jajnabalkya (guhathakurta@ct-lab-stuttgart.de), CT-LAB Stuttgart, Germany
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The interpenetrating composites (IPCs) are built up of a ceramic skeleton and metallic matrix, which fills the ceramic foam under pressure and high temperature. The specific examples of IPCs analysed in the paper are made of the ceramic skeleton - SiC or Al2O3 - which is a brittle material, whereas the matrix is created by AlSi12 alloy – elasto-plastic material. Both phases of IPCs are crushable and their degradations under the loading are subjected to two different damaging processes. The ceramic foams are brittle throughout the loading process, but the AlSi12 alloy is brittle during the elastic phase; then, its behaviour becomes viscous-plastic. The presentation concerns the experimental testing and simulations of the impact and fragmentation of metal matrix composite - AlSi12/(SiC or Al2O3). The microstructure of the composite is complex and consists of a metallic phase (85%), ceramic skeleton, porosity, and a system of imperfect interfaces. The presented data-driven micromechanical numerical model is based on micro-CT scanning of composite material to get information about the internal structure and the assessment of local thermo-mechanical properties done by Alemnis observations under SEM at nanoscale or microscale using nano- or microindetation technique. The description of the dynamic response of IPCs by impact is investigated in a few scenarios. The exemplary scenario is realised by imposing the initial conditions on the sample that hits a hard elastic barrier. The second one corresponds to SHPB experiments. The last one is the hitting of an elastic impactor against the sample. The influence of the impact velocities and material parameters of the phases on the failure modes is observed. Previously, analyses of the modes of loading application on the micromechanical failure of metal matrix composite were analysed in [1, 2]. An analysis of the empty SiC scaffolds is presented in [3]. The proposed finite element model of the AlSi12/SiC composite behaviour describing gradual degradation under impact loading was tested for different impact scenarios. In all cases, the damage growth in the composite is very realistic. These results conclude that the proposed finite element model is very effective. Acknowledgement: The results presented in this paper were obtained within the framework of research grant No. 2019/33/B/ST8/01263 financed by the National Science Centre, Poland. Numerical analyses: PLGRID facilities - ICM UW Warsaw, CI TASK in Gdańsk, CYFRONET, Kraków and LUMI in Kajaani (Finland). References: [1] Postek, E. and Sadowski, T. Distributed microcracking process of WC/Co cermet under dynamic impulse compressive loading. Compos. Struct. (2018) 194: 494-508. [2] Postek, E. and Sadowski, T. Qualitative comparison of dynamic compressive pressure load and impact of WC/Co composite. Int. J. Refract. Hard. Met. (2018) 77: 68-81. [3] Postek, E., Sadowski, T. and Bieniaś, J. Simulation of impact and fragmentation of SiC skeleton, Phys. Letters (2021) 24:578-587.

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abst. 1115
DANTE
Wednesday
September 4
11h30

Application of bone healing simulation technique to the design of orthoses/prostheses made of flexible fibrous composites

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It is well known that mechanical stimulation directly affects and controls cell and tissue development in the fractured bones in terms of mechano-regulation theories which correlate mechanical stimuli and bone healing. There are many different types of mechano-regulation algorithms which use different types of mechanical stimuli such as principal strain, fluid velocity, deviatoric strains and so on. External load types and prostheses type may change mechanical condition at the fracture site especially in calluses

where the cells and tissues and this controls developing pathways and consequently determines cell and tissue phenotypes. Consequently, flexible composite prostheses may generate appropriate strains which provides positive effect on cell development relative to the high stiffness metal prostheses. The healing performance was compared with according to the prostheses stiffness by using finite element analysis. As a result, it was found if we can find the most appropriate mechanical condition provided by flexible composite prostheses we can accelerate bone healing and also we can use this information for the design of orthopadic implant and orthoses for rehabilitation after bone fracture healing. To accomplish the actual bone healing process modeling of cell's whole life including cell migration, differentiation and bone resorption, callus configuration and biphasic mechano-regulation algorithm which uses deviatoric strain and fluid velocity as mechanical stimuli were implemented in the finite element analysis. Moreover, devices like orthoses for helping rehabilitation of the healed bones can be designed by using this bone healing simulation technique and this system can precisely detect forces and strains around the fracture site for better healing.

Waves in solids with surface stresses

abst. 1137
Room DANTE
Thursday
September 5
09h00

Eremeyev, Victor (eremeyev.victor@gmail.com), University of Cagliari, Italia

We discuss propagation of surface and interfacial waves in elastic and viscoelastic media possessing surface stresses and surface energy. Nowadays mechanics of media with surface stresses found various applications at small scales as well as at macroscales. The discussed class of models describes of coupled deformations of solids with thin coatings or interface layers. In particular, surface stresses could be responsible for size-effects observed at the nanoscale. With the lecture we discuss a series of boundary-value problems for antiplane motions, see [1-7] for details. These problems illustrate the influence of surface stresses. For example, antiplane surface waves exist in an elastic half-space only if one takes into account surface kinetic energy and surface strain energy in addition to classic constitutive equations in the bulk. Here we discussed the propagation of antiplane waves in an elastic half-space, in an elastic strip perfectly or non-perfectly attached to a half-space. Transverse waves are also studied in an elastic cylinder. Dispersion curves were obtained and analysed. In particular, it was shown that surface waves related to surface stresses propagate with lower speed than others. Finally, viscosity effects were analysed. We demonstrated that even small dissipation essentially changes the behaviour of dispersion curves and the decay with the depth. This is more pronounced for relatively large values of a wave frequency. This work has been supported by the project "Metamaterials design and synthesis with applications to infrastructure engineering" funded by the MUR Progetti di Ricerca di Rilevante Interesse Nazionale (PRIN) Bando 2022 - grant 20228CPHN5, Italy. References: 1. Eremeyev, V.A., Rosi, G. and Naili, S., 2016. Surface/interfacial anti-plane waves in solids with surface energy. Mechanics Research Communications, 74, 8-13. 2. Eremeyev, V.A., Rosi, G. and Naili, S., 2019. Comparison of anti-plane surface waves in strain-gradient materials and materials with surface stresses. Mathematics and mechanics of solids, 24(8), p 2526-2535. 3. Eremeyev, V.A. and Sharma, B.L., 2019. Anti-plane surface waves in media with surface structure: Discrete vs. continuum model. International Journal of Engineering Science, 143, 33-38. 4. Eremeyev, V.A., Rosi, G. and Naili, S., 2020. Transverse surface waves on a cylindrical surface with coating. International Journal of Engineering Science, 147, 103188. 5. Mikhasev, G.I., Botogova, M.G. and Eremeyev, V.A., 2022. Anti-plane waves in an elastic thin strip with surface energy. Philosophical Transactions of the Royal Society A, 380(2231), 20210373. 6. Mikhasev, G., Erbaş, B. and Eremeyev, V.A., 2023. Anti-plane shear waves in an elastic strip rigidly attached to an elastic half-space. International Journal of Engineering Science, 184, 103809. 7. Eremeyev, V.A., 2024. Surface finite viscoelasticity and surface anti-plane waves. International Journal of Engineering Science, 196, 104029.

Efficient numerical strategies to predict the structural behavior of FRCM reinforced masonry

abst. 1158
Room DANTE
Wednesday
September 4
09h00

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Fiber Reinforced Cementitious Matrix FRCM composites represent a relatively new strengthening technology suitable especially for the reinforcement of masonry, that has gained traction in the last two decades in substitution of the more consolidated external retrofitting with FRP (Fiber Reinforced Polymer). The utilization of an inorganic matrix is probably the main difference with FRP, where the fiber is glued to the substrate with a polymeric adhesive. When compared with FRP, it has many advantages, such as a better compatibility with the substrate, vapor permeability, reversibility. The mechanical performance to debonding is obviously lower, but still adequate to obtain a good seismic upgrading of existing masonry. It is used in particular to reinforced arches and double curvature vaults, because of their reversibility. The experimental literature available for FRCM is nowadays quite comprehensive and mainly deals with (i) coupon and (ii) debonding tests, or (iii) experimentation on entire structural elements (shear walls, arches, vaults). On the contrary, the analytical and numerical counterpart appears still patchy. The aim of the keynote speech is therefore to review and classify what already exists in the field of advanced analytical and numerical modelling for FRCM composites applied to brittle substrates, and to investigate the near future possible developments. Some analytical and semi-analytical approaches will be reviewed when applied in a variety of laboratory experimentation, including coupons and shear tests carried out on FRCM bonded to flat and curved substrates. In the study of such examples, attention will focus on different numerically efficient strategies used to predict the global and local behavior of the FRCM components at progressively increased external loads. A particular insight will be provided for (i) the recursive utilization of the elastic solution when sawtooth constitutive laws for matrix and interfaces are assumed and for (ii) multi-dimensional shooting numerical algorithms generalized to systems of ordinary differential equations. Having clear in mind the limits of applicability of the aforementioned approaches, the keynote will then introduce a new simple truss finite element with 16th degrees of freedom. The finite element is a two-node assemblage of three trusses representing matrix and fiber layers. The interfaces between the layers are modeled with shear and normal springs lumped at the nodes, mutually connecting contiguous trusses and the inner matrix to the substrate. The degrees of freedom, 8 per node, are the longitudinal and transversal displacements of the three layers and of the substrate, evaluated at the nodes. The particularly appealing simplicity and the direct possibility of implementation within already existing FE software dedicated to the advanced analysis of masonry, allows to study the behavior of large-scale structures reinforced with FRCM at a fraction of the computational burden required by a heterogeneous discretization of the reinforcing package. The keynote will end with real scale applications, which include reinforced arches, vaults and in- and out-of-plane loaded panels.

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abst. 1399
Room DANTE
Tuesday
September 3
11h30

Multiscale non-local (size-dependent) continuum descriptions of materials with periodic and random microstructure

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The mechanical behaviour of materials endowed with specific microstructure, characterized by complex non-linear behaviour and complex internal sub-structure (micro), strongly depends on their microstructural features. In particular, in the modelling of these materials, such as particle composites, polycrystals with thin or thick interfaces, rock or masonry-like materials and materials with random microstructure, the discrete and heterogeneous nature of the matter must be taken into account because interfaces and/or material internal phases dominate the gross behaviour. This is well established. What is not completely recognized, however, is the possibility of preserving the memory of the microstructure and the presence of material length scales without resorting to discrete modelling, which can often be cumbersome, in terms of non-local continuum descriptions. For materials made of particles of prominent size and/or strongly anisotropic media, lacking in material internal scale parameters and the possibility of accounting for non-symmetries in strains and stresses, the classical Cauchy continuum (Grade 1) does not always seem appropriate for describing the macroscopic behaviour, taking into account the size, orientation, and disposition of the micro-heterogeneities. This necessitates non-classical continuum descriptions [1-3], which can be obtained through multiscale approaches aimed at deducing properties and relations by bridging information at proper underlying sub-levels via energy equivalence criteria. Within such multiscale modelling, the non-local character of the description is crucial for avoiding physical inadequacies and theoretical computational problems, particularly in problems where a characteristic internal (material) length is comparable to the macroscopic (structural) length [4]. Among non-local theories, it is useful to distinguish between 'explicit' or 'strong' and 'implicit' or 'weak' non-locality [5]; where implicit non-locality concerns generalized continua with extra degrees of freedom, such as micromorphic continua or continua with configurational forces. This presentation addresses the modelling and homogenisation of composite materials with varied microstructural characteristics as generalised continua. The numerical analyses begin by focusing on composites considered as polycrystals with grain boundaries or thin interfaces, where a periodic microstructure can be recognised. For these materials, discrete continuum homogenization approaches, derived from the molecular theory of elasticity, have proven effective [6, 8]. The investigation then extends to polycrystals with thick interfaces, employing a statistical homogenization procedure [7, 9] applied to a variety of other composite materials, including fibre-reinforced composites, ceramic/metal matrix composites, concrete, ashlar masonry. The nonlinear modelling of ceramic matrix composite materials is also investigated using a novel method that combines the Virtual Element Method (VEM) with non-linear interface Finite Element approach [10], allowing for a more accurate representation of the material's behaviour under different loading conditions. Keywords: Multiscale approaches, non-local continua, micropolar continua, anisotropic media with internal lengths, non-linear behaviour [1] Capriz G. (1989), Continua with Microstructure, Springer-Verlag, New York [2] Eringen, A.C. (1999), Microcontinuum Field Theories, Springer-Verlag, New York [3] Gurtin, M. E. (2000), Configurational Forces as Basis Concept of Continuum Physics, Springer-Verlag, Berlin. [4] Trovalusci P., Ed. (2016), Materials with Internal Structure. Multiscale and Multifield Modeling and Simulation, P. Trovalusci (Ed.), Springer Tracts in Mechanical Engineering, Vol.18:109-131, Springer. [5] Kunin I.A., (1984) On foundations of the theory of elastic media with microstructure. Int. J. Engn. Sci., 22, pp. 969–978 [6] Trovalusci P. (2014), Molecular approaches for multifield continua: origins and current developments. CISM (Int. Centre for Mechanical Sciences) Series, 556: 211-278, Springer. [7] Trovalusci P., M. Ostoja-Starzewski, M.L. De Bellis, A. Murrali (2015), Scale-dependent homogenization of random composites as micropolar Continua, Eur J Mech A / Solids, 49, 396–407, 2015. [8] Leonetti L., Fantuzzi N., Trovalusci P., Tornabene F. (2019), Scale Effects in Orthotropic Composite Assemblies as Micropolar Continua: A Comparison between Weak- and Strong-Form Finite Element Solutions Materials, 12(5), 758. [9] Homogenization of Random Porous Materials with Low-Order Virtual Elements (2019), ASCE-ASME J Risk and Uncert in Engrg Sys Part B, 5(3) [10] Gatta,C; Pingaro A., Addessi D., Trovalusci, P. (2024), A coupled virtual element-interface model for analysis of fracture propagation in polycrystalline composites. Submitted.

Quantum Computing Enhanced Data-Driven Computational Mechanics for Composite Structures

abst. 1400
DANTE
Wednesday
September 4
14h30

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Bypassing constitutive modeling, the distance-minimizing data-driven computational mechanics has its potential in the modeling and simulation of advanced composite materials and structures. However, the numerous distance calculations between constitutive database and conservation law are extremely heavy in high-dimensional cases, and often consume most of the computational resources. Here, we propose a quantum computing enhanced data-driven framework, where the distance calculation tasks are assigned to a quantum computer. Compared to the classical computing, the use of quantum computing allows to achieve an exponential reduction in computational complexity. This framework has been validated not only on a quantum simulator but also on a real superconducting quantum computer. Furthermore, to address the quantum hardware noise issue, an error mitigation technique is implemented to improve the accuracy of quantum computing. We believe this work represents a promising step towards using the power of quantum computing in the field of composite materials and structures.

Advancing Sustainable Composite Materials with Recyclable Thermoplastic Resin and Low-Impact Raw Materials

abst. 1401
Room DANTE
Tuesday
September 3
14h30

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The use of composite materials, particularly fiber reinforced plastics (FRC), is experiencing rapid growth, driven by increasing demand across various industries such as aerospace, automotive, nautical, and wind energy. These materials, known for their high stiffness-to- weight and strength-to-weight ratios, offer significant performance advantages over traditional materials like metals. However, the rapid expansion in the use of composites highlights a critical environmental issue: their recyclability. FRC are generally composed of synthetic fibers embedded in a thermoset matrix, creating a material that is challenging to disassemble and recycle efficiently. This limitation poses significant environmental concerns, as the disposal of composite materials typically results in landfill accumulation or incineration, contributing to pollution and resource depletion. Northern Light Composites, a clean-tech company founded in 2019, is dedicated to making composites more sustainable. NLcomp has developed rComposite, a recyclable composite material that addresses the end- of-life issues of fiberglass and has a lower impact than traditional composites due to the use of thermoplastic resin and natural and recycled fibers. To validate rComposite, NLcomp has built sailing boats, the most notable of which is "ecoracer," a vessel that has won the Italian Championship and numerous international awards.

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abst. 1402
DANTE
Thursday
September 5
11h30

Composite Structure quick repair in motorsport

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Faenza boasts a rich cultural and industrial heritage and can lay claim to one of the most interesting stories relating to Formula 1. It all started with local-born Giancarlo Minardi, who first established a team in his name in 1980 and then from 1985 to 2005 it competed in Formula 1 for 21 seasons, before being bought by Red Bull. It was renamed Scuderia Toro Rosso as from the start of the 2006 season, with the aim of providing a springboard into Formula 1 for young drivers. In that it has been successful having launched the careers of champions and race winners such as Sebastian Vettel, Max Verstappen, Carlos Sainz, Pierre Gasly and Daniel Ricciardo. Since the start of the 2024 season, still part of the Red Bull family, that team now races under the Visa Cash App RB F1 Team name. The first win and indeed the first pole position came at the 2008 Italian Grand Prix in Monza courtesy of the aforementioned Vettel. In 2020, the team name became Scuderia AlphaTauri, which it celebrated with another Italian Grand Prix victory that same year, courtesy of Pierre Gasly. The previous year, its last as Toro Rosso, saw the STR 14 car secure two more podium finishes: a third place in Germany for Daniil Kvyat and a second place in Brazil with Gasly. As of 2024, under the new Visa Cash App RB banner, the team still maintains its mission of bringing on talented youngsters, not just the drivers on the track, but also in terms of the factory staff, within a company that has carved out a reputation for excellence in the sphere of motorsport. Today, Formula 1 requires a high level of specialisation in every area, from design to production and every single member of staff makes a valuable contribution. Even the smallest increase in performance, can make a big difference in the competitive environment of F1, both on and off-track. Indeed, the structure of the team has gone through a process of constant change over the years to reach the current point where it is housed in a state-of-the-art facility which operates at the highest technological level while also taking into account environmental sustainability.

Micro- and nano-mechanics

Pyroelectric effect in nano sized piezoelectric structures

abst. 1211
Room DANTE
Tuesday
September 3
15h10

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The pyroelectric energy harvesting technology has gained huge attention for application of harvesting wasted heat energy in power generation and nano sized sensing systems. The so called size effect phenomenon which has been experimentally observed in nano sized structures plays important role. Having included the higher-order gradients of primary field variables into the constitutive relationships it is possible to explain the size effects qualitatively within the generalized theory of continua. It is well known that the heat propagation at nano scales behaves differently from that at macro scales. In this paper the strain gradient elasticity and nonlocal higher grade heat conduction theory are applied. The piezoelectric and pyroelectric effect are taking into account and considered in constitutive equations. Because of the size-effect in higher-grade theories of continua, the polarization in piezoelectric solids under a non-uniform strains in nano-sized structures is significantly influenced by flexoelectricity. Making use the variation principles, the mathematical formulation of the boundary value problems is derived within higher-grade theory of heat conduction and flexoelectricity. Due to the higher order of derivatives in gradient theories it is needed to use advanced computational method. To this end the mixed FEM formulation is developed here. The C0 continuous interpolation is independently applied for both the displacements and displacement gradients. Performing parametric studies with respect the micro-length scale parameters, we discus numerical results in comparison with classical solution. The influence of the size effect is demonstrated by some numerical examples. Acknowledgements The authors acknowledge the support registered under number VEGA-2/0084/24

Exploring Void Defects in LATP Manufacturing through 3D Microscale Modelling

abst. 1387
DANTE
Tuesday
September 3
15h30

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The advancement of cutting-edge manufacturing techniques has revolutionized the aerospace industry, with laser-assisted automated fibre placement (LATP) standing out as a prominent innovation. LATP enables the production of components by consolidating fibre-reinforced thermoplastic composite materials in situ, eliminating the need for secondary consolidation processing steps [1]. Recent studies [2,3] demonstrate that the quality of LATP manufacturing and the formation of defects is influenced by several factors, including nip-point temperature, tape placement speed, and consolidation pressure. Variation of these factors can result in a higher concentration of voids within the formed structure, leading to significant variations in the material's mechanical properties. In this context, this work aims to conduct a detailed analysis of voids in LATP-manufactured laminates at the microstructural level through a 3D Representative Volume Element approach using finite element analysis implemented in an Abaqus-Python script. The model development relies on the microscopic analysis of samples manufactured via LATP, enabling the creation of a reliable representation of the random distribution of fibres. Subsequently, the model predicts the material's homogenised elastic properties and strength parameters, accounting for different percentages of voids that occur during LATP manufacturing. Through experimental analysis, the computational numerical model will be validated by comparing the results obtained under multiple combinations of roller pressure and manufacturing speed.

Multi-scale analysis of composites

abst. 1051
Room GALLA PLACIDIA
Friday
September 6
11h50

Multiscale modelling of a bimorph piezo-actuator made of nano-inclusions reinforced PVDF

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This study focuses on the multi-scale modeling of a piezoelectric nanocomposite, which is made of Polyvinylidene fluoride (PVDF) matrix reinforced with different nanoparticules. The effective properties of the piezoelectric composite are evaluated by the well-known Mori-Tanaka (MT) micromechanics scheme. For such a purpose, the Eshelby piezoelectric tensors were computed for an anisotropic matrix based on a gaussian quadrature. A systematic exploration of the aspect ratio and orientation of the nanoparticles within the matrix, was conducted to examine their impact on the overall mechanical and piezoelectric behaviors of the composite. Ithe case of CNTs, the findings indicate enhanced mechanical properties for infinitely long inclusions . Additionally, an improvement in the piezoelectric coefficient e33 along the fiber direction, was observed when CNTs were oriented transversely to the PVDF. Next, the identified piezoelectric nanocomposite, exhibiting favorable mechanical and piezoelectric performance, was employed as input for simulations of a bimorph actuator using the Finite Element software ABAQUS. The tip deflection of the actuator was determined and compared with an analytical solution. The results demonstrate a commendable agreement between the Finite Element results and the analytical solution, with a minimal error of 0.45%.

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abst. 1068
Room GALLA PLACIDIA
Friday
September 6
12h30

Multi-physics modeling for composite processing and optimization for thick and multi-directional prepregs

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The cost-effective fabrication of composite structures is of great importance, particularly for fiber-reinforced plastics, where an optimized coupled process simulation is much needed with improved analytical and numerical solutions. For the simulation of prepregs, knowledge of micro-analysis is a must to boost the performance of the models. A study composed of thermo-chemical, flow-compaction, and stress-deformation with void analysis modeling is coupled to develop an ultimate solution for multi-directional continuous fiber-reinforced plastics. The models were modified based on three fundamental properties: temperature, degree of cure, and fiber volume fraction. A new cure kinetics model is developed, which can solve thermo-chemical analysis with fewer parameters and higher accuracy. The parameters like the viscosity, the density of composites, heat generation, heat capacity, and the transverse and longitudinal thermal conductivity of resin, fiber, and composites can be dynamically predicted for applied external pressure and temperature for different geometries. Furthermore, the thermal lag between the surrounding and part, thermal gradients with the part and tool, and exothermic reactions can be optimized with the developed solution. Similarly, the flow-compaction model is modified before the gelation point with an improved fiber-bed compaction equation for the case of composite curing. Longitudinal and transverse permeability models are modified to predict actual permeability behavior while curing, as prior equations are not suitable to discuss permeability while curing the composites. This resulted in improved resin velocity calculations. The solution is useful for studying laminate thickness changes, and timing resin pressure development properly to reduce voids and improve compaction.

To predict the manufacturing process-induced deformations like warpage, spring-in, and residual stresses in thick multidirectional laminates, a stress deformation model is proposed after gelation is achieved. It considers the coefficient of thermal expansion (CTE) mismatch of fibers and resin, cure-dependent chemical shrinkage of resin, modulus, and Poisson ratio prediction. Lastly, a void growth model based on gas diffusion control is coupled to reduce the void ratio. An optimal manufacturing approach to fabricate multi-directional thick composites is suggested based on the modified multi-physics model. The experimental data showed good agreement with the simulations.

Dynamic tensile deformation and failure mechanism of the -HMX single crystal and polycrystal with defect distribution

abst. 1100
Room GALLA PLACIDIA
Friday
September 6
11h30

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To study the influence of internal defects on the mechanical behavior of -HMX single crystal and polycrystal, different defects characteristics involving porosity, void number and void distribution morphology were designed, and futher the deformation, damage and failure process under dynamic tension was simulated by molecular dynamics method based on Smith force field. The result showed that the mechanical behavior of -HMX single crystal was obviously affected by defects. The tensile strength of the model decreased with the increase of porosity. When the porosity was the same, the tensile strength decreased with the increase of the number of voids. However, the mechanical behavior of polycrystals was not strongly affected by defects, When the porosity increased from 1% to 2%, The change of the tensile strength of the model was not obvious, and the cracks always generated at the binder. To make the model closer to reality, the voids with random position distribution were designed in the model, and the voids size followed the normal distribution. The dynamic tensile results showed that the failure mechanism of single crystal and polycrystal was different, the tensile strength of single crystal was related to the distribute of void size, but the effect of defects on polycrystal was not obviously, because the polycrystal always started to fracture at the binder. In summary, due to the different fracture mechanism between -HMX single crystal and polycrystal, the influence mechanism of defects on the mechanical behavior was different.

Multiscale Modeling of Glass Fiber Hierarchical Composites with Locally Engineered Microstructures for Structural Applications

abst. 1166
Repository

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Increasing complexity in structural design requirements has driven research efforts towards upgrading current practices in material design and manufacture world-wide [1, 2]. In the case of composites, this can be accomplished through appropriate selection and selective organization of the constituent materials [1]. In this direction, research in recent times has focused on the development of hierarchical polymer composites that combine reinforcements at different length scales allowing significant space for material design optimization. Multiscale modelling approach has also been a key enabler for the development and characterization of hierarchical composites [3, 4]. In recent experimental studies by the authors [5, 6], open hole tensile and fatigue behavior of Carbon Nanotube (CNT)-incorporated glass/ epoxy composites were evaluated. External electric fields were employed to alter the orientation and distribution of CNTs around the cut-outs and the effect of local microstructure modification on the overall mechanical behavior of the composites was evaluated. The current study presents a multiscale modelling approach to predict the behavior of open hole glass fiber hierarchical composites under tensile

static loading. At the microscale, using continuum approach, representative volume elements (RVEs) are obtained considering 0.1 wt. % randomly oriented and aligned CNTs within epoxy matrix. Inputs to the model including the matrix behavior is based on experimental data from previous studies. At the mesoscale, the RVEs consider glass fibers and the epoxy matrix containing random/ aligned CNTs as per the fiber volume fractions obtained from experiments. Numerical homogenization techniques are employed to estimate the effective properties. The effect of locally altered CNT orientation in hierarchical composites containing circular cut-outs is numerically investigated and compared with experimental results. Parametric studies to understand the effect of varying CNT concentration, CNT orientation, and varying cut-out shapes are performed. Experimental results indicate a significant improvement in mechanical response of the composites on account of reduced stress concentration effects due to local microstructure modification. Numerical studies are currently in progress and a good agreement between the simulation and experimental results is projected. Further, the numerical analysis scheme for static loading case enables future extension to model fatigue loading. The study is expected to be highly beneficial in the development of hierarchical composites for structural applications. Keywords: Multiscale modeling, Hierarchical composites, Carbon nanotubes, Static loading, Fatigue loading. References: [1]Y. Chen, Y. Ma, Q. Yin, F. Pan, C. Cui, Z. Zhang and B. Liu "Advances in mechanics of hierarchical composite materials", Composites Science and Technology, Vol. 214, 108970, 2021. [2]Z. Yang, C.H. Yu, K. Guo and M. J. Buehler "End-to-end deep learning method to predict complete strain and stress tensors for complex hierarchical composite microstructures", Journal of Mechanics and Physics of Solids, Vol. 154, 104506, 2021. [3]A. Allahdadian and M. Mashayekhi "Experimental and numerical study of mode I interlaminar behavior of carbon nanotube reinforced glass–epoxy composite: A multiscale approach", Engineering Fracture Mechanics, Vol. 290, 109494, 2023. [4]M. Kim, Y.B. Park, O.I. Okoli and C. Zhang "Processing, characterization, and modeling of carbon nanotube-reinforced multiscale composites", Composites Science and Technology, Vol. 69, pp 335–342, 2009. [5]J.R. Pothnis, D. Kalyanasundaram and S. Gururaja "Enhancement of open hole tensile strength via alignment of carbon nanotubes infused in glass fiber-epoxy-CNT multi-scale composites", Composites Part A: Applied Science and Manufacturing, Vol. 140, 106155, 2021. [6]J.R. Pothnis, A.K. Hajagolkar, A.R. Anilchandra, R. Das, S. Gururaja "Open-hole fatigue testing of UD-GFRP composite laminates containing aligned CNTs using infrared thermography", Composite Structures, Vol. 324, 117557, 2023.

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abst. 1234
Room GALLA PLACIDIA
Friday
September 6
13h10

Concentration tensors in micropolar periodic laminates with imperfect interfaces

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Asymptotic homogenization techniques have been recently applied within the framework of three-dimensional linear micropolar media to compute the effective engineering moduli of a laminated micropolar elastic composite with centre-symmetric isotropic layers and imperfect (spring-type) contact between them [1, 2]. In this work, we calculate the concentration tensors linking the macroscopic averaged quantities (stress and strain) with their microscopic counterparts. A parametric analysis is proposed, to study the influence of material constants and microstructural parameters on the local stress and strain fields. References [1] Y. Espinosa-Almeyda, V. Yanes, R. Rodríguez-Ramos, J.A. Otero, C.F. Sánchez-Valdés, H. Camacho-Montes, P.P. Longoria, F.J. Sabina, "Effect of imperfect interface on the effective properties of elastic micropolar multilaminated nanostructures" Z Angew Math Mech. 00, e202200368 (2023). [2] R. Rodríguez-Ramos, V. Yanes, Y. Espinosa-Almeyda, C. F. Sánchez-Valdés, F. Lebon, R. Rizzoni, M. Serpilli, S. Dumont, F. J. Sabina "Effective engineering constants for micropolar composites with imperfect contact conditions". In: Altenbach, H., Bruno, G., Eremeyev, V.A., Gutkin, M.Y., Müller, W.H. (eds) Mechanics of Heterogeneous Materials. Advanced Structured Materials, vol 195. Springer, Cham (2023).

Multiscale Fracture Modelling of Nano Fibrous Composite by bridging Molecular Dynamics and Peridynamics

abst. 1309
Room GIUSTINI
Friday
September 6
16h10

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Polylactic acid (PLA) nanofibrous networks are of significant interest in various areas of engineering and science, including tissue engineering, drug delivery, and filtration, due to their unique and multifunctional properties, such as biodegradability, tuneable mechanical properties, and surface functionality. Challenges in predicting their mechanical behaviour arise from structural complexity, multiscale features, and variability in material properties. Many of these features represent multiscale configurations, and hence, a true multiscale representation of such nanofibrous structures can aid in more accurate analysis and prediction of their mechanical behaviour. In the present work, a hierarchical multi-scale approach is adopted that bridges atomistic modelling and non-local continuum mechanics, peridynamics, to investigate the fracture properties of three-dimensional nanofibrous network. At the atomistic scale, all-atom molecular dynamics simulations are performed on freestanding pristine and silver-doped polylactic acid nanofibres to determine the energy release rate, elastic modulus, and Poisson's ratio. At the microscale, dynamic fracture analysis is performed using the peridynamics method to assess crack propagation and determine fracture toughness for mode I and mode II in both aligned and randomly oriented fibrous networks. A good agreement with the available experimental data is observed. The current research paves the way for the development of stronger and more durable eco-friendly nanofibrous networks with optimised performance.

A hierarchical beam model in the framework of data-driven computational homogenization method

abst. 1318
GALLA PLACIDIA
Friday
September 6
12h50

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During their loading process, large deformation at both material (mesoscopic) and structural (macroscopic) levels can be observed, and both of them are closely related to each other. However, direct simulation may not be the most cost-effective option as it requires many elements, resulting in a rather expensive simulation due to the interactive coupling between the material-level large deformation and structural-level large deformation. To address this issue, our project aims to develop an accurate and

efficient multiscale model based on data-driven computational homogenization methods. Firstly, we plan to construct a database of constitutive information for macroscopic Gauss points by collecting the stress-strain data of RVE models under various loading conditions. Secondly, we will develop a hierarchical data-driven multiscale model based on the data-driven computational homogenization method.

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abst. 1323
Room GALLA PLACIDIA
Friday
September 6
12h10

Transverse failure prediction of unidirectional carbon fiber reinforced polymer composites subjected to uniaxial and biaxial loading by stress-triaxiality-dependent computational micromechanics

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Accurate characterizing the mechanical behavior of the component materials is crucial for failure predicting of unidirectional carbon fiber reinforced polymer (UD CFRP) composites. A stress-triaxiality-dependent micromechanics model is developed for the transverse failure prediction of the composites in this study, in which the stress triaxiality is innovatively adopted to define the plastic hardening behavior of the matrix material. Therefore, diverse hardening behaviors generated by heterostructures, accurate confirmation of biaxial failure, as well as hardening behavior evolution caused by stress status changes during loading process can be considered. The accuracy performance of the micromechanics model is provided by comparing the predicted results (stress-strain curves, RVE profiles and failure points) with existing experimental data and failure envelopes of failure criterion. The comparison results show that the micromechanics model can accurately capture the failure phenomenon and failure evolution mechanism of the composite under uniaxial and biaxial loadings.

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abst. 1332
DANTE
Tuesday
September 3
17h10

Development of Ultrasound Inversion Methods for Characterising Features in 3D Woven Composite Materials

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There is an increasing interest in the use of 3D woven composites in applications that require improved strength-to-weight ratios. In addition, the use of these structures helps to reduce CO2 emissions. Woven composites offer many benefits including many possible architectures with high ratios of strain to failure. Woven composites are structures made by interlacing some continuous fibres (known as wefts) in one direction and other continuous fibres (known as warps) in a perpendicular direction. In the case of 3D woven composites, the third direction is reinforced by other continuous fibres known as binder. This study deals with the development of ultrasound inversion methods to characterize features in 3D woven composite materials. The study focuses on orthogonal weave-type only. Both theoretical (simulated) and measured data are analysed and used to calculate features such as the warps, wefts, and binder locations. The analytical-signal response, including the definition of three instantaneous parameters, is analysed and their capabilities to calculate the warp, weft and binder locations are demonstrated. These instantaneous parameters are the instantaneous amplitude, phase and frequency. The simulated data is obtained from a 3D time domain Finite Element model whereas the measured data is acquired from scanning a built specimen using an ultrasound immersion tank. The inversion techniques developed in this study can be extended to other 3D woven weave-types.

Coarse-grained molecular dynamics simulation of hydrogel microstructures

abst. 1341
GIUSTINIANO
Friday
September 6
16h30

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Hydrogels are composed of cross-linked polymer networks wrapped with a large amount of water. They have large deformation, strong toughness, and are currently attracted considerable attention owing to their unique mechanical properties. The microstructure and dissipation mechanism of polymer networks in hydrogels are the basis for their desired properties. Hence, we proposed a practical and efficient data-inspired method for coarse-grained molecular dynamics model with greatly simulation efficiency compared to all-atom molecular dynamics simulation. Furthermore, the effect of energy dissipation mechanisms on the dynamic modulus and viscoelasticity of hydrogels is investigated by coarse-grained molecular dynamics. The coarse-grained molecular dynamic simulation of hydrogels successfully described the microstructure of hydrogels, explored the strength mechanism of hydrogels, reduced the difficulty of constructing multi-scale models, and expanded the intelligent applications of hydrogels.

Optimization techniques and methods

abst. 1031
DANTE
Wednesday
September 4
15h10

Innovative Predictive Modeling and Optimization of Composite Material Properties Using Machine Learning and Genetic Algorithms

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This study is focused on developing an advanced predictive model capable of accurately anticipating the linear elastic and thermal properties of composite materials. It leverages a wide array of influencing parameters, including the shape of inclusions (circular, elliptical, square, triangle), their spatial coordinates within the matrix, orientation, fixed volume fraction, and contrast between the two phases. Various machine learning techniques such as decision trees, random forests, support vector machines, k-nearest neighbors, and an artificial neural network (ANN) are employed to construct this predictive model. The dataset, enriched with diverse input variables, serves as the foundation for creating machine learning and genetic algorithm-based models. These models are meticulously trained not only to predict but also to provide insights into the mechanical and thermal conductivity of composite materials. Going beyond mere prediction and optimization, this research incorporates user-defined thermomechanical properties into an inverse analysis using genetic algorithms. The primary goal is to identify microstructures that match the user-defined thermomechanical response of composite materials. The cornerstone of this research is the establishment of a comprehensive database that encompasses the previously mentioned input parameters. Significantly, the integration of machine learning and genetic algorithms has proven highly effective, yielding predictions with remarkable accuracy, boasting scores ranging between 0.97 and 0.99. This accomplishment signifies a substantial breakthrough, showcasing the potential of this innovative approach in the field of materials engineering

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abst. 1063
DANTE
Wednesday
September 4
15h50

Optimal local reinforcement designs for maximum strength of laminated composite plates with a cutout

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The load-bearing capacity of composite structures severely diminishes if a cutout is required for functional purposes. Rather than uniformly increasing the thickness of the entire structure, reinforcing the area around the notches proves to be a significantly more effective method to enhance the strength of a notched structure. This study aims to identify the optimal design of reinforcing layers around a hole in a composite laminated plate, seeking to maximize not only the first-ply failure strength but also the ultimate strength while minimizing the use of reinforcing material. The ultimate failure load is determined through a progressive damage model based on the Puck failure criterion and the material property degradation method. A finite element (FE) model is developed to obtain the structural response of the plate during loading. The numerical model is validated by comparing predictions with experimental results from previous studies. The optimal design for local reinforcement is identified through a modified simulated annealing algorithm, known as a reliable stochastic global search algorithm. Adopting a multi-objective optimization strategy, the objective function incorporates both the strength and the reinforcement weight, with the aim of maximizing strength while minimizing material usage. The optimization variables are chosen as the fiber-orientation angles and the size of the reinforcing layers. The laminates with the optimal reinforcements are compared with unreinforced laminates in terms of the final failure load and the weight. Significant improvements in the strength are obtained with minimal added mass through optimization. The findings of this study have significant implications for enhancing the design of notched composite structures. Keywords: Laminated composites; notches; first-ply failure strength; ultimate strength; progressive damage analysis; FEA

Optimizing Filament Winding Processes for Fiber-Reinforced Composites: A Multi-Scale Numerical Analysis Approach

abst. 1066
DANTE
Wednesday
September 4
16h10

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As the application areas of fiber-reinforced composite materials expand, there is a growing interest in manufacturing processes aimed at maximizing physical properties while minimizing costs. Among these, filament winding (FW) methods, including wet and dry windings emerge as a top automated method for creating convex-shaped composites. Dry FW, favored for its simplicity and cost-efficiency, offers superior control over resin volume fraction. However, FW processes often encounter defects, notably voids, impacting mechanical properties. Void formation during FW process, stems from non-uniform impregnation of resin, necessitating resin flow monitoring and control to minimize defects. Resin flow control involves temperature and pressure management during fabrication to ensure proper resin flow, complete thermoset matrix curing, and reduced fabrication time. The consolidation process and resin bleeding under specified pressure and temperature profiles (cure cycle) are critical, involving complex physical phenomena such as resin flow, fiber migration, and void transport. While detailed analytical or numerical simulations face challenges due to complexity, simplified models like the Sequential Compaction Model (SCM) and Squeezed Sponge Model (SSM) have influenced research. However, multi-scale investigations are crucial due to FRP's complexity, requiring attention from micro to macro scales to optimize cure cycles and product quality. This study introduces a multi-scale numerical analysis methodology to evaluate the curing cycle of dry FW products, focusing on the cylinder region where fractures commonly occur. The analysis starts at the microscopic scale and progresses incrementally, Selecting appropriate boundary conditions for each analysis stage, and validating simulation with ring burst tests.

Topology optimization of metamaterials for improved shear modulus

abst. 1119
Room DANTE
Wednesday
September 4
16h30

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Mechanical metamaterials are manufactured structures with extreme mechanical properties that do not exist in nature. It is the array of microstructures designed to provide specific properties. Such properties are achieved with unique geometrical configurations of the unit cell instead of the material properties. Topology optimization (TO) aims to find optimum material design for specific boundary conditions by optimizing the objective function in a design domain iteratively. This study aims to economically develop metamaterials for improved shear modulus properties using topology optimization. The microscale properties of microstructures are related to the macroscale properties of the material through homogenization theory. The density variables in TO are updated using optimality criteria. We can significantly increase the microstructure's properties with topology optimization. Maximizing the shear modulus of metamaterials can improve the structure's performance and durability in various engineering applications. Metamaterials with a high shear modulus could be used to design buildings and other structures more resistant to earthquake-induced shear forces and reinforce existing structures, such as bridges and tunnels, increasing their load-bearing capacity and reducing the risk of failure.

Topology optimization of multi material structures using physics informed neural networks

abst. 1288
Room DANTE
Wednesday
September 4
16h50

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Multi-material topology optimization (MMTO) that relies on mesh-based finite element analysis (FEA) encounters inherent challenges, such as extraction of fine features and precise calculation of density field gradients. To address these challenges, we present a novel mesh-free MMTO approach solely relying on neural networks. The aim is to derive the optimal topology and determine the optimal distribution of two or more materials within the design space. A framework for MMTO is proposed where the density fields are represented in a mesh-independent manner, utilizing the activation functions of a physics-informed neural network (PINN). In this framework, the PINN's weights and biases serve as design variables, and the FEA solver in the conventional topology optimization algorithm is replaced with a differentiable deep energy PINN (DEM PINN) to determine the deformation state. These two PINNs are independent of each other and linked by the cost function defined by the Lagrangian, comprising a design objective function and a penalty term associated with the total potential energy and volume fraction constraints. Then, by relying on the PINN's built-in optimization routines the MMTO problem is solved. We demonstrate that the proposed method can extract fine features through a straightforward post-processing step. Based on several examples, we conclude that PINN-based designs outperform traditional mesh-based designs, revealing new and promising opportunities for MMTO.

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abst. 1334
Repository

A M-VCUT Level Set Based Data-driven Model of Microstructure and The Optimization of Two-scale Structures

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The optimization of two-scale structure can adapt to the different needs of materials in different regions by reasonably arranging different microstructures in the macro scale, thereby greatly improving structural performance. In this paper, a M-VCUT (Multiple Variable Cutting) level set based data-driven model of microstructure is developed, and an optimization method based on this model is proposed for the design optimization of two-scale structures. The geometry model of microstructure is constructed by using the M-VCUT level set method; the effective macroscopic properties of microstructures are obtained by using the homogenization method. Then, a database of microstructures containing their geometric parameters and mechanical parameters is constructed. The two sets of parameters are respectively taken as an input dataset and an output dataset, and a mapping relationship between the two datasets is established, hence offering a data-driven model of microstructures. During the optimization of the two-scale structures, such a data-driven model is used in the macro-scale finite element analysis and sensitivity analysis. Because the computational costs of invoking such a data-driven model are much less than those of the homogenization, the efficiency of analysis and optimization of two-scale structure is improved.

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abst. 1350
Room DANTE
Wednesday
September 4
15h30

Parallel Constrained Bayesian Optimization Algorithm for Optimizing VRB/OW-GFRP Structures

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The hybrid structure of the variable-thickness rolled blank with steels and the orthogonal woven glass fibre reinforced plastic (VRB/OW-GFRP) offers advantages in terms of crashworthiness, lightweighting, and cost reduction. Meeting manufacturing constraints is a necessary preliminary step to achieve large-scale applications of VRB/OW-GFRP structures. The crashworthiness optimization design of the VRB/OW-GFRP hybrid structure under manufacturing constraints is a time-consuming optimization problem with both explicit and implicit constraints. To efficiently solve this type of the optimization problem, a Parallel Constraint Bayesian Optimization (PCBO) algorithm is proposed. The search accuracy and efficiency of the PCBO algorithm are improved in three ways: 1) A bilog transformation is applied to the implicit constraint function to reduce the identification difficulty of the feasibility (feasible or infeasible solutions) of "expensive" sample points near the constraint boundary; 2) A trust region

update strategy is introduced to dynamically update the search space, which can balance the exploration and exploitation during the search process; 3) A parallel sampling method based on multiple acquisition functions is proposed, which increases the diversity of optimization solutions and achieves multi-task parallel computation in the optimization process. Then, the optimization capability of the PCBO algorithm was compared with existing algorithms in several classic test cases, and the convergence and robustness of the PCBO algorithm was validated. Finally, based on the PCBO algorithm, the thickness distribution and crashworthiness optimization design of the VRB/OW-GFRP front bumper beam were conducted, and good lightweight results with the constraints of the manufacturing and performance were achieved.

Assessing seismic performance of historical buildings using FRCM systems: a case study

abst. 1375
Repository

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Existing buildings with historical or monumental value represent an extraordinary heritage, and their structural protection is crucial. It is important to maintain the historical and architectural value of these structures while enhancing their seismic performance. To avoid altering the aesthetic of the facade, the benefit of applying new composite materials, such as the Fabric Reinforcement Cementitious Matrix (FRCM), only from the internal side is assessed. This paper evaluates the effectiveness of the FRCM system applied to masonry buildings. Nonlinear analyses are conducted on a single wall to observe the effect of the matrix, varying the mechanical characteristics and the density of the fabric mesh to improve structural behavior. The use of FRCM system can optimize structural retrofitting interventions, minimize invasiveness, and maintain the aesthetic integrity of historical buildings. This approach not only preserves the exterior appearance but also provides a practical solution for conserving heritage structures, ensuring their longevity and safety.

Optimization of photonic nanojets for formation and characterization of composite films

abst. 1377
Repository

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The successful development of laser technology has opened up new opportunities in the formation and characterization of composite films and coatings. The use of lasers with ultrashort pulses in the femtosecond range allows the implementation of new principles for the formation of three-dimensional film structures of various materials with submicrometer resolution. Using local and collective effects in the formation of photonic nanojets has the potential to optimize laser modification method, which can be used to create microstructured functional composite films with higher resolution. Photonic nanojets make it possible to overcome the diffraction limit in beam focusing and significantly increase the radiation intensity. The main research direction is the development of technologies for microstructuring of the surface of functional layers by ultrashort laser pulses. To determine the optimal processing mode, a theoretical study of the interaction of laser radiation with matter is carried out. The laser parameters, technological parameters, as well as optical, thermodynamic and mechanical properties of

the material are taken into account. The next stage involves the creation of a unique microrelief and phase composition distribution of coatings with quality control of the laser-treated surface based on the geometric properties and properties of the substance in the laser treatment zone, as well as further optimization of laser microprocessing. On the other hand, the same approach can be used to improve resolution and sensitivity when characterizing composite films. The formation of photonic nanojets was simulated depending on the degree of order, symmetry, microstructural and morphological features of the structured composite coatings. An important feature of our findings is the ability to deepen the nanojet focus to some depth far from interfaces, which allows for high resolution depth profiling achievement of laser microtechnology and characterization methods of composite films.

PRIN 2022: New Insights in the Mechanical Modeling of Cultural Heritage for Sustainable Restoration: Green Composites and Nano-Technologies (GreNaTe) (chaired by N. Fantuzzi, D. Baraldi, P. Trovalusci)

In-plane behaviour of NFRCM-strengthened masonry modelled by means of discrete elements

abst. 1287
DANTE
Tuesday
September 3
12h10

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In the last years, the attention to the use of eco-compatible materials and the development of sustainable solutions for structural strengthening has increased, leading to fibre-reinforced cementitious matrices (FRCM) made by natural fibres (NFRCM, de Carvalho et al. 2017). NFRCM strengthening systems, in the same manner as FRCM ones, can be considered an alternative to fibre-reinforced-polymer (FRP) reinforcement for masonry structures, to improve the compatibility of reinforcement applied to masonry substrate (di Tommaso et al. 2017). The numerical assessment of NFRCM and/or FRCM strengthened masonry is an active field of research and it represents a complex task, due to the complexity of both reinforcement and support materials, which can be considered as composite ones. In literature, some macro-models consider both masonry components (bricks and mortar) as a homogeneous continuum, and FRCM layers are considered as an additional equivalent continuum, with the textile fibres assumed as an embedded reinforcement of mortar matrix (Wang et al. 2017). These models have been extended to NFRCM (de Carvalho et al. 2019). Recently, a simplified micro-model approach was proposed for diagonally loaded masonry panels reinforced with FRCM (Murgo et al. 2021), adopting a 2D FE model with one-dimensional interfaces for masonry panels, and adding a bi-directional grid of trusses for representing the reinforcement. An updated discrete element model for simulating the in-plane behaviour of masonry walls strengthened with FRCM or NFRCM has been recently introduced by authors (Baraldi et al. 2021). This model is based on an existing discrete or rigid block model having rigid elements and nonlinear one-dimensional interfaces between them, able to represent both mortar joints and brick cracking (Baraldi et al. 2020). Such a model has been improved by considering masonry strengthened on both sides The hypothesis of perfect adhesion between the wall and reinforcement and also between the matrix and fibres of the strengthening system is assumed, in order to avoid the increase of model degrees of freedom with respect to the unreinforced masonry (URM) case. The reinforcement is modelled by means of further stiffness and strength parameters accounting for the FRCM/NFRCM geometrical and mechanical properties. The proposed model has already turned out to successfully simulate cracking both on masonry and the external reinforcing layers and it was calibrated with respect to an existing simplified numerical model (de Carvalho et al. 2019). In this work, the proposed discrete model is calibrated and compared with respect to several existing laboratory tests of in-plane loaded masonry panels reinforced with FRCM and NFRCM layers, in order to highlight its effectiveness and potential improvements. References Baraldi D, De Carvalho Bello CB, Cecchi A, 2020, Refined Rigid Block Model for In-Plane Loaded Masonry, Adv Civil Eng Baraldi D, Boscato G, Cecchi A, de Carvalho Bello CB, 2021, An Updated Discrete Element Model for the In-Plane Behaviour of NFRCM Strengthened Masonry Walls. Key Eng Mater, 19:249-255 de Carvalho Bello CB, Cecchi A, Meroi E, Oliveira DV, 2017, Experimental and Numerical Investigations on the Behaviour of Masonry Walls Reinforced with an Innovative Sisal FRCM System. Key Eng Mater, 747:190-195 de Carvalho Bello CB, Baraldi D, Boscato G, Cecchi A, Mazzarella O, Meroi E, Aldreghetti I, Costantini G, Massaria L, Scafuri V, Tofani I, 2019, Numerical and theoretical models for NFRCM-strengthened masonry. Key Eng Mater, 871,44-49 di Tommaso A, Focacci F, Micelli F, 2017, Strengthening historical masonry with FRP or FRCM: Trends in design approach. Key Eng Mater, 747:166-173. Murgo FS, Ferretti F, Mazzotti C, 2021, A discrete cracking numerical model for the in plane behavior of FRCM strengthened masonry panels. Bull Eartq Eng, 19:4471-4502 Wang X, Ghiassi B, Oliveira DV, Lam CC, 2017, Modelling the Nonlinear Behaviour of Masonry Walls Strengthened with Textile Reinforced Mortars. Eng Struct, 134:11-24

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abst. 1363
Room DANTE
Tuesday
September 3
12h50

On the mechanical description of composite materials as micropolar continua

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Composite materials play a primary role in many engineering applications. However, their mechanical characterization proves challenging because, at finer scales, they are characterized by the presence of significant heterogeneities in size and texture, which affect the macroscopic response. Classical continuum models of such materials are not always suitable for describing their macroscopic behaviour, especially when it is important to consider the microscopic level. To adequately address scale effects, several non-classical/non-local formulations have been proposed in the literature. Among these, micropolar continua have proven effective in representing the mechanical behaviour of anisotropic media, taking into account the arrangement, size, and orientation of particles [1, 2]. Thus, this work focuses on modelling composites as both continuous and discrete systems, with the latter description assumed as the benchmark, as it provides a finer representation of the material. The aim is to identify micropolar models to describe the mechanical response of composite materials made of rigid blocks and thin interfaces. Micropolar constitutive parameters of composites, characterized by different block shapes and sizes, are derived through a homogenization procedure based on an energy equivalence criterion between the discrete micromechanical model and the continuum one [1]. Moreover, a heuristic optimization approach based on the Differential Evolution algorithm [3] is investigated to derive the constitutive micropolar parameters by exploiting static and dynamic analyses performed on the discrete systems. The obtained results [4], for different material symmetry classes, indicate that the proposed strategies yield satisfactory outcomes, paving the way for experimental validation and potential applications. References: [1] Trovalusci, P., Masiani, R. (1999). Material symmetries of micropolar continua equivalent to lattices. International Journal of Solids and Structures, 36(14), 2091-2108. [2] Trovalusci, P., Pau, A. (2014). Derivation of microstructured continua from lattice systems via principle of virtual works: the case of masonry-like materials as micropolar, second gradient and classical continua. Acta Mechanica, 225(1), 157-177. [3] Storn, R., Price, K. (1997). Differential evolution–a simple and efficient heuristic for global optimization over continuous spaces. Journal of global optimization, 11, 341-359. [4] Colatosti, M., Carboni, B., Fantuzzi, N., Trovalusci, P. (2023). Composite material identification as micropolar continua via an optimization approach. Composites Part C: Open Access, 11, 100362.

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abst. 1397
Room DANTE
Tuesday
September 3
12h30

Clay composite as a construction material through additive manufacturing process

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Additive manufacturing, known as 3D printing, has emerged as a transformative technology across various industries, including construction. it led to a further expansion of architectural boundaries with the introduction of complex geometries, aiming to achieve innovative and flexible structures with minimal use of material and construction time. Combining 3D printing and eco-friendly materials, such as clay, offers additional advantages. It enables a reduction in environmental impact, significantly aids in passively equilibrating indoor relative humidity, reduces energy consumption and achieves hygrothermal

comfort. Nevertheless, several challenges persist, particularly the mechanical performance of clay-based materials, which impedes excellent compressive strength. Clay structures are susceptible to cracking and shrinkage when exposed to rapid changes in temperature and moisture, moreover, the stability and buildability of clay composites during printing is a significant hurdle. To address these challenges, we study the mechanical behaviour and the printability of a clay composite reinforced with hemp and wood fibres through a series of experimental tests, the addition of f (5%, 10%, 15%, and 20%) of fibres into clay matrices enhances its ductility and reduces the shrinkage. However, the printability and stability of these composites in the fresh state necessitates meticulous control over printing parameters and the selection of a suitable printer and extrusion system.

Probabilistic models for composites

abst. 1040
Room GALLA PLACIDIA
Friday
September 6
16h30

An efficient reliability evaluation methodology for composite tubes using Artificial Neural Networks and Monte Carlo Simulation

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Thin-walled tubes made with polymer-matrix fiber-reinforced composite materials are increasingly being used in automobile, mechanical, and aerospace engineering applications due to their fatigue-resistant, corrosion-resistant, and high stiffness-to-weight ratio and strength-to-weight ratio characteristics. Global buckling is an important design consideration for thin-walled composite tubes with a low radius-to-length aspect ratio. In industrial applications, the production of composite components is done on a mass scale. The practical ply manufacturing parameters and tube manufacturing parameters have considerable influences on the in-situ material properties of the composite material in the manufactured tube. Due to the inherent unavoidable variations in these parameters, it is not practically feasible to fabricate multiple composite tubes with identical in-situ material properties and test them all for quality control and performance assurance. The uncertainties in the material properties of the composite plies exert considerable random influences on the global buckling failure of the composite tube. The resulting random variations in buckling loads need to be considered at the design stage. In the present work, considering this important practical need, an efficient reliability evaluation methodology based on the Artificial Neural Network modeling and Monte-Carlo Simulation method, that takes into account the random spatial distributions of in-situ stiffness properties of composite tubes, is developed. The global buckling loads of the uniform-diameter composite tube subjected to axial-compressive loading is determined considering linear buckling and based on the three-dimensional finite element modeling and analysis. Existing works in the literature are used to validate the finite element model developed using the software ANSYS®. The reliability-based critical buckling loads of the composite tube are determined. It is shown that the change in the critical buckling load of the tube with the reliability is not linear and is not monotonic. The corresponding threshold values are determined. It is also shown that when conventional design methodology is used in conjunction with the mean values of the material properties, only 50% reliability is achieved. The methodology developed in the present work provides the reliability-tailoring design capability that will be very useful and is highly desired in practical applications of composite tubes.

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abst. 1135
Room GALLA PLACIDIA
Friday
September 6
16h50

Statistical analysis of the tensile strength in open-hole composite laminates: The effect of stacking sequence and material properties variability.

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Lightweight alloys have been supplanted by composite materials in various high-performance structural applications. Their remarkable specific stiffness and strength, along with their tailorability, have prompted significant investment in the aeronautic sector to achieve a weight reduction in primary and secondary structures without lowering their safety. However, challenges persist due to inherent uncertainties in these materials and their sensitivity to manufacturing defects. Consequently, certification agencies continue to mandate rigorous experimental activities to evaluate the load-bearing capacities of these structural details. This process, currently based on the Composite Material Handbook [1] or certified company guidelines, aims at identifying the coupon allowables for each of material involved in the design process of any component. However, it entails substantial costs and a significant time investment that could be remarkably reduced by increasing the confidence in statistical numerical approaches. State-of-the-art high-fidelity finite element simulations of composite laminates have already demonstrated their capabilities in predicting the experimental outcome of different structural details for multiple loading conditions. However, due to their computational cost the use of this tools for

generating an amount of data suitable for the estimation of the coupons allowables is still unpractical. To overcome this limitation and produce a suitable robust database, the definition of surrogate models has been identified as a possible valuable alternative. Within this work, a multi-level statistical quantification of the strength variability for open-hole tensile coupons is performed starting from numerical results. High-fidelity finite element analyses are performed to generate a database for unidirectional carbon fibre lay-up of aeronautical interest. This database would cover laminates typically applied in high-performance applications and satisfying industrial design constraints. Moreover, for each lay-up the simulations will include the effect of both the stacking sequence and the variability of the most relevant lamina properties. First, uncertainty quantification techniques (e.g . Bayesian approaches) will be implemented to quantify the strength variability within the same laminate produced by the scatter in the base material properties. In a second step, a second statistical analysis is performed to identify a surrogate model coping with laminates with different stacking sequence but the same in-plane lamination parameters [2]. The outcome of this multi-step approach will generate a series of surrogate models to quickly evaluate the coupon strength suitable for the estimation of the laminate allowables. References: [1] Military Handbook, 2002. Mil-hdbk-17-1f: Composite materials handbook, volume 1-polymer matrix composites guidelines for characterization of structural materials. [2] Tsai, S.W., Pagano, N.J., 1968. Invariant properties of composite materials. Tech. Rep.; Air force materials lab Wright-Patterson AFB Ohio

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A probabilistic constant life diagram based on a weakest link approach with application to composite fan blades

abst. 1327
GIUSTINIANO
Wednesday
September 4
16h50

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Composite fan blades, as the front-end component of high bypass ratio turbofan engines, bear both centrifugal and aerodynamic forces and are vibration sensitive components. Non steady aerodynamic excitation can cause resonance of fan blades, leading to a sharp increase in stress, exacerbating high cycle fatigue cumulative damage, and increasing the risk of failure during the lifespan. The operability requirement of airworthiness clauses is that fan blades have sufficient vibration stress margin under non design conditions. High cycle fatigue design based on the Goodman curve often includes the variability of critical quality characteristics (CTQs) caused by multiple sources of uncertainty factors (such as manufacturing, assembly, geometric tolerances, and operational wear) using empirical safety factors or material strength statistical benchmark values. However, neither treatment method can quantify the safety of fan blade design. In addition, compared to traditional metal blades, the manufacturing defects and inherent dispersion of fatigue strength in composite structural components are greater, posing challenges to the deterministic high-cycle fatigue design evaluation method for fan blades. Due to the anisotropic mechanical properties of composite material stiffness and strength, based on the design experience of international aero engine companies such as GE Aviation, it is required to evaluate the possibility of high cycle fatigue failure in various damage modes of composite fan blades. A statistical methodology for the assessment of high cycle fatigue failure probability is presented with a focus on structural integrity design of laminated composite fan blades in large bypass ratio turbofan engine. Firstly, Based on a probabilistic anisomorphic constant life diagram for composite laminas at mesoscale level within the considered composite structure in combination with a weakest link approach, the approach allows quantitatively assess high cycle fatigue failure probability with respect to all competing damage modes of unidirectional carbon fiber reinforced epoxy matrix prepreg. Probabilistic design constant life diagrams are deduced based on the unit constant life diagram for each ply stress component in order to assess the failure probability of components with complex geometries and applied loadings. Local steady and vibrational stresses are factorized with respect to the ply stresses at the critical local position to obtain the respective probabilistic design curves. Secondly, three types of composite material sheet specimens with different stress concentration factors are designed by dimensioning different size of notches. Accompanying high fidelity finite element models were established to provide accurate ply stress fields used in the non-local theoretical model, which takes into account the ply stress gradient implicitly by numerically integrating the entire domain full of layered solid elements. The posterior maximum

points of material mechanical properties (shape and scale two parameter Weibull distribution, in-plane fracture toughness ratio of in-plane to , critical stress ratio, relative fatigue strength at ratio at critical stress ratio) were calibrated by employing an inverse Bayesian inference based on a limited number of data set. A predictive result from multiple batches of leave-one-out cross validation show good agreement with test data. In order to expand its application at the end, the proposed model with inferred parameter set is applied to evaluate the global fatigue failure probability of a real composite fan blade under centrifugal forces at nominal design rotation speed as well as first natural frequency harmonic excitation from unsteady aerodynamic force. The results show its effectiveness and convenience for practical engineering design.

Recent Developments and Challenges in Design and Manufacturing Composite Pressure Vessels (chaired by P.M. Weaver, S. Daghighi)

Multi-dimensional collaborative design of composite pressure vessel via failure mechanism based modeling

abst. 1032
Room DANTE
Friday
September 6
14h30

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Filament-wound composite pressure vessel is committed for lightweight requirement to accomplish performance index advancement with cost-effective manufacturing. Given that most reported composite winding technologies are focusing on process optimization but lack of rigorous failure theory support, it is still challenging for manufactured pressure vessel to satisfy the design expectation in terms of bearing capability. To this end, this study presents a mechanism-driven model for high-precision strength prediction of composite pressure vessel under multiple working conditions, aiming to break through the design bottleneck due to manufacturing conflict between winding feasibility and structural characteristics. The micro-defect evolution behavior is captured via reduced-order multiscale modeling and a new failure criterion that takes into account the interlaminar in-situ effect, which overcomes the problems of low prediction accuracy as well as computational efficiency using traditional strength principles. Interestingly, we disclose the quantitative mechanical response of bearing capability at dome section to filament winding wear and uneven adhesive property, then accurately uncover the damage progression mechanism of evolving from microscopic fiber fractures and local debonding in helical layers to macroscopic burst. More importantly, a multi-dimensional collaborative design approach integrating factors between material, structure, manufacture, and service is further proposed by combining the failure theory and optimized winding technology. This innovative methodology is capable of overcoming the over-reliance on experiential and trial-and-error methods for the sake of higher winding accuracy, shortened design iteration cycle, and utmost lightweight design. To sum up, the proposed design approach should be of great significance for enhanced strength prediction accuracy and efficiency of filament-wound composite structure, which also sheds light on the automated systematic design and manufacturing of high-performance pressure vessel.

Isotensoid design and manufacture of Type V composite pressure vessels for mobility using automated fibre placement

abst. 1055
Room DANTE
Friday
September 6
14h50

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Composite pressure vessels (CPVs) have garnered a high level of research interest for their substantial weight savings over traditional metallic vessels. This is particularly important for applications in aerospace and automotive, where CPVs are being used for the storage of hydrogen and other fluids. Two challenges facing future CPVs are the evolution of their manufacturing, as the process has largely remained unchanged for decades, and overcoming the manufacturing and permeability implications of state-of-the-art liner less, or Type V, CPVs. Since their inception, filament winding has been the primary manufacturing method for CPVs due to its high speed and cost effectiveness. However, since the fibre in filament winding must be continuous, excess material is often placed on the cylinder to sufficiently reinforce the domes or to transition between two desired winding angles. For some larger vessels, particularly those used in the space industry, automated fibre placement (AFP) has been adopted. AFP has the potential to optimise vessel design as the cut-and-add placement capability and roller-dominated tow compaction gives the designer greater flexibility in tailoring material placement. In this work the application of AFP to smaller scale CPVs, i.e. those sized for automotive applications, has been investigated. A 2-piece, CF/epoxy prepreg pressure vessel has been designed, manufactured, and tested to

understand the benefits, challenges, and limitations of the AFP process. In this work, the adaptation of the isotensoid design to produce domes with fibre angles not achievable using filament winding is presented. This resulted in a fully composite dome design with no metal boss. Finite element analysis package ANSYS has been integrated with AFP programming software VERICUT to feed manufacturing simulation data into the design phase and assist FE modelling. The development of a collapsible layup mandrel has also been undertaken and challenges encountered with AFP layup, curing and de-moulding are given in the full presentation. It was found that commercially available AFP equipment produced gaps on the double curved domes near the equator and failed to adequately compact the laminate towards the poles. During hydrostatic testing, leakage was correlated to these defect prone regions, necessitating subsequent adjustments to the design, programming, and manufacturing process. Following prototyping and initial experimentation, detailed design optimisation was undertaken to co-optimise the dome thickness and fibre angles. Ply drops were implemented to tailor the dome thickness using two different dropping strategies. Both geodesic and non-geodesic fibre paths were also simulated for structural performance and manufacturability. Thickness optimisation was found to give an average 21.1% improvement in a non-dimensional performance factor and the use of non-geodesic fibre paths yielded an average improvement of 26.6%. A demonstrator non-geodesic dome with optimised thickness was manufactured using AFP and its thickness and tow positioning were verified using laser 3D scanning. Finally, the largest problem facing Type V tanks is gas leakage as they forego the internal polymer or metallic liner found on established vessel designs. This leakage is primarily caused by the accumulation of interconnected microcracks that form leakage paths for the contained fluid. Substantial work has been conducted on the modelling and prediction of microcrack formation in cross ply laminates and some work has been done on predicting the microcrack formation in pressure vessel laminates and the resulting permeability. However, design strategies for suppressing microcracking in CPVs have been seldom explored and the impact of altering the laminate to minimise matrix cracking on key performance metrics has not been thoroughly investigated. In the full presentation our work on product-scale consequences of design for matrix crack control will also be discussed.

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abst. 1092
DANTE
Friday
September 6
15h10

Virtual characterization of the rate- and temperature-dependent mechanical properties of composite materials for hydrogen pressure vessels

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Composite materials play an important role in the design of weight-efficient pressure vessels. In recent years, they have gained relevance for hydrogen storage in mobility applications where they undergo varying temperature and loading conditions during service life. For the design of such structures, knowledge of the rate- and temperature-dependent material behavior is essential. Due to the inherent inhomogeneity and anisotropy of endless fiber-reinforced composites, the required test campaigns are time – and cost-intensive. In this study, we use a virtual characterization approach to support and replace physical experiments, which significantly shortens the development process in the early phase. The computational micromechanics framework uses Representative Volume Elements consisting of fiber, matrix, and interface to predict the behavior of the unidirectional ply of a carbon fiber-reinforced epoxy polymer and to study sensitivities for different parameters. Finally, we compare the predictions of the numerical models to physical experiments on coupon specimens. Both virtual and physical experiments show significant rate- and temperature-dependence of the matrix-dominated mechanical properties.

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abst. 1094
Room DANTE
Friday
September 6
15h30

Roadmap for production of large-format composite pressure vessels for storing cryogenic hydrogen in the commercial vehicle sector

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As the commercial vehicle sector moves towards sustainable energy solutions, the need for effective hydrogen storage technologies becomes increasingly critical. Large-format composite pressure vessels for cryogenic hydrogen storage stand out as a promising solution, offering a blend of lightweight design and high performance under extreme conditions. Traditionally, these vessels have been manufactured using wet winding techniques. However, the high mechanical requirements require the exploration of alternative methods, such as the use of towpreg for filament winding, to increase efficiency and reliability. A collaborative research project is investigating the transition from traditional wet winding to towpreg filament winding in the production of these advanced vessels. Towpreg pre-impregnated with resin provides more consistent material properties and easier handling, which is critical for producing large format vessels that meet stringent standards for cryogenic hydrogen storage. In this study, we outline a roadmap for the development of hydrogen pressure vessels through the production of high-performance tanks using the towpreg winding process. The process begins with the mechanical characterization of the towpreg material, which serves as an input for the numerical simulations of the vessel. The winding process simulations include modeling non-geodesic winding paths and patterns, crucial for assessing both theoretical performance and practical implications, such as production efficiency and layup quality. Additionally, we examine the curing process for thick layups to ensure material integrity. The investigation concludes with the production and testing of initial prototypes, providing valuable insights into their performance. This evaluation not only demonstrates the feasibility of the towpreg winding process but also highlights areas for further improvement, setting a foundation for future advancements in hydrogen storage technology.

Advantages of Tow Steering for the Next Generation of Composite Pressure Vessels for Hydrogen Storage

abst. 1095
Room DANTE
Friday
September 6
15h50

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Recently, there has been rapidly growing interest in hydrogen as an energy source in Europe and worldwide. One of the challenges in using hydrogen as an energy source in applications related to the transportation system is the need for efficient, lightweight pressure vessels with improved packing efficiency, which enables storing more media in the same amount of space and consequently enables travelling for longer distances without the need for frequent fuelling. Furthermore, for some applications with limited space, conventional shapes are inappropriate, and there is a need for conformable pressure vessels. For instance, toroidal shapes defined as curved, endless, hollow shapes can be an efficient alternative configuration for pressure vessels that eliminate the need for end caps. However, one of the difficulties arising from conformable shapes with non-circular cross-sections in pressure vessels is the bending stress that inevitably arises in conventional designs caused by internal pressure. The bending stress elevates stress levels beyond that of similar circular pressure vessels, which is countered by making it thicker, making the design inefficient. Alternatively, composite materials can be used to benefit from tailoring the stiffness throughout the structure, which can result in a bend-free design. Bend-free composite pressure vessels redistribute the stress gradient uniformly through the thickness, increasing the overall load-carrying capacity and significantly reducing weight. These advantages make them potential candidates for the next generation of pressure vessels. In light of these premises, we discuss the current developments in stiffness tailoring using the tow steering to design bend-free conformable pressure vessels and compare their performance with conventional design in terms of hydrogen weight efficiency (HWE). Results suggest that the HWE of the bend-free tow-steered pressure vessel is 18.6% larger than the HWE of the best conventional design studied.

A fast multi-scale modeling analysis for progressive damage failure of composite over-wrapped pressure vessel (COPV) under thermo-mechanical loads

abst. 1099
Room DANTE
Friday
September 6
16h30

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Fiber reinforced composite materials and structures have been increasingly adopted in the aviation and aerospace industries, for instance, horizontal and vertical tails for aircrafts and rocket fairings for spacecrafts, due to their superior specific stiffness and strength. For some applications, such as composite over-wrapped pressure vessels (COPVs), the composite materials may be recommended to work at the liquid hydrogen (LH2) temperature and must be able to ensure safety and reliability in service. For the analysis of thermo-mechanical behaviors of composite materials at macro-scale, the layers were usually assumed to be homogeneous and behave as transversely isotropic/orthotropic material. Therefore, most of the thermal stress analysis focus on the mismatch of thermal expansion coefficients between composite layers. However, the differences in thermal expansion coefficients between the reinforcing phase and the matrix phase should also be considered. In this paper, a fast multiscale model based on the Self-consistent Clustering Analysis (SCA) is developed to predict the matrix failure process of COPV. Finite element analysis is performed on a representative volume cell (RVC) based on the micro-structure of fiber and matrix to determine conversion relationship between the macro strain fields and the micro stress fields. A reduced-order model is established by SCA method based on the high-fidelity microscopic RVE, which is combined with a progressive damage approach to predict the matrix failure process of the COPV. By comparing with prediction results of the PUCK criterion, the prediction accuracy of the RVC is demonstrated and the maximum error of the predicted damage strength did not exceed 10%. It can be concluded that the mechanical performances of composite materials are significantly influenced by the change of service temperature. The thermal-force coupling analysis of the COPV is carried out by integrating the above models, and the effect of temperature on the load-bearing performance of the composite structure is analyzed.

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abst. 1184
Room DANTE
Friday
September 6
16h10

Design Optimisation of a Conformal Composite Liquid Hydrogen Tank

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In this paper, we present the results of two-step optimisation of a conformal composite liquid hydrogen tank. In the first step, the tank geometry is optimised and then, in the second step, the composite laminate is optimised, with an objective to reduce structural mass to meet the gravimetric index (GI) requirement – defined as the ratio of fuel mass to the mass of the tank with fuel. Hydrogen has emerged as one of solutions for achieving net-zero carbon emissions by 2050 [1]. The COCOLIH2T (Conformal Composite Liquid Hydrogen Tank for Regional Aircraft) consortium, coordinated by Collins Aerospace Ireland, proposes a disruptive double-walled, vacuum-insulated, conformal, thermoplastic composite, low-pressure vessel concept [2]. Although hydrogen can be stored in several ways, only liquid hydrogen (LH2) seems to be feasible in aviation due to its low volumetric energy density. Even in liquid form, LH2 requires approximately 4.5 times the volume required by kerosene, dictating a LH2 larger tank [3,4]. Consequently, storage density is mainly driven by the tank design. Fibre-reinforced composite tanks can potentially offset the mass penalty and reduce the thermal aspects of heat-conducting metallic tanks. However, they present other design challenges: particularly, matrix microcracking and hydrogen permeation. High-performance lightweight structures can be realised by effectively utilising geometric stiffness in addition to material stiffness. Optimising tank begins with the geometry and involves shape parametrisation and considers geometric constraints imposed by the design envelope and design volume in addition to the mechanical performance and thermal dormancy requirements. Therefore, a doubly curved stressed skin structure is conceptualised and parameterised. Geometric constraints, i.e., length, width, and height, are derived from the proposed design envelope to locate the tank with a capacity to store 57 kg of LH2 in the empennage of regional aircraft, e.g., ATR-72. A key parameter in the design of

pressure vessels is the proof pressure, which is derived from maximum operating pressure and considering a safety factor, e.g., liquid sloshing under dynamic crash loads. Resulting from heat input during the ground operations or flight, the pressure inside the tank raises according to the boil-off rate. Typically, venting systems are implemented to relieve the pressure due to boil-off. Once the pressure reaches the maximum allowable tank pressure, venting systems actuate to maintain or decrease the pressure level. Therefore, the design volume includes an empty fraction, which can accommodate the gaseous H2 due to boil-off. Winnefield et al [3], 14% empty tank for a vent pressure of 4 bar. In this study, a 32% empty tank to meet the 24-hour boil-off requirement is considered. Moreover, to minimise the thermal leak, a constraint on tank surface area is considered. To alleviate matrix microcracking, a conservative design stress limit on the composite laminate is imposed as a strength constraint. To implement this first step, a structural optimisation framework is developed; herein, the optimisation is based on an open-source Python library, pyOptSparse [5] – a further development of the legacy pyOpt [6], which allows formulating and solving a nonlinear constrained optimisation problem, and shape parametrisation and structural analysis is performed using ABAQUS finite-element solver [7]. For composite laminate optimisation, a hybrid multi-stage approach is utilised; this approach combines the benefits of gradient search using lamination parameters and evolutionary algorithms while alleviating its drawbacks [8–10]. In the first stage, a conceptual optimum stiffness distribution is achieved by considering either a balanced and symmetric laminate or a symmetric laminate, with constraints to define a predefined set of fibre angles [11–13] and limit the laminate stress [14]. To implement this first stage, a structural optimisation framework is developed; herein, the optimisation is based on an the aforementioned open-source Python library, and structural analysis is performed using ABAQUS finite-element solver. Further, a multi-panel composite laminate, i.e., patchwork design, is considered for efficient material utilisation. At the second optimisation stage, the goal is to find a suitable stacking sequence for each panel compromising the structure to match the optimum combination of the conceptual stiffness distribution and manufacturing constraints, such as the 10% rule, disorientation, ply contiguity and continuity, and blending[15,16]. The results from the tank geometry optimisation highlight the increase in gravimetric index through optimising the double-curvatures and decreasing the empty fraction, while, still meeting the thermal dormancy requirements. The results from composite laminate optimisation emphasize the improvements in gravimetric index relative to conventional, quasi-isotropic 'quad' laminate. In addition, the trade-off between the number of patches, effect of laminate characteristics, and sensitivity to design stress limit, while considering manufacturing feasibilities is highlighted. Overall, optimal fibre-reinforced composite structures maximise the benefits of employing composite materials, activating the virtuous cycle of lightweight engineering design philosophy! Such optimal fibre-reinforced composite structures are essential to accomplish the extremely ambitious goals of future sustainable aircrafts. Keywords: Structural Optimisation, Matrix microcracking, Lamination Parameters, Gradient-based Optimisation, Stacking Sequence Tables Funding Acknowledgement: COCOLIH2T is co-funded by the EU Clean Hydrogen Partnership under Grant Agreement 101101404. The project is supported by the Clean Hydrogen Partnership and its members. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or Clean Hydrogen Joint Undertaking. Neither the European Union nor the granting authority can be held responsible for them. References [1] European Commission. Directorate General for Mobility and Transport., European Commission. Directorate-General for Research and Innovation. Flightpath 2050 : Europe's vision for aviation : maintaining global leadership and serving society's needs. 2011. https://doi.org/10.2777/50266. [2] COCOLIH2T (COmposite COnformal LIquid H2 Tank) n.d. https://www.cocolih2t.eu/. [3] Winnefeld C, Kadyk T, Bensmann B, Krewer U, Hanke-Rauschenbach R. Modelling and designing cryogenic hydrogen tanks for future aircraft applications. Energies 2018;11:1–23. https://doi.org/10.3390/en11010105. [4] Eissele J, Lafer S, Mejía Burbano C, Schließus J, Wiedmann T, Mangold J, et al. Hydrogen-Powered Aviation—Design of a Hybrid-Electric Regional Aircraft for Entry into Service in 2040. Aerospace 2023;10:1–23. https://doi.org/10.3390/aerospace10030277. [5] Wu N, Kenway G, Mader C, Jasa J, Martins J. pyOptSparse: A Python framework for large-scale constrained nonlinear optimization of sparse systems. J Open Source Softw 2020;5:2564. https://doi.org/10.21105/joss.02564. [6] Perez RE, Jansen PW, Martins JRRA. PyOpt: A Python-based object-oriented framework for nonlinear constrained optimization. Struct Multidiscip Optim 2012;45:101–18. https://doi.org/10.1007/s00158-011-0666-3. [7] ABAQUS. Abaqus 6.14. Abaqus 614 Anal User's Guid 2014. [8] Gürdal, Zafer; Haftka, Raphael T; Hajela P. Design and Optimization of Laminated Composite Materials. Wiley Interscience; 1999. [9] Ghiasi H, Pasini D, Lessard L. Optimum stacking sequence design of composite materials Part I: Constant stiffness design. Compos Struct 2009;90:1–11. https://doi.org/10.1016/j.compstruct.2009.01.006. [10] Ghiasi H, Fayazbakhsh K, Pasini D, Lessard L. Optimum stacking sequence design of composite materials Part II: Variable stiffness design. Compos Struct 2010;93:1–13. https://doi.org/10.1016/j.compstruct.2010.06.001. [11] Diaconu CG, Sato M, Sekine H. Feasible region in general design space of lamination parameters for laminated composites. AIAA J 2002;40:559–65. https://doi.org/10.2514/2.1683. [12] Bloomfield MW, Diaconu CG, Weaver PM. On feasible regions of lamination parameters for lay-up optimization of laminated composites. Proc R Soc A Math Phys Eng Sci 2009;465:1123–43. https://doi.org/10.1098/rspa.2008.0380. [13] Setoodeh S, Abdalla MM, Gürdal Z. Approximate feasible regions for lamination parameters. Collect Tech Pap - 11th AIAA/ISSMO Multidiscip Anal Optim Conf 2006;2:814–22. https://doi.org/10.2514/6.2006-6973. [14] IJsselmuiden ST, Abdalla MM, Gürdal Z. Implementation of Strength-Based Failure Criteria in the Lamination Parameter Design Space. AIAA J 2008;46:1826–34. https://doi.org/10.2514/1.35565. [15] Irisarri FX, Lasseigne A, Leroy FH, Le Riche R. Optimal design of laminated composite structures with ply drops using stacking sequence tables. Compos Struct 2014;107:559–69. https://doi.org/10.1016/j.compstruct.2013.08.030. [16] Liu D, Toropov V V., Osvaldo MQ, David CB. Bi-level optimization of blended composite panels. Collect Tech Pap - AIAA/ASME/ASCE/AHS/ASC Struct Struct Dyn Mater Conf 2009. https://doi.org/10.2514/6.2009-2182.

Smart composites and structures

Effect of the external pressure on Li-ion pouch cell and development of multi-functional composite battery exterior at high C-rate conditions

abst. 1054
Room GALLA PLACIDIA
Thursday
September 5
14h50

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Rechargeable Li-ion batteries (LIBs) are the power source used widely in portable electronic devices and are becoming increasingly important in the automotive industry applications. To address the demand of large driving ranges of batteries in electric vehicles (EVs) and hybrid electric vehicles (HEV), batteries need to be high-energy, safe and cost effective. Nowadays, the development of Next-Generation High-Energy-Density system such as Li-S, Li metal or Si/C anode batteries are great interest in research for energy-demanding applications. However, limitations involve Li dendrites, the shuttle effect and detrimental silicon self-pulverization leading to batteries thermal runaway and make it difficult to commercialize [1,2]. Therefore, technologies of extending cycle life of LIBs and reducing component degradation are required. Also, battery management system is key factor to solve one of bottlenecks to extend cycle life of lithium ion pouch cells originates from the depletion uniformity by controlling temperature and applying the external pressure during the battery operation [3,4]. Presently, the recharging time for batteries in EVs is long compared to the refuel time for gasoline powered vehicles which preventing the widespread adoption of battery powered EVs into the transportation sector. Achieving fast charge has been considered as one of the most important directions for the progression of EVs in the market and it can possibly lead to increased customer acceptability by reducing charging time. However, fast charging of LIBs makes it susceptible to lithium plating and induce high temperature results in the decomposition of electrolyte during the operation. Thus, the understanding of capacity fade and long cycle life at a high C-rate is critical for the design of LIBs [5]. In this study, we developed a novel multifunctional composite battery exterior to enhance the battery performance and prevent the capacity fade by controlling the mechanical pressure. For structural composite battery exterior, the effect of the external pressure and high C-rate on lithium ion pouch cell was analyzed to optimize the pressure condition of LIBs. The charging speed was set to 1,5 and 10C-rates in the constant current/constant voltage (CC-CV) mode to test fast charging conditions. Finally, the composite exterior which shows high load carrying capacity and induces the internal pressure was fabricated based on the research results. The morphology of battery components, pressure distribution and internal resistance under fast charging condition were analyzed using the scanning electron microscopy analysis, pressure mapping system, and electrochemical impedance spectroscopy, respectively. Overall, it reveals the mechanical pressure induced by the multi-functional composite exterior brings significant improvement on the battery cycle life capacity fade even in high C-rate of process without component degradation. Reference: [1] Xiao, Y., et al., New lithium salt forms interphases suppressing both Li dendrite and polysulfide shuttling. Advanced Energy Materials, 2020. 10: p. 1903937. [2] Furquan M., et al., Efficient conversion of sand to nano-silicon and its energetic Si-C composite anode design for high volumetric capacity lithium-ion battery. Journal of Power Sources, 2018. 382: p. 56-68. [3] Mussa, A.S., et al., Effects of external pressure on the performance and ageing of single-layer lithium-ion pouch cells. Journal of Power sources, 2018. 385: p. 18-26. [4] Chen, F., et al., Air and PCM cooling for battery thermal management considering battery cycle life. Applied Thermal Engineering, 2020. 173: p. 115154. [5] Wassiliadis, N., et al., Review of fast charging strategies for lithium-ion battery systems and their applicability for battery electric vehivles. Journal of Energy Storage, 2021. 44: p. 103306

Hybrid actuator utilizing shape memory alloy and polymer composite in a two-way mechanism

abst. 1065
Room GALLA PLACIDIA
Thursday
September 5
15h10

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Over the past few years, shape memory materials have been studied and developed as next-generation smart materials due to their inherent shape-changing ability and simplicity. One of the significant downsides of conventional shape memory materials, such as shape memory polymers (SMPs), is that they only exhibit one-way shape recovery from deformed states to original states and they need to repeat the shape programming process for reusing. This can restrict expanding their applications because two-way motion is necessary in most cases such as robot arms and actuators with repetitive tasks. To address these challenges, many researchers have been trying to develop two-way shape memory materials using various mechanisms. Although most of these two-way shape memory materials showed good performance in terms of the shape recovery ratio, their mechanical properties often fall short for mechanical structures, which is undesirable because the recovery forces are essential, especially in the aerospace and robotics fields. Therefore, two-way hybrid actuator mechanisms employing shape memory alloys (SMAs) and SMPs emerged as promising candidates to fulfill this need due to their relatively high mechanical properties. However, the significant difference in modulus between SMA and SMP results in an inconsistent recovery ratio during the initial recovery (from original states to deformed states) and the second recovery (from deformed states to original states), with the recovery ratio during the latter being notably smaller. In this study, SMA/SMP hybrid two-way actuator was designed to improve its shape memory performances. The optimized recovery condition was achieved by modifying the stoichiometry ratio of the epoxy system to reduce the glass transition temperature (Tg) of the SMP below the martensite start temperature (Ms) of the SMA. The reduction of Tg resulted in a 13 times higher recovery ratio during the second recovery. Moreover, enhancing the mechanical properties of SMPs with carbon fibers (Shape memory polymer composites, SMPCs) raised the shape recovery ratio by 30% and increased the recovery speed by 144% compared to the actuator with pristine SMPs. Additionally, the use of joule heating with carbon fiber contributed to an accelerated heating and cooling speed of the SMA layer compared to conventional oven heating. Finally, the possibility of future applications using two-way hybrid actuators was proved as both grippers and deployable systems.

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abst. 1074
LLA PLACIDIA
Thursday
September 5
15h30

Buckling of Hinged Composite Booms for spacecraft deployable structures

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Deployable structures play a crucial role in enabling key functionalities in communications and remote sensing for spacecraft (such as antennae), power systems (such as solar panels), and science applications (such as reflectors for space telescopes). These structures are compactly folded into a smaller volume for launch and can expand in space to form extensive and rigid supports that allow large structures to be deployed. This study focuses on carbon-fibre reinforced composite deployable hinges due to their low density and excellent structural properties such as avoiding failure in the folding process. The hinges analysed are thin cylindrical booms with integral slots that fold via carpenter tapes on the upper and lower surface. They can be folded pre-launch and subsequently deployed in space forming long rigid booms with a high natural frequency. In this study, a novel and computationally efficient analytical model is derived and improved upon to predict the moment-rotation relationship of the hinge. The model analyses the bending behaviour of a cantilever hinged boom loaded at one end. The derivation of maximum buckling load is established using eccentric buckling principles and classical laminate theory. Firstly, the bending stiffness is calculated from the design variables and laminate properties. Then,

the internal stress distribution is determined from the applied loads and the deflection before buckling. Finally, the stress is integrated over the lower half and compared to the critical buckling load calculated from the boundary conditions and bending stiffness. After some iteration, the buckling load of the boom is determined, and the bending behaviour of the hinge can be predicted. When compared with experimental results, the predictions of the analytical model have a relative error of less than 5% which is similar to the error achieved by Finite Element Models. This model can be used to quickly design booms for unique mission requirements and investigate the dynamic properties of the structure to ensure reliable deployment.

A Smart Soft Gripper Embedded with Flexible Composite Sensor for Tomato Harvesting

abst. 1222
GALLA PLACID
Thursday
September 5
14h30

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In order to address the issue of agricultural labour shortage, the employment of harvesting robots provides an effective solution. A key concern lies in enhancing the success rate of tomato harvesting. This work proposes a biomimetic rigid-flexible coupled gripper for smart fruit harvesting robot, distinguished by the incorporation of a flexible composite hydrogel pressure sensor with wide detection range, high sensitivity, and excellent stability. Consequently, we develop a signal acquisition system based on the sensor array, which is capable of accurately capturing force signals during the tomato grasping process. Primarily, the sensor array captures the tactile sequence raw data generated during the mechanical gripper's tomato-grasping operation in real-time, integrating it with the compressive deformation data from the fruit itself to form a comprehensive dataset. Subsequently, a classification model is established for recognizing tomato ripeness, followed by training and testing procedures. The established Long Short-Term Memory (LSTM) deep learning network discerns the ripeness of tomatoes by assimilating the dataset. The overall recognition accuracy for tomatoes of varying ripeness levels of the same variety, under room temperature, is determined to be 100%. The results indicate that the incorporation of a flexible harvesting gripper, augmented with composite hydrogel sensors, ensures both the intactness of tomatoes during the grasping process and accurate detection of fruit ripeness. This advancement holds the potential to enhance the performance of tomato harvesting robots.

Topology optimization of hard-magnetic soft laminates for wide tunable SH wave band gaps

abst. 1347
GALLA PLACID
Thursday
September 5
15h50

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The periodic laminates made of hard-magnetic soft materials (HMSMs) have recently received increasing attention due to their tunable phononic band gap characteristics-ranges of frequencies at which sound and vibrations cannot propagate, which can be controlled remotely through magnetically induced finite deformations. In this work, we present a gradient-based topology optimization framework for obtaining the optimum distribution of laminate phases to optimize the anti-plane transverse wave (SH wave) band gap characteristics. In particular, by employing the method of moving asymptotes (MMA), we maximize the band gap width when the laminate is subjected to external magnetic fields, as well as the relative change in the band gap width with respect to the laminated composite in the absence of a magnetic field. The Gent material model of hyperelasticity, in conjunction with the ideal HMSMs model, is used to describe the constitutive response of the laminate phases. To extract the band structure of the hard-magnetic soft laminate, we employ an in-house finite element model. A parametric study is presented to highlight the effects of the applied external magnetic field on the optimized band gap characteristics and the design of the periodic laminated composite unit cell. The optimization framework presented in this study will be helpful in the design and development of futuristic tunable wave manipulators.

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abst. 1384
Room GALLA PLACIDIA
Thursday
September 5
16h10

Shape-Change Morphing of Tensegrity V-Expander Plate Metamaterials

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This paper explores the shape-change morphing of tensegrity V-expander plate metamaterials using nonlinear tensegrity statics. We begin by introducing the topology of V-expander plates constructed from V-expander elementary cells. The cable-actuation process is then described, where appropriate cables are selected as active and passive elements. During actuation, the lengths of active cables decrease, while passive cables adjust their lengths to accommodate the structure's movement. The study considers the types of shape changes, including stretching, shrinking, and shear. We analyze the nonlinear static and metamaterial behaviors throughout the morphing process, focusing on material properties, structural complexity (particularly the plate structure), shape morphing, and Poisson ratios. The developed approaches are applicable to the design and analysis of various tensegrity metamaterials. Through this study, we demonstrate the practical viability and versatility of V-expander plate metamaterials. Potential applications in fields such as aerospace, ocean, and civil metamaterials and structures are explored, highlighting the advantages of adaptive and reconfigurable structures. Our work paves the way for advanced shape-morphing materials, contributing to the evolution of intelligent structures in various engineering disciplines.

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abst. 1396
Repository

Analysis of Debonding in NSM Strengthening Systems Using Structural Battery Reinforcement

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The combined application of two baseline technologies—(i) strengthening of concrete structures using fiber-reinforced polymers (FRP) reinforcement and (ii) monolithic batteries embedded into FRP material—leads to a multifunctional retrofitting system for concrete structures, where the reinforcement is an FRP structural battery. The use of FRP materials as a strengthening method has gained widespread acceptance in recent years. Successful applications worldwide include the strengthening of bridges, masonry walls, subways, underpasses, floor slabs, and balconies. The high mechanical performance, improved durability, resistance to corrosion, and high strength-to-weight ratio of FRP make it an ideal candidate for strengthening new or long-standing structures that have suffered material degradation or are now functionally obsolete. One of the most common solutions for using FRP as a strengthening element is the near-surface mounted (NSM) technique. The NSM technique involves cutting a groove along the concrete surface, filling it with adhesive, and inserting the FRP reinforcement, ensuring that the FRP is fully coated by the adhesive, thus providing protection against vandalism and environmental effects. Although the NSM strengthening technique is extensively used, one limitation is the potential for failure due to debonding between the FRP reinforcement and the structural element. Existing design codes for FRP externally bonded reinforcement address this limitation, expressing it in terms of maximum strain or maximum bond strength. Single-shear tests not only aim to determine the ultimate load or bond strength but are also used to establish the bond-slip law. Parameters such as bonded length, mechanical properties of the materials, and surface configuration influence the failure mode and resistance to debonding. Moreover, the multifunctional reinforcement not only enhances the mechanical capacity and safety of the structure but also stores electric energy from renewable

sources. Unlike separate batteries, this integrated reinforcement is protected against environmental exposure and vandalism and does not occupy habitable space. In addition, it distributes electrical energy storage throughout the concrete structure, thus creating a distributed power network which enables the connection of electronic devices from multiple points of the structure and, at the same time, sets up the basis for the future development of sell-powered smart structures. However, combining FRP strengthening of concrete structures with monolithic batteries embedded into FRP material has not yet been applied in the construction sector. This work presents the design of an NSM multifunctional retrofitting system and assesses its application in concrete structures. The employed battery cell solution (Al/Na2.99Ba0.005OCl/Cu) stores three times more energy than comparable Li-ion cells, has a longer lifespan of 1200 charge cycles compared to 500 cycles for Li-ion batteries, and can harvest energy from heat and thermal sources due to spontaneous polarization of the ferroelectric electrolyte below 170°C, thus having the potential of converting waste heat into electricity. In this study, pull-out tests have been conducted on the NSM joint behavior, analyzing failure modes. Additionally, during the mentioned tests, the electrical response and behavior of the battery has been monitored. Gathered electrical data has been analyzed in order to investigate the influence of stress levels and the loss of adherence between the concrete and the multifunctional reinforcement system on the electrical performance of the inner battery. The results are compared against the behavior observed in the characterization campaign on separate FRP structural batteries.

Stability of nano, micro and macro composite structures

abst. 1144
Room DANTE
Tuesday
September 3
15h50

A finite element formulation for buckling analysis of composite laminated thin-walled beam-type structures considering shear deformation effects

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This paper introduces a shear-deformable finite element formulation for the buckling analysis of beam-type structures with composite laminated thin-walled cross-sections. Each wall of a thin-walled cross-section is assumed to be a symmetric angle- or cross-ply laminate. Applying the updated Lagrangian formulation and the nonlinear displacement field of a thin-walled cross-section, which accounts for the second-order displacement terms due to large rotations and restrained warping, the incremental equilibrium equations of a straight composite beam element are derived. Although the cross-sectional rotations are allowed to be large, strains are assumed to be small. It is also assumed that the cross-section is not deformable in its own plane, but is subjected to warping in the longitudinal direction; shear strains in the middle surface of a thin-walled cross-section due to the St. Venant torsion can be neglected, while shear strains due to the shear deformability are assumed to be constant through the wall thickness; each ply in the composite laminate is assumed to be thin plate made of homogeneous and orthotropic material; no delamination is allowed to occurs. Plane stress state conditions are valid in each ply and in each laminate branch, and the material of each ply obeys Hooke's law. Due to the nonlinear displacement field, the incremental geometric potential of semi-tangential moment is obtained for all of the internal moments, thereby preserving the moment equilibrium conditions at the frame joint to which beam elements of different space orientations are connected. To prevent the shear-locking occurrence, the Hermitian cubic interpolation functions are used for de-flections and twist rotation, and the associated quadratic ones for slopes and warping. The incremental-iteration algorithm scheme is based on the generalized displacement control method. The updating of nodal coordinates as well as orientations of the cross-sections and axes of each element is performed at the end of the each iteration. The updating of nodal orientations is based on the semitangential rotation transformation rule. The effectiveness of the proposed beam formulation is validated through the test problem, and obtained results confirm that it can be classified as a shear locking-free one. Also, the results validate the effectiveness of the presented approach in capturing the intricate behaviour of composite beam-type structures under geometrically nonlinear regimes.

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abst. 1169
Room DANTE
Tuesday
September 3
16h10

Exploring the relationship between buckling and delamination in composites with different ply thicknesses

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Composite laminates, ranging from thin-ply to thick-ply configurations, are gaining attention in the industry due to advancements in manufacturing technology. Variations in ply thickness inherently influence mechanical properties. The current state of research in literature explores the influences of

changing ply thickness, spanning from micro to macro levels, on structural behaviors. It is well noted in the literature that thin-ply laminate (thickness < 100 m) often exhibits superior performance in strength compared to thick-ply laminate (thickness > 100 m), with a notable difference in their damage initiation and accumulation processes. Despite the growing interest in this field, there is a critical need for in-depth exploration, particularly in understanding the interactions among material and structural failure modes. Notably, the combination of delamination and buckling poses a significant challenge in compression members, impacting both structural stability and mechanical performance. The interplay between these phenomena is crucial, as minor delamination defects can amplify the risk of premature local buckling or the growth of delamination size leading to structural failure. This study aims to understand the buckling behavior of delaminated composite specimens with varying ply thicknesses (thin-ply to thick-ply). The study has been performed in a nonlinear finite element framework where nonlinearities are integrated during the modeling phase. The results will provide more information about the measures to be taken while designing structures susceptible to buckling failure, considering various ply thicknesses where the risk of delamination growth is expected.

Stability Analysis of Multilayer Shells with Eigenstrain Mismatch using CUF Method

abst. 1268
DANTE
Tuesday
September 3
16h30

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Multilayer shells can exhibit a variety of intriguing configurations due to interlayer eigenstrain mismatch, which has garnered widespread attention and research interest. In the absence of external constraints, this deformation becomes unstable and bifurcates as the mismatch strengthens, resulting in several stable configurations. Current research on configuration stability primarily focuses on analytical models, often overlooking geometric nonlinearity and complex stress states within the shell (such as transverse shear stress). In this study, we employ the Carrera Unified Formulation (CUF) to predict accurate stress solutions for all layers in multilayer structures under different configurations. Furthermore, we consider geometric nonlinearity to investigate the critical bifurcation conditions and the post-bifurcation configuration evolution. We investigate configurational bifurcation in isotropic, anisotropic, and isotropic-anisotropic hybrid multilayer shells, referencing existing theoretical solutions and ABAQUS results to evaluate the accuracy of CUF predictions.

Sustainable and recyclable and recycled composite materials (chaired by C. Mingazzini)

abst. 1045
Room DANTE
Thursday
September 5
12h10

Unlocking Potential: Exploring the Use of Waste Mixed Plastics and Waste Fibres in High-Performance C-Sections

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Thin-walled steel and aluminium structures are widely utilised in the construction industry for their impressive strength-to-weight ratio and ease of assembly. Despite their numerous advantages, these structural components often carry high embodied carbon footprints, rendering them less desirable in modern construction practices. Thus, it becomes imperative to explore sustainable alternatives. This study investigates the performance of C-sections made from waste mixed plastics (wMP) sourced from packaging waste, reinforced with short, randomly oriented waste glass fibres (wGF) and recycled carbon fibres (rCF) under uniaxial compression. Three wGF/wMP C-sections and three hybrid (wGF/rCF/wMP) C-sections were subjected to uniaxial compression testing, and their results were compared against each other and with existing literature. The weight-specific load capacity of the hybrid C-sections was found to be approximately four times higher than that of the wGF/wMP C-sections and superior to similar C-sections documented in the literature, such as ultra-thin-walled steel and hybrid fibre-reinforced polymer-timber C-sections. As waste products, these composites offer a solution for reusing waste, benefitting from employing a thermoplastic matrix that enables recycling at the end of the product's life cycle, thus providing a genuine circular economy solution. Findings indicate that hybrid C-sections have great potential for structural use, especially in low-demand settings including playground structures, handrails, and non-load-bearing wall frames.

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abst. 1087
Room DANTE
Thursday
September 5
12h30

Specification Desideratum to Form and Use Industrial Waste-Based Composites to Practice, Sustainable Building Performances in the View of Analytical Hierarchy Process

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The requirement to develop feasible, economical, and efficient, methodologies and material allocation systems, built up with composite materials to ameliorate existing building performances has received profuse deliberation recently. According to the evidence provided by researchers, there is a hierarchy level to ensure the performance level of the building. Those can be identified as health, safety, and security performance; functional, efficiency, and workflow performance and psychological, social, cultural, and aesthetic performance. But those hierarchy levels must be secured and framed by the sustainable development goals. The selection of specific composite establishments for each of those performance levels will ensure well-specified outcomes from the building occupants. Alignment of each composite material should be carefully done according to a standardized method to ensure sustainable performance. There are many complex analyses in the world where people have to make serious decisions. In this regard, the decision-making procedures and the methodologies play an important role in identifying the best decision which will help for the better approach and analysis of the alternatives according to the system. Multi-criteria decision analysis is a well-known approach to decision-making criteria. This research study is mainly conducted to ensure the suitability of industrial waste material to build composite structures to enhance building performance by the concept of the analytical hierarchy process. When it considers the issue identification approach and cause identification, a questionnaire survey was conducted among the building practitioners and building use general public. Based on that a database was prepared to identify a weight factor for each person based on their major issue identification

concerning how each representative was aware of those composite material allocations for building performances. After the identification of the issues and the causes the concepts of the analytical hierarchy process is used to finalize the solutions for the sustainable allocations of each composite-based material to ensure the Building Performance. According to the research, it is specifically shown that the awareness of each performance task and composite material towards sustainable approaches, which are used in the building are not up to date to ensure the new establishments to be placed under each performance level. Therefore suitable specification establishment procedure is required to use the composite material selections for each performance level.

Influence of process parameters on quality of aluminum High Pressure Die Casting (HPDC) parts manufactured with a novel vertical chambered machine

abst. 1162
Room DANTE
Thursday
September 5
12h50

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Against the background of increasing demands on resource efficiency, the moulding manufacturing processes with their great design freedom and the associated load-adapted geometries plays a crucial role. In particular, the combination of aluminum alloys in die casting and thermoplastics in injection molding processes offers the advantage of a lightweight design [1] that also offers good recyclability [2]. A new type of combined process is used for optimized process control, in particular using a temperature control cascade for efficient waste heat utilization, which combines the die casting, stamping and injection moulding processes. In addition, the novel process of vertical die casting with two movable pistons is developed and prototyped, which promises both high efficiency and a low-porosity and therefore high-quality material structure [3]. The material structure and the associated mechanical properties of the structural components are determined by a number of influencing factors [4]. To estimate a process window for the newly developed process, a simulation model is set up using ESI's ProCast software. This study provides information on the key aspects of the simulation model and technical limitations. For example, the process control with two moving pistons or the holding pressure phase can only be modeled with the software to a limited extent according to the state of the art. Strategies are therefore presented and critically discussed in order to develop a workaround for these problems. Finally, based on several simulations with different influencing variables such as melt or mould temperature, a parameter study is carried out according to a fractional factorial design in order to identify the main influencing variables and quantify their sensitivities. Based on these findings, critical parameter combinations during production and their negative effects on the quality, for example the amount of air entrainment, are identified. Finally, the simulation results are compared with the casting images of manufactured parts of the vertical chambered HPDC machine. These insights enable understanding of the reasons for defects detected by optical and X-ray examinations. This makes it possible to significantly reduce development times and the experimental effort involved in running die casting processes and to produce high-quality components with resource-saving energy consumption. References: [1] Messer, Patrick, A. Bulinger, U. Vroomen, and A. Bührig-Polaczek. 'Multi-Component High Pressure Die Casting (M-HPDC): Temperature Influence on the Bond Strength of Metal-Plastic-Hybrids Manufactured by M-HPDC'. In Light Metals 2019, edited by Corleen Chesonis, 423–28. The Minerals, Metals Materials Series. Cham: Springer International Publishing, 2019. https://doi.org/10.1007/978-3-030-05864-7_54. [2] D'Errico, Fabrizio, G. Perricone, and M. Alemani. 'A Novel Flexible SSM and HPDC Equipment to Process Secondary Aluminium Alloys for Decarbonising Lightweight Parts in Automotive Sector'. In Light Metals 2019, edited by Corleen Chesonis, 1475–83. The Minerals, Metals Materials

Series. Cham: Springer International Publishing, 2019. https://doi.org/10.1007/978-3-030-05864-7_185. [3] Druckguss Service Deutschland GmbH. 'Presentation DuoCast Series by DSD'. Accessed 26 March 2024. https://www.dgs-hl.de/duo-cast-serie.html. [4] Dos Santos, Silvano Leal, R. Altobelli Antunes, and S. Ferreira Santos. 'Influence of Injection Temperature and Pressure on the Microstructure, Mechanical and Corrosion Properties of a AlSiCu Alloy Processed by HPDC'. Materials Design 88 (December 2015): 1071–81. https://doi.org/10.1016/j.matdes.2015.09.095.

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abst. 1179
Room DANTE
Thursday
September 5
16h50

FILLING EPOXY WITH SEAWASTE: MECHANICAL AND MORPHOLOGICAL CHARACTERIZATION OF A NOVEL FAMILY OF SUSTAINABLE COMPOSITES

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One of the possible strategies of circular economy is based on the introduction of waste as secondary raw material in polymers, in replacement of commonly used fillers. In particular, in this work sea waste from the Adriatic Sea, of ceramic and cellulosic nature, has been proposed for filler and prospective reinforcement of thermosetting polymers in view of their possible use in a hybrid configuration and of the future use of biobased matrices. More specifically, different categories of samples were produced. Epoxy and bio-epoxy matrices were filled with 5 and 10% of different types of shell powder (clams, mussels, and oysters) with a maximum granulometry of 80 µm, or with 15% of seagrass (Posidonia oceanica) fibers cut to a length of 5 mm. The difficulty to introduce the former was in the irregularity of the profile of the particular fillers, whilst for the latter the large variability of the aspect ratio (length/diameter) reduced the interfacial strength of the composite. Both situations affected the matrix-filler interaction, resulted in a possible pull-out and discouraged the introduction of large amounts of particles/fibers so far. After performing three-point flexural testing and Shore hardness measurements, some beneficial effects and the achievement of a sounder interface has been observed especially in the introduction of clam fillers, as confirmed by microscopical investigations.

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abst. 1313
DANTE
Thursday
September 5
13h10

Investigation of Physical-Mechanical Characteristics of Granulated Artificial Aggregates Synthesized from Wood Ash Using Green Technology

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Different ecological binders have been used to minimize the negative effects of cement production and use on the environment. Wood ash is one of these alternative binders, and there has been increasing research related to this topic recently [1]. The incineration process in power plants produces numerous amounts of residues, the potential applications of which remain incompletely understood. However, it is established that wood ash improves concrete properties, serves as a fertilizer, and substitutes natural aggregates in artificial aggregate production [2]. This study presents the production and properties of wood ash artificial aggregate, their integration into concrete, and the assessment of their strength. Due to the aforementioned large amount of incineration waste accumulating in landfills, the recovery of this waste is important, and reuse and recycling of this waste is necessary. Artificial aggregates stand out as a significant innovation in this effort. In this study, the artificial aggregate was carbonized using wood waste incineration ash and alkali activators, with the alkaline activator consisting of $Ca(OH)2$. Various mixtures were formulated, incorporating different materials and compositions of activators. Initially, fillers were created using wood ash, followed by formulations subsequently supplemented with wood ash. A series of tests, including XRD, SEM, and compression tests, were conducted. The artificial aggregate exhibits minimal water absorption and holds potential as a substitute for natural

materials. Its prospective applications extend to agriculture, where it could function as a fertilizer, and construction, where it could serve as an artificial aggregate. Concrete incorporating the artificial aggregate demonstrates stability, stiffness, and relatively low density. In our research, a test was developed and applied to determine the compressive strength of a manufactured artificial aggregate, not by direct loading, but by subjecting a cementitious test specimen containing the aggregate under test to a load. In this way, the test not only determines the effect of the aggregate on the compressive behavior of such a specimen but also the characteristics of the fracture, which shows how these artificial aggregates adhere to the cement matrix. This testing methodology holds promise for evaluating the suitability of artificial aggregates in construction materials, not only in terms of their load-bearing capacity but also of their adhesion to the mineral binder. The results showed that the mechanical properties of granular artificial aggregates vary significantly with the amount of binder (lime), i.e. an increase of 15% in the amount of binder resulted in an increase in the crushing strength of the carbonized aggregate by 15-20%, while the compressive strength of the cementitious specimen with this aggregate increased by 18%.

Innovative Approaches to Recycling Fiber-Reinforced Polymer (FRP) Composites: A Comprehensive Review

abst. 1314
Room DANTE
Thursday
September 5
14h30

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Fiber-reinforced polymer (FRP) composites have become indispensable across critical sectors like aerospace, marine, construction, automotive, and sports due to their exceptional properties. However, managing their end-of-life (EOL) phase presents significant challenges with far-reaching environmental implications. According to recent projections by Daphne and Leon (2024), the aircraft and wind turbine industries are anticipated to collectively generate an annual CFRP waste total of 840,300 tonnes by 2050. In Europe, the total composite waste is projected to reach an astounding 683,000 tonnes per year by that time, while global recycling capacity lags at less than 100,000 tonnes. Consequently, FRP producers and suppliers may face the risk of losing market share to metal and other industries shortly. Here the authors conduct a comprehensive review of current FRP waste management practices and evaluate various recycling methodologies. Through an analysis of contemporary practices and technical limitations, this study identifies and assesses emerging approaches such as pyrolysis, mechanical shredding, and chemical dissolution techniques. Additionally, novel methodologies including solvolysis and supercritical fluid extraction are explored for their potential to enhance fiber recovery rates and facilitate resin reclamation. The primary objective is to contribute towards existing limitations and promote a paradigm shift to the evolution of sustainable waste management practices and environmental conservation efforts within the composite materials sector. By fostering transformative interdisciplinary discussions and offering actionable insights, this study aims to pave the way for a paradigm shift towards greener and more robust FRP composite recycling methodologies, thereby advocating ways to implement circular economy principles and fostering resource efficiency throughout the composite materials lifecycle. Ultimately, this research seeks to explore second-life options, optimizing the value and durability of these materials through various techniques such as repurposing and refurbishing, leading to a more sustainable approach to composite waste management.

Mechanical properties of inorganic polymer-based fiber-reinforced composites under fatigue loading

abst. 1351
Room DANTE
Thursday
September 5
14h50

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The demand for secure materials in the electric vehicle (EV) industry, especially for constructing battery enclo-sures, has grown significantly in recent years. This increase is primarily due to heightened safety concerns regard-ing potential fire hazards. Additionally, the effort to reduce reliance on critical raw materials for EV components has led to extensive research focused on developing more sustainable, fire-resistant structural materials in line with circular economy principles. To meet the mechanical performance requirements for battery enclosures—both before and after simulated fire incidents—while using environmentally friendly materials and technologies (including waste raw materials), the "FENICE - Fire rEsistant eNvironmental frIendly CompositEs" project has developed innovative composite materials. These new materials utilize continuous or randomly chopped carbon fiber combined with water-based inor-ganic polymeric matrices. These matrices are derived from aqueous blends of aluminosilicate clay powders and amorphous silica, which are chemically activated at room temperature using alkaline solutions of potassium sil-icates and hydroxides, in a process known as geopolymerization. The inclusion of refractory micropowders of oxidic ceramics enhances the material's functionality and thermal stability. The resulting slurry possesses rheo-logical properties that align well with vacuum impregnation and lamination processes used in traditional compo-site (PMC, Polymeric Matrix Composites) production. Furthermore, by implementing a simple post-curing pro-cess at 180-220°C, the material achieves outstanding resistance at high temperatures (>650°C) and becomes fully fire-resistant. Nevertheless, while being attractive due to their ease of synthesis, low processing temperatures, and resistance to heat and oxidation, these inorganic based composites might suffer from a non-negligible loss of mechanical properties under cyclic loading, constituting a possible limit for their use in applications where continuous stress-es are expected during standard operating conditions. To this aim, fatigue behaviour of carbon fiber reinforced composites, based on an inorganic polymer matrix, are being assessed, thus identifying the most realistic work-ing conditions to maintain adequate safety levels for these materials. Both flexural and tensile cyclic loading will be considered, being tensile tests the standard way to operate, but flexural tests those which are being used to measure the effect of other ageing conditions on the samples (such use thermal fatigue or exposure to aggressive or corrosive chemical environments, such as salty spray, or even fire exposure). Acknowledgements: EIT RawMaterials GmbH is acknowledged for supporting and funding this research within the project KAVA9 FENICE- Fire rEsistant eNviron-mental frIendly CompositEs (Project Agree-ment n.o. 21099.

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abst. 1361
Room DANTE
Thursday
September 5
15h10

Corrosion behaviour of ferronickel slag mixed mortar exposed to chloride-bearing environment

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Ferronickel slag (FNS) is a supplementary cementitious material (SCM), produced from the electric arc furnace in the manufacturing ferronickel alloy by water quenching or air chilling. However, due to uncertain chemical properties of FNS in the hydration process of the cement matrix, it has been mostly dumped or used as a filler in in-situ construction. It has been studied to apply to concrete materials such as fine aggregate. FNS became further increasing in terms of concrete properties including enhancement of the compressive strength and reduction of the risk of alkali-silica reaction, supposing that FNS aggregate almost nullifies the pozzolanic reaction such as interaction with water molecules or/and cement-hydrated material. This study covers the resistance of steel corrosion in mortar with FNS exposed to chloride and carbonation conditions. To consider the resistance property of FNS hydration material against corrosion arising from chloride and carbonation, the acid neutralization capability of paste with FNS was quantitatively determined at a given acid concentration, which could provide a prediction of the corrosion resistance. The resistance to corrosion driven by chloride penetration was measured by the current density, potential and mass loss, whilst the degree of carbonation was obtained by the pH profile against the depth of the FNS-mixed mortar, on which assessed the possibility of depassvation of the steel surface. In this study, the assessment of the resistance capacity of FNS-mixed mortar was conducted by experimental methods with respect to chloride- and carbonation-induced corrosive conditions. To evaluate the corrosion degree arising from the chloride, the corrosion current density and potential were measured for 400 days, then subsequently, the mass loss of the steel rebar driven by rust formation was determined. The corrosion resistance level of FNS 10 and 30 was lower or at least like to ordinary portland cement (OPC), whilst FNS 50 was indicated excessive corrosion. The buffering capacity of hydration materials in FNS-mixed paste for a pH fall may lead to a higher resistance of FNS 10 and 30, which could hold on the passivity due to being acidify on the steel surface. Additionally, FNS 10 and 30 were more sustained positive compared to OPC, which was probably due to the interruption of access of water molecules and gaseous oxygen to the depth of the steel arising from the lower property of the cathodic reaction. This effect would result in the reducing mass loss of steel rebar. In fact, the FNS could be enhanced in resistance to corrosion arising from chloride in steel rebar, due to a greater suspension capacity against pH fall and maintaining the further corrosion potential. However, the mortar mixed with FNS was vulnerable to carbonation, as evidenced by the pH profile, which consistently recorded lower values at all depths compared to OPC. Particularly, FNS 50 ranged below a pH of 10.0 throughout the entire depth, indicating exposure to conditions highly vulnerable to carbonation. The FNS mixture results in the formation of hydrotalcite, which presumably leads to an inevitable risk of carbonation.

Sustainable FML (Fibre Metal Laminates) composite battery boxes for automotive electrification: improving thermal and fire management and corrosion resistance

abst. 1390
Room DANTE
Thursday
September 5
16h30

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The electrification of the automotive sector is a global priority to reduce greenhouse gas emissions and mitigate climate change. However, the transition to electric vehicles (EVs) poses significant challenges in developing lightweight, safe and sustainable batteries. The weight of battery boxes is a critical factor for the range of electric cars, while safety and sustainability are prerequisites for their large-scale deployment. The FENICE project (www.fenice-composites.eu) aims to address these challenges by developing innovative battery boxes based on fibre metal laminates (FMLs). FMLs are composite materials consisting of alternating metal and fibre layers, which offer an excellent combination of lightweight, mechanical strength and stiffness. This contribution aims to present the results of in-depth research into the thermophysical characterisation and salt spray corrosion resistance of three different FML systems, to assess their suitability for applications in electric vehicles. The three systems share a common basic structure, consisting of: Aluminium: used as a metal layer, with a thickness ranging between 0.1 and 0.5 mm Multiaxial basalt fibre fabric: which will be compared with weaved fabrics Resin: the key variable among the three systems, supplied by different manufacturers (hybrid resins from Crossfire, Helium from Arkema; PFA from Transfurans Chemicals), with different chemical and physical properties. Thermophysical characterisation has made it possible to assess the thermal conductivity of materials up to 200 °C, a critical temperature for the operation of EV batteries. Effective thermal management is essential to ensure optimal performance, prevent overheating and extend battery life. Since in electric cars thermal dissipation is obtained using a hydraulic system, to optimise thermal and fire management, sandwich structures perform better than monolithic ones, since thermal insulation in fire accidents ensures the skin not directly exposed to high temperature keeps its mechanical properties longer, and, in harsh weather, thermal insulation protecting from external temperature below -20 °C preserves battery operation. Sandwich structures are also those which are better performing in terms of specific strength. Corrosion resistance of aluminium layers has been assessed through accelerated ageing salt spray testing, which simulates long-term exposure to corrosive environments. Since EV batteries often operate in harsh environmental conditions, the corrosion resistance of battery box materials is crucial to ensure the safety and longevity of the system. By applying sol-gel treatments on aluminium

both the advantages of some electrical insulation and resistance to both neutral and acidic salty environments are ensured. A further aspect investigated in this study is the effect of aluminium thickness on the most promising FML solution. Reducing the aluminium thickness to 0.1 mm could lead to a further lightening of the battery box, but it is crucial to assess the impact of this change on the mechanical strength and durability of the material. The results presented in this contribution provide valuable data for the design of lighter, safer and more sustainable EV battery boxes. Thermophysical characterisation and corrosion resistance assessment, complemented with further ongoing mechanical analyses, will enable accurate modelling of material behaviour under realistic operating conditions. Through this research, the FENICE project will contribute significantly to the development of better-performing EV battery boxes and the advancement of sustainable electric mobility, addressing the key challenges of automotive electrification. Acknowledgements: EIT RawMaterials GmbH is acknowledged for supporting and funding this research within the project KAVA9 FENICE- Fire rEsistant eNvironmental frIendly CompositEs (Project Agreement n.o. 21099, 2022-2025).

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abst. 1393
DANTE
Thursday
September 5
15h30

FML composites for fire resistant battery boxes: comparison of sandwich and monolithic structures in terms of mechanical performances

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Mass production of battery boxes is urgently required for electrification in the automotive, in line with 2050 EU carbon neutrality target. Weight reduction makes fibre reinforced composite materials the best solution however production costs and sustainability have to be optimised a lot compared to state of the art. In addition, safety considerations (resilience to both internal or external fire accidents) suggest the composite structures have to include aluminium layers. FENICE project (www.fenice-composites.eu) is developing different types of FMLs, in terms of chemical composition, whose sustainability is based on the use of recyclable and low C footprint mineral fibers, secondary aluminium foils, and a polymer matrix based on either (1) biobased or (2) closed loop recyclable resins. In terms of mineral fibres, FENICE project is considering glass or basalt, and evaluating the C-footprint in both cases, interacting with EU basalt manufactures. Regarding biobased resins, PFA (polyfurfuryl alcohol) is considered, processed as a semifinished material in the form of prepregs or SMC. Regarding closed loop recyclable resins, FENICE is considering Elium from Arkema (France) and Crosspreg, from Crossfire (Italy), being the second one, a project partner. The presentation will discuss mechanical performances of possible sandwich and monolithic structures, both after production and after reasonable ageing protocols (simulating long term operation). To complete the characterisation, fire tests (performed, in the project, by Gaiker, Spain), corrosion resistance and thermophysical properties (performed by Certimac, Italy) will be presented in other talks in the same session. Considering FENICE project aims at mass production of these components for the mid-end automotive, the different systems are also compared in terms of: (1) fast processing into complex shapes by warm pressing; (2) industrial production flowchart and corresponding CAPEX and OPEX estimations. Some of the solutions will not be appropriate for the mid-end automotive (because of slow or expensive processing) but could be interesting for other applications, such as marine (yacht and superyacht fire resistant structures) or sports cars (which require battery boxes with higher performances, but can afford to pay them accordingly). Acknowledgements: EIT RawMaterials GmbH is acknowledged for supporting and funding this research within the project KAVA9 FENICE- Fire rEsistant eNvironmental frIendly CompositEs (Project Agreement n.o. 21099, 2022-2025).

HEMP-BASED NATURAL FIBER COMPOSITES FOR CARBON DIOXIDE STORAGE

abst. 1398
Room DANTE
Thursday
September 5
15h50

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The present work investigates the development of innovative green materials, technologies and systems for the absorption and storage of CO2 emissions from industrial applications. Natural Fiber Composite (NFC) materials, based on natural materials like hemp have good mechanical properties for automotive field, green buildings and several others industrial applications. Various scientific studies have shown that hemp (Cannabis Sativa) is an excellent solution for the absorption of atmospheric CO2. The rapid growth of the plant (it can reach 5 meters in 120 days) makes it a rapid tool for converting CO2 to biomass, fixing it permanently inside the fiber and hemp which will subsequently be used to obtain highly sustainable and renewable products such as industrial fabrics, bio-based epoxy resins, construction material for green building, bioplastics, cosmetics and more. Cement is a low-cost product, but its production is responsible for 8% of CO2 emissions. We aim to create high-performance NFC materials for real-world applications with storage of carbon dioxide. We will emphasize the use of hemp-based polymers for the matrix and the utilization of hemp fibers. Our project aims to design and develop eco-friendly composites, with a focus on fiber-reinforced polymers (FRP) and hemp-based resins. These composites will undergo real-world testing to optimize their environmental impact across their lifecycle, from production to disposal. We aim to create high-performance NFC materials for real-world applications with a reduced carbon footprint and sequester and storage of carbon dioxide. In total, one hectare, with a yield of 10 tons, cultivated with industrial hemp can sequester 19.38 tons of CO2, of which 16 will be fixed inside the materials obtained from fibers and hemp, preventing their return to the atmosphere, while the remaining 3 tons left in the field will contribute to the enrichment of the soil with organic substances. Acknowledgements: MARIPOSA Regione Toscana Bandi RSI - POR FESR 2014-2020. Codice Domanda: CUPST:3389.30072014.068000248. PRIN 2022, Project 2022YLNJRY (CUP: J53D23002500006) funded by the European Union – Next Generation EU.

Self-compacting concrete with recycled coarse aggregate from demolition of Large Panel System – modified Equivalent Mortar Volume method in mix design

abst. 1403
Room DANTE
Thursday
September 5
16h10

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Large Pabel System buildings built between 1945 and 1990 are big part of house stock in Central and Eastern Europe. In this study, concrete panels of demolished Large Panel System building built in 1960 are proposed to be recycled into Recycled Coarse Aggregate to be applied in Self-Compacting Concrete. Self-Compacting Concrete is characterized by good fluidity (the balance between the plastic viscosity and the flow limit), stability (a lack of the sorting of the components) and the ability to flow around reinforcement. Composition of raw materials, incorporation of chemical and mineral admixtures, aggregate, packing density, water to binder ratio (W/B) and design methods can influence properties of fresh mix and hardened concrete. Having high residual mortar content, for optimal design of Self Compacting Concrete, modified Equivalent Mortar Volume method of mix design was used. Detailed literature review shows that this method in theory has potential to strengthen properties of concrete compared to Conventional Mix Design and eliminate drawbacks of ordinary Equivalent Mortar Volume. However, this method was not verified for Self-Compacting Concrete. Thus, this study analyses chosen

fresh and hardened mix properties of Self-Compacting Concrete with Recycled Coarse Aggregate to confirm that designing the mix according to modified Equivalent Mortar Volume has the potential to enhance properties of Self-Compacting Concrete.

Thermal problems on composite structures

Thermal Buckling Analysis of Composite Laminated Profiles

abst. 1121
TEODORICO
Friday
September 6
09h00

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This paper investigates the temperature effect on the buckling behaviour of thin-walled composite tube fabricated from carbon-epoxy composite materials, subjected to axial compression. The experimental tests were performed on a servo-hydraulic testing machine at temperatures ranging from -20°C to 80°C, in 20°C increments. The primary objective was to assess how temperature fluctuations impact the buckling load and load-bearing capacity of these composite profiles under axial compression. The experimental setup allowed for precise measurement of load-displacement and load-deflection characteristics, and the critical load at which buckling initiation occurred. Observations revealed that the buckling resistance of the profiles exhibited a complex dependence on temperature. At lower temperatures, the composite material demonstrated enhanced stiffness and strength, marginally increasing buckling resistance. Conversely, at elevated temperatures, a noticeable degradation in mechanical properties was observed, leading to a reduced buckling load and altered failure modes. To complement the experimental findings, a comprehensive finite element (FE) analysis was conducted for sample in room temperature. The FE model, developed to replicate the experimental conditions closely, employed an eigenvalue-based approach to predict the buckling initiation and progression accurately. The presented results are the results of preliminary tests and they will be expand about more samples. This research was funded in whole by the National Science Centre Poland under the project UMO-2022/47B/ST8/00600.

Influence of mullite and halloysite reinforcement on the ablation properties of epoxy composite

abst. 1178
Room TEODOR
Friday
September 6
09h20

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Ensuring thermal insulation in the aerospace industry (thermo-protective shields) of sensitive components such as flight data recorders, aerodynamic surfaces, missile loads, nuclear warheads, probes, and space shuttles against overheating occurring during a flight in the earth's atmosphere at a hypersonic speed is a key issue of safety and efficiency of executed tasks. During high-speed (hypersonic) flights, there is a significant increase in the temperature of heated elements. The temperature growth may be dispersed through the use of ablative materials in places that are capable of creating a kind of thermal barrier to a heat flow due to their properties. Even since Man managed to achieve high speeds for his constructions, research has been conducted into various types of ablative materials and additives that heighten material ablative properties. The paper attempts to handle the impact of the application of a powder additive in the form of halloysite and mullite upon the change in thermo-protective properties of a powder composite. The authors used epoxy resin CES R70 with CES H72 hardener, modified with a changing amount of the powder additive. The composite measuring approximately 38 mm in diameter and approximately 10mm in thickness was subjected to an impact of a mixture of combustible gases at a temperature of approximately 1,000°C. The most important parameter analyzed in the course of the investigations was the temperature on the rear surface of the sample and the ablative loss mass of the tested material. The examinations of a temperature rise on the rear surface of the sample, exposed to a hot stream of flammable gases, were carried out for 120 seconds. During the examination, temperature was the main measured parameter. The measurement was made by: • a pyrometer - measuring the temperature of an ablative surface; • a thermal imaging camera - measurement of the temperature of the rear surface of the composite; • thermocouples - spot measurement of the rear surface. Another parameter involved in the analysis and interpretation of data is ablation mass loss. In this process, an essential role is played by the charred sample layer, as it is responsible for blocking oxygen diffusion from the boundary layer of the original material. This layer absorbs the thermal energy until it has reached the temperature when it undergoes oxidizing or is mechanically removed due to an erosion impact of the heating factor. The conducted experimental research on the ablative properties of a polymer composite with an addition of halloysite as well as mullite led to the formulation of the following conclusions: • Using the additive affects the thermal properties of a polymer composite, which is confirmed both by the temperature measurement with the thermal imaging camera and the collective graph for each series. The largest difference was characterized by a series with the highest amount of the additive. On average, it equaled approximately 8°C for the halloysite and 12°C for the mullite; • The use of the additive reduced the ablation loss of mass from 57% to 39.9% for the sample with the powder addition of halloysite and 57% to 18.8 % for the sample with the amount of the powder addition of mullite;

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abst. 1206
m TEODORICO
Friday
September 6
09h40

Thermal-stress analysis of a composite hydrogen storage system for aerospace applications

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In the last decades, several studies were conducted to investigate the application of new composite materials in the design process of hydrogen storage systems for aerospace applications [1]. High-pressure hydrogen storage is the most conventional type of hydrogen tank, the trade-off with utilizing high pressure storage is the increase in structure wall thickness and, as a consequence, in tank mass necessary to withstand the higher pressures. In order to reduce the tank mass, a possible solution can be cryogenic storage of hydrogen at low pressure [2]. It is possible to increase the hydrogen density keeping it at the liquid phase around 260○C. In this work the thermal-stress analysis of cryogenic hydrogen composite tanks has been conducted at different temperature scenarios. The insulation properties and the multi-layered stacking sequence design have been investigated [3]. Composite materials with variable stiffness distribution have been taken into account. Possible design solutions are given depending on the mission requirements and the structural boundaries. Some results are presented for different insulation solutions and various stacking sequence. Acknowledgments The research leading to these results has received funding from the Innovate UK ATI program under grant agreement no. 10003070 (AETHER, Advanced Solutions for Hydrogen Zero Emission Fuel). REFERENCES [1] R.M. Sullivan et al., Engineering Analysis Studies for Preliminary Design of Lightweight Cryogenic Hydrogen Tanks in UAV Applications. NASA/TP-2006-214094, 2006. [2] A.J. Colozza, Hydrogen Storage for Aircraft Applications Overview. NASA/CR-2002-211867, 2002. [3] J.E. Fesmire et al., Spray-on foam insulations for launch vehicle cryogenic tanks, Cryogenics, Vol. 52, pp. 251-261, 2012

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abst. 1276
m TEODORICO
Friday
September 6
10h00

High-temperature operation of alkali-activated slag porous composite material

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As the global population grows drastically, the use of sustainable materials to ensure technological and environmental development in the building sector is increasingly being questioned. Alkali-activated binders could be one of the eco-friendly construction materials. Alkali-activated slag porous composite materials were made from ground metallurgical slag with a phosphogypsum additive and was activated using an alkali activation process. These by-products were generated at the fertilizer plant (Lithuania) and in the metallurgical industry (Finland). Their initial composition, physical properties, interactions during hydration and behavior at high temperatures were investigated. The aim was to develop a porous, high-temperature resistant composite material that could be used in the construction sector as a sustainable insulation material. The initial materials of this porous composite were industrial by-products based on aluminosilicate and calcium compounds. The results are described based on 5 different material compositions: compressive strength after 3 and 28 days of curing, air pore distribution in the cross-section, thermal conductivity properties, density and compressive strength after exposure to temperatures of 200, 400, 600 and 800 °C. Degradation mechanism of composites was explained according to the variation of the mineral composition of the samples. Based on the results obtained, a phosphogypsum content of 3 % to 5 % in the alkali-activated material is recommended for an optimum distribution of mechanical, thermal conductivity and high-temperature resistance properties. Slag and phosphogypsum, activated by alkali, can be used for the production of partition blocks and for the protection of structures against high temperatures.

Experimental study of the thermal properties of EPDM used as thermal insulator in solid rocket motor

abst. 1368
Room TEODOR
Friday
September 6
10h20

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The interior of the solid rocket motor (SRM) is exposed to severe environment of high temperature (3000 °C) and high pressure (5-20 MPa) gas with molten particles. In order to protect the SRM shell from being destroyed by the extreme large heat flux during operation, it is essential to install a thermal insulation material with superior thermal insulation performance on the inner surface of the SRM shell. Ethylene Propylene Diene Monomer (EPDM) is a polymer composite material composed of ethylene, propylene and diene monomers. Since it has low density, low ablation rate, positive aging resistance, excellent thermal protection performance and corrosion resistance, it is widely used as the thermal insulator in the combustion chamber liners of SRM. Upon exposure to heat, EPDM efficiently absorbs heat, leading to an increase in its temperature. When the temperature reaches 200 ℃, EPDM will begin to pyrolyze. The internal components of the material undergo thermal chemical reactions and take away some heat. As the temperature rises to around 400 ℃, the macromolecules within the material begin to pyrolyze violently, generating a significant amount of gas. This process results in EPDM ablation and carbonization dehydration, removing a large amount of heat. The porosity of EPDM after ablation increases, and the thermal properties (such as thermal conductivity, specific heat capacity, emissivity) change, improving the thermal insulation performance of EPDM. This reduces the amount of heat entering the SRM shell and maintains the shell within tolerable limits. At present, there are still some shortcomings in the research of physical properties of EPDM. Many scholars have primarily focused on the mechanical properties of EPDM and its modification by incorporating additives. Few studies investigated the thermal properties of EPDM, but most of them only conducted the experiment at room temperature before ablation happens. The thermal properties of EPDM are related to the design of the internal thermal environment of SRM, so this study conducted the experimental investigation of the performance of EPDM before and after ablation. The study accurately measured the thermal conductivity, specific heat capacity, emissivity, and thermogravimetry of EPDM before and after ablation. These precise measurements are crucial for enhancing the design of SRM thermal protection systems. The findings contribute significantly to a better understanding of the thermal properties of EPDM and its role in protecting SRM from extreme large heat flux conditions.

The material selected for this study is EPDM, which derived from the internal insulation layer of a certain SRM. The thermogravimetric curve and specific heat capacity of EPDM are measured using the STA PT 1600 simultaneous thermal analyzer (LINSEIS, Germany) based on thermogravimetry (TG) method and differential scanning calorimetry (DSC) method. EPDM is placed in an alumina crucible, and the nitrogen atmosphere is maintained during the test process. The heating rate is set at 5 °C/min, with a maximum temperature limit is 600 °C. The test heat flux of EPDM is analyzed by a three-step method and its specific heat capacity is calculated. Notably, the ablation temperature of this EPDM is 440 °C, and it is completely ablated and pyrolyzed at 490 °C. It is experimentally demonstrated that temperature can significantly affect the specific heat capacity of EPDM, especially before and after ablation. In the thermal conductivity test of EPDM, a "sandwich structure" measurement system is developed with the 1D steady-state method. The surrounding of the material is wrapped with insulation foam with thermal conductivity of 0.027 W·m-1·K-1 to reduce the heat loss and suppress the influence of the external environment. During the test, the electric heating film is positioned between two identical slices of EPDM, and the stabilized power supply is used to provide consistent heating power. The other surface of the EPDM is cooled at a constant temperature with a cooling water circulator. The temperature gradient of the material is detected by K-type thermocouple, and the "uniform temperature layer method" is used to determine the thermal conductivity as a function of temperature. In addition, the thermal conductivity of EPDM is also obtained using the TPS2500S thermal constant analyzer (Hot Disk, Sweden) based on transient plane source (TPS) method, and the tubular high-temperature furnace provided the ambient temperature for this experiment. The ablation temperature of EPDM is known from the thermogravimetric analysis above. Therefore, the thermal conductivity of EPDM can be measured from -50 °C to 500 °C in this study. The 1D steady-state method uses unilateral heating, and the EPDM partially undergoes ablative carbonization during the heating process, while the TPS method is carried out in a tubular high-temperature furnace, and the EPDM completely undergoes ablative carbonization. The thermal conductivity of EPDM before and after ablation is measured by both methods, and the results of the thermal conductivity under partial ablation and complete ablation are analyzed. In the emissivity measurements of EPDM, hemispherical reflectivity spectra of EPDM at room temperature is acquired with a Fourier-transform infrared spectrometer INVENIO R (Bruker, Germany) equipped with a gold-coated integrating sphere. This spectrometer covers the wavelength range of 1.25-25 m. The total reflectivity could be obtained from the spectral reflectivity by the integral method, and the emissivity can be obtained according to Kirchhoff's law. To measure the emissivity at elevated temperatures, the material is placed on a high-temperature furnace. Using the energy method, the emissivity of the material at specific temperature is obtained by comparing the radiation intensity between a blackbody and the material. The measurement temperature range is 200-500 °C. Through these two tests, the change in emissivity of EPDM before and after ablation can be assessed. Furthermore, the composition of EPDM before and after ablation is tested using the X-ray fluorescence spectrometer, and the microstructure of EPDM before and after ablation is observed using scanning electron microscopy. Finally, the measurement uncertainty is also discussed.

Use of innovative composites materials for the strengthening of historical and archaeological sites (chaired by S. Belliazzi, F. Fabbrocino, G. Ramaglia)

An innovative approach to retrofit heritage masonry buildings

abst. 1391
TEODORICO
Friday
September 6
10h40

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The strengthening strategies on existing structures have achieved high efficiency and development in the last few years. When the strengthening techniques are performed on ordinary buildings, the existing modern building codes and the retrofit techniques provide great performances in terms of increasing of the structural capacity and high efficiency with the existing materials. However, both the techniques and the available capacity models present some drawbacks when the object become masonry structures typical of historic centers and archaeological sites. Especially the modern capacity models show major limitations making these strengthening systems not applicable to existing heritage buildings. In fact, the strengthening strategies for heritage structures requires specific models able to optimize the effect of the strengthening system. In this work, a new calculation model for composite reinforcements in FRCM applied to masonry structures is analyzed. It is analyzed how the contribution of the matrix becomes non-negligible especially if the intervention is extended to the entire building. This type of approach allows us to optimize intervention strategies on valuable structures such as listed buildings and archaeological sites in compliance with the requirements of minimum invasiveness, reversibility and historical identity.

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