Full List of Abstracts

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Title: MULTIFUNCTIONAL REDUCED GRAPHENE OXIDE COATING IN LAMINATED COMPOSITES

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Topic(s):
- Smart Material Structures
- Applications of Composites
- Hybrid Composites

Keywords:
Electrical conductivity, wettability, multifunctional composite structures, coating, Reduced Graphene Oxide Films (RGOF)

Abstract:
Carbon Fiber Reinforced plastics (CFRPs) are commonly used for structural applications thanks to their high specific mechanical properties. Such plastic composites can also be functionalized exploiting a combination of several materials that introduce multifunctional features to the global performance of the structure and widen their range of operations. This work investigates the use of Reduced Graphene Oxide (RGO) Films as multifunctional coating on Carbon Fiber Reinforced Plastics (CFRPs). Exploiting the inherent properties of such films, surface properties of composite structures such as electrical conductivity and wettability can be improved. Moreover, potential built-in functions, as strain sensing and DC-biased thermography, are studied. Three point bending tests demonstrated a negligible influence of the RGO films on the flexural properties of the CFRP laminates and confirmed a satisfying adhesion between the coating and the structure.

Comments:
Title: Machine learning for impact detection on composite structures

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Topic(s): NDE and Structural Health Monitoring (SHM)

Keywords: Low Velocity Impact, BVID, Machine learning, cross correlation.

Abstract: In order to overcome the current limitations of the impact localisation process on composite materials, mainly the a-priori knowledge of the mechanical properties and the direction dependency of the speed waves, a novel method, based on the machine learning approach, is proposed. The algorithm is formed by two steps: the first one detects the impact location by mean of the highest cross-correlation coefficient, obtained after the interpolation of the impact response baseline using the Radial Basis Function method; the second step exploits the impact training process with the aim to quantify the magnitude of the impact event. Experimental tests are performed on a composite structure with complex geometry, with two types of arrangements: one with free body drop setup and one using modal instrumented hammer. Results showed a good impact localisation, with an error below 10 mm, and accuracy in the impact magnitude estimation.
Debulking of prepreg (pre-impregnated resin system) layers during hand lay-up manufacturing of carbon fibre reinforced polymers (CFRP) is a key-step to reduce air content and maximise the mechanical properties of the final product. Debulking is usually performed using vacuum-bag cycles of 10-15 minutes applied after the lay-up of every three or five prepreg layers, leading to a considerable time-consuming process. In this work, the use of ultrasonic stimulation during vacuum is studied to improve the efficiency of the debulking process and reduce the number of operations in order to decrease the overall manufacturing time. Three CFRP laminates were laid-up using the proposed ultrasonic consolidation (UC) with three different exposition times (5, 10 and 15 minutes) and cured in autoclave. The UC debulking process consists in a vacuum cycle with ultrasonic waves sent to the uncured material through an ultrasonic transducer. In order to evaluate the efficiency of this process interlaminar shear strength (ILSS) and in-plane compressive properties were tested. Experimental results show compressive properties comparable with the ones obtained from reference samples manufactured using the traditional debulking technique, and high improvements in terms of ILSS (>20%). Therefore, UC debulking process can be used during hand lay-up of prepreg in order to improve the interlaminar properties of the final part and reduce the debulking time by over 95%.
ID: 4

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Title: Design of a Gas Gun for composite structures impact testing

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Topic(s): - Impact and Dynamic Response - Other

Keywords: Composite Materials, Impact Damage, Impact gun

Abstract:
The use of composite material in the Aircraft industry has steeply increased in the past few years thanks to their specific properties of strength, stiffness and light weight [1]. In fact, other industries, like transportation for example, has have also increased the number of components that are made from composite materials and since the user perception has been so positive even components that are non-critical and that could be manufactured easily in less expensive material are also being made in composites.

But while smart design can increase structural performance and at the same time even reduce structural weight it is paramount to ensure that other important properties are maintained, like impact performance. This property is paramount in the aero-space industry as the need for lightweight pushes design for minimum surface thickness and this negatively combined with a much higher aircraft velocity can result in catastrophic structural failure following collision with foreign objects [2].

Such objects can range from very small hard irregularly shaped light weight particles to larger heavy birds [3].
In this paper we propose the design of a flexible ballistic system that uses compressed gas to accelerate a variety of projectiles in the range 10 m/sec to ca. 200 m/sec, medium sub high velocity range [4]. Various tests were carried out to investigate the impact performance of various specimens and analyse the repeatability and accuracy of the designed gas gun.

Title: THE MAPPING OF DAMAGE BEHAVIOUR IN A UNIDIRECTIONAL COMPOSITE SUBJECTED TO UNIAXIAL LOADING USING DIGITAL VOLUME CORRELATION

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Topic(s): Damage, Fatigue and Fracture
Keywords: DVC, SRCT, fibre fracture, strains, particles

Abstract: This paper presents the implementation of a three-dimensional microstructural speckle pattern to study local deformation and fibre fracture processes in Carbon Fibre Reinforced Polymers (CFRPs) through Digital Volume Correlation (DVC), in concert with in situ Synchrotron Radiation Computed Tomography (SRCT). DVC is a relatively novel tool for quantifying full-field volumetric displacements and implicit strain fields [1]. For the novel materials systems we have developed, measurement sensitivity and noise are considered, along with the spatial filtering intrinsic to established DVC data processing. It is shown that unique, mechanistically consistent measurements may be made in relation to local fibre failure events, proving the opportunity to refine the understanding of composite failure processes.

ON THE CHALLENGES OF MODELLING IMPACT ON SHELL LIKE STRUCTURES MADE OF FIBER REINFORCED POLYMERS

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- Mechanics of Composites
- Impact and Dynamic Response
- Multiscale Modelling
- Other

Keywords: Finite Elements, impact, modelling techniques, constitutive models

Modelling impact scenarios of continuous fiber reinforced polymers with finite elements is even nowadays a rather challenging task. While state-of-the-art constitutive models are widely available in the respective codes, the fact that the corresponding modelling approach plays a major role to achieve sufficiently predictive results shouldn’t be underrated. The present contribution discusses different modelling techniques to model deformation, damage and fracture of structures made of endless fiber reinforced polymers where focus is set on advantages and shortcomings of various element types starting with classical 5-parameter shell elements, continuing with some widely used enhancements thereof like stacked thick shell formulations and concluding with full 3D setups. Clearly the modelling techniques are closely connected to the applied constitutive models that need to be suited and fit for the corresponding application.

Furthermore the contribution will discuss corresponding constitutive models and their features (plasticity, damage, orthotropy, strain rate dependency etc.) which might be applied for impact analysis and of which the corresponding properties need attention to maximize the benefit of numerical simulation. Of special interest might be prediction of delamination which in turn requires separation features within the finite element discretization. Typically this is done via cohesive approaches that might be either taken into account by special cohesive elements or via respective contact formulations. Both approaches come with advantages and disadvantages. However, the underlying traction and fracture laws may in principle be identical which in turn helps when it comes to parameter identification from experimental investigations.

Last but not least a comment on element size dependency and regularization approaches in the context of the modelling technique is made. It seems that this topic is often underrated as well and may lead to uncertainty if not addressed in a basic way.

The present investigation was carried out in the frame of the EXTREME project which received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 636549.
3D/4D PRINTING OF SHORT AND CONTINUOUS FLAX FIBRE REINFORCED COMPOSITES

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Topic(s): Green Composites
Keywords: 3D printing, 4D printing, flax fibres, moisture, smart materials

Abstract: 3D printing is increasingly being used to produce customized microstructured materials. It is low cost, relatively high speed and has the potential for reinventing the design process [1]. However, today several drawbacks remain their low quality that limit their wide development especially for load bearing applications. Recently, natural fibres have been gaining interest as composite fillers with Fused filament Fabrication (FFF) process even their properties remains moderate compared to pure polymer [2][3][4]. As natural fibre composite properties depend on fibre species, flax fibres which exhibit high tensile properties should be tested. In addition, thanks to industrials partners it is possible to obtain a wide range of high quality fibre grades. This paper aims to develop both short and continuous flax fibre composites for 3D/4D printing. First of all mechanical properties are evaluated and compared to literature. 4D printing potential of natural fibre composite being hygromorph actuators is also discussed. The tensile behavior of 0° and 90° printed short flax fibres/PLA blend samples is characterized. For 0°, the load is applied in the direction of the printing direction. A slight difference of tensile behavior is observed between the orthogonal printing directions where 0° samples are tougher with higher stiffness (E=2527±94 MPa), and tensile strength (σ=23.1 ± 0.4 MPa) than 90° samples (E =2100±81 MPa, σ=17.7±0.6 MPa). Anisotropic ratio (E0°/E90°) is relatively moderate compared to literature on wood/PLA blend composites [5] which may be due to a
weak orientation of flax fibres within the filament. However, tensile properties on 0° direction is 15% higher than wood biocomposites printed in similar conditions and between 20 to 50% in the transverse direction [5].

Continuous flax fibre/PLA biocomposites have been developed for the first time and exhibit a non-linear tensile behaviour typical of natural fibre unidirectional composites. Mechanical properties are drastically higher than short fibre counterparts with E = 13560 ± 825 MPa) and σ = 236 MPa ± 15 MPa but also outperform those published in the literature due to higher quality of fibres [6] (+100% and + 350% for the modulus and strength respectively).

Natural fibres are hygroscopic which is currently assumed to be a major drawback for their use. However, recent works of Le Duigou et al [5], have shown that is possible to develop novel hygromorph functionality for natural fibres. Indeed, inspired from natural hydraulic actuator (i.e. pine cone) and their microstructure, the idea is to use the anisotropic hygro-elastic properties of biocomposites to print a bilayer microstructure with differential elastic and swelling properties. Such kinds of biocomposites could actuate in response to a moisture gradient and belong to 4D printing.

References:

Influence of hygroscopic stresses on natural fibre/epoxy interfacial properties

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Topic(s): Green Composites

Keywords: Natural fibre, Biocomposite, Interfacial Properties, Hygroscopic Stress

The use of natural reinforcements in biocomposite materials gives rise to additional concerns as compared to synthetic materials in terms of moisture sensitivity, hygroscopic stability or compatibility with polymer matrices. At the composite scale, moisture sorption associated to hygroscopic strains lead to a degradation of the mechanical performances, generally associated with a weakening of the fibre/matrix adhesion. Studying and controlling the interfacial properties thus constitutes an essential requirement for the development of high performance biocomposites.

This study aims at understanding the influence of humid environments on the generation of hygroscopic stresses at the fibre/matrix interface of a hemp/epoxy system at the microscopic scale. A direct evaluation of the fibre/matrix interfacial shear strength and friction stress was evaluated and showed a non-monotonic evolution before and after debonding with the increase in moisture. This behaviour displays a competition between various phenomenon occurring during water sorption such as the generation of compressive radial stresses at the interface favoring the charge transfer that may influence interfacial shear strength. Initially considered as a drawback for the development of biocomposites, this work shows that the sensitivity to moisture of plant fibres could be beneficial for improving composite interface properties.
Title: DEVELOPMENT AND CHARACTERIZATION OF EMBEDDED QUANTUM RESISTIVE SENSORS FOR MONITORING APPLICATION IN FIBRE REINFORCED COMPOSITES

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Alternate Contact: - NDE and Structural Health Monitoring (SHM)

Topic(s): - Smart Material Structures
- Nano Composites

Keywords: Quantum resistive sensor / Nanocomposites/ Carbon nanotubes / Embedded sensors / strain monitoring

Abstract: The use of composite materials in large structures such as wind turbine blades is increasing. Monitoring these structures is essential to prevent increased maintenance. In addition to current stress and damage monitoring techniques, such as strain gages or optical fibres, this article proposes quantum resistors (QRS) as an alternative. QRS is a nano additive structured strain sensor that can be positioned on the surface or core of the composite. In this work, integration of the Quantum resistive sensor was performed at several locations inside fibre-reinforced epoxy composites, which were then subjected to mechanical loading, i.e. static and dynamic three point bending and a variable amplitude impact test to simulate point-in-time damaging events. The electrical behaviour obtained from the integrated QRS showed that the developed sensors could be used to probe the induced strain and damage and estimate the resulting degradation of the specimen subjected to impact loads.
Study of the consolidation phenomena in vacuum-bag-only manufacturing of carbon/PEKK laminates

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Topic(s): Composite Manufacturing

Keywords: thermoplastic composites, vacuum-bag-only manufacturing, out-of-autoclave manufacturing, process parameters, interlaminar consolidation, crystallization kinetic

Abstract: Summary. A challenge of the aeronautic sector in the next decade is to meet the growing need for high performance parts. Thus, a rise of production speed becomes indispensable. In this context we focus on the analysis of the out-of-autoclave consolidation process for thermoplastic composite laminates. An experimental set-up for in-situ monitoring of manufacturing process has been developed to investigate the consolidation phenomena in terms of temperature gradient and laminate thickness evolutions. The influence of material and process parameters on these phenomena has been analyzed. Finally a finite element simulation has been performed to describe and predict these coupled phenomena: heating, intimate contact establishment, matrix crystallization and flow of the material melt.

Recently high performance thermoplastic composites have attract the interest of the aeronautic industry. Indeed they can lead to higher impact resistance and shorter cycle time than their thermoset counterparts. Moreover the welding and recycling possibility they offer is a major advantage of this material. Their process conditions often require high temperature and pressure, however and the manufacturing cost is high. For this reason, their adoption in the aircraft design is still slow. To reduce the manufacturing cost, more attention is being paid to
the out-of-autoclave (OoA) consolidation manufacturing and particularly to the vacuum-bag-only (VBO) manufacturing. The goal of this study is to identify and to model the different consolidation phenomena which happen during the low pressure consolidation of a thermoplastic laminate. In this case we focus on unidirectional carbon/PEKK laminates.

Firstly, we present an experimental set-up which has been developed to identify the major consolidation phenomena by monitoring the evolution of the temperature gradient and of the laminate thickness during the consolidation cycle. These phenomena have already been investigated in the conditions of high pressure, such as the intimate contact establishment [1], [2], the autohesion at the interlaminar interfaces, the crystallization of the matrix and finally the flow of the molten material above the melting temperature. Nevertheless the impact of the compaction pressure on these phenomena has been very rarely studied in the literature and hence not fully understood yet [3], [4].

By dint of this experimental set-up two major consolidation phenomena are observed in low pressure conditions. The first one takes place at the glass transition temperature which is associated with the establishment of an intimate contact between the adjacent layers. The second one happens at the melting temperature and corresponds to the flow of the molten material. These two phenomena are correlated with a decrease of the temperature gradient in the thickness direction which can show the reduction of the contact thermal resistance at the interlaminar interfaces. The influence of some process and material parameters on these phenomena has also been investigated. For example the initial degree of crystallinity of the matrix has a high impact on the intimate contact establishment because only the amorphous part of the matrix contributes to this phenomenon.

Secondly, we present the modelling of the consolidation phenomena which have been separately considered so far. The crystallization kinetic has been modelled according to the Choupin’s method [5] (with a Hillier law [6]) both for cold and melt crystallizations. The flow of the molten material has been evaluated by squeeze flow tests [7], [8] at different temperatures around the melting temperature. The intimate contact evolution is represented by an improvement of the thermal conductivity at the interlaminar interfaces. All these phenomena are finally integrated into a FE model to predict the evolution of consolidation phenomena during the consolidation cycle.

This work can be further developed to determine the optimal material and process parameters for thermoplastic composite laminates with high interlaminar consolidation quality and reduced production time.

REFERENCES
Advanced Thermal Protection System Materials Development for Space Exploration Applications

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Topic(s): - Mechanics of Composites
- Composite Manufacturing

Keywords: Thermal Protection Systems, Ablator, Heatshield, PICA, HEEET

Lightweight Thermal Protection Systems (TPS) for NASA space exploration heatshield applications have been developed at Fiber Materials Incorporated (FMI, Biddeford, Maine, USA) over the last twenty years. Phenolic Impregnated Carbon Ablator (PICA) is a lightweight, low thermal conductivity chopped fiber composite capable of withstanding heat fluxes up to 1500 W/cm². PICA manufactured by FMI has been used as the planetary entry heatshield for several NASA missions since 1999, including Stardust, Mars Science Lab, OSIRIS REx, and Mars 2020. Due to the obsolescence of the input fiber source, a new PICA material (PICA-D) has been developed under funding from NASA Ames Research Center (Moffett Field, California, USA) using Lyocell, a domestic fiber source. Since 2017, FMI has developed and tested PICA-D tile materials and single-piece net shaped heatshields to support this program. In Phase I, initial materials were fabricated, tested for material properties, and arc-jet tested for aerothermal performance. Results were comparable to baseline PICA material, indicating a “drop-in” replacement to heritage PICA for future NASA mission needs. Phase II of the project, completed in 2018-2019, included optimization of PICA-D tile material fabrication, high-temperature thermal-structural property characterization, and the manufacturing scale-up demonstration of a single piece net shaped heatshield capable of earth planetary re-entry for Mars Sample Return application. The single piece heatshield, at 1.4 to 1.5 meters in diameter, is the largest single monolithic PICA component made to date. Phase I-II results are presented. Since 2014, FMI has been under contract by NASA Ames Research Center for the manufacturing scale-up of a 3D woven composite TPS material called HEEET (Heatshield for Extreme Entry Environment Technology). The goal of NASA's HEEET program is to deliver a heatshield system capable of withstanding atmospheric entry heating conditions with peak heat flux up to 10,000 W/cm², well beyond the capability of current state-of-the-art materials. HEEET's dual layer, 3D composite design results in a 40-50% reduction in areal mass and greater temperature resistance compared to legacy carbon-phenolic systems from the 1990’s. Following initial fabrication demonstrations, manufacturing scale-up, tile acreage and gap filler testing, the culmination of the program resulted in the delivery of heatshield components for NASA’s HEEET Engineering Test Unit, completed in 2018. FMI present results from this program.
Title: Meso-scale finite element simulation of the braiding process

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Topic(s): Mechanics of Composites, Multiscale Modelling, Textile Composites

Keywords: FEM simulation, braiding process, digital process simulation, multi-scale simulation, braided composite material

Abstract: Braiding is an attractive, cost efficient technique to manufacture continuous, interlaced preforms that can be tailored for a wide range of applications. It leads to lightweight, stiff sectional composites that have a high tolerance to impact. In the last decades braided textiles have been attracting the interest of the aerospace and automotive industries amongst others, including defense, energy and sport industries. Applications of braided composites include pressure vessels, driving shafts, structural components of automobiles, bi- and tri-axially braided blades, and sectional components for aircraft applications. During the design of braiding composites, the prediction of the resulting correlation between manufacturing
parameters in a particular braiding run is a complex task. To define the optimal combination of machine settings that leads to the required braid architecture without fiber damage or defects many costly and time consuming trial and error tests are necessary. Simulation of the manufacturing process provides an alternative means to increase reliability and cost-effectiveness to manufacture high-performance braided composites. Since composite materials consist of matrix and rovings, which in turn are made of filaments, there are several possible levels of observation for the simulation of the mechanical behavior. These individual levels differ in terms of the model scale and consideration of the physical phenomena. The standard approach to predict mechanical behavior of a composite structure consists in the mechanical analysis of the entire structure, which is commonly achieved through finite element analyses involving a global-to-local approach. This initial assessment defines “hot spots” which are prone to damage; these are then further evaluated in a refined analysis. Expensive and time consuming experimental tests are performed to determine the value of the required model parameters to describe the material constitutive behavior. A multi-scale modeling strategy can overcome many limitations of the standard approach and lead to accurate predictions of the mechanical behavior of composite materials.

This paper introduces some of the methods applied to develop a multi-scale finite element simulation framework for braided composites. This methodology is developed in an ongoing joint research project between ITA and IFB. Some preliminary results are also presented and discussed. The meso-scale finite element model of the braiding process developed at ITA is coded using the software Abaqus/Explicit. The full model consists of 48 yarns, which are modeled as isotropic material and discretized using truss elements. An iterative optimization methodology for model reduction, model property improvement and multiplication is proposed to reduce the simulation time of the meso-scale model. The application of this method helps reduce the computation time, resulting in a computation time comparable to that of macro-models, or even analytical models. A good correlation between simulated braids and experimental results was obtained in terms of braid architecture. An experimental test program is designed to assess the influence of parameters of the braiding process (mainly yarn pretension and angular velocity) on braid architecture, which is defined by braiding angle and cover factor. Bi- and tri-axially reinforced braids are manufactured and tested. The range of angular velocities is varied from 50 rpm to 150 rpm, with yarn pretension modified by using springs with pretensions varying from 100 g to 700 g. The planned experimental test program will also characterize braid architecture and fiber damage in the meso- and micro-scales. For that, a combination of several characterization techniques is applied. Of particular interest is the X-ray computed tomography (CT), which allows highly accurate 3D assessment of fiber architecture, manufacture induced defects, fiber damage and fiber undulation.
The study of the behaviour of the inter-ply interface in fibrous composite materials is the main focus of this work. Micromechanical analysis [1] considers phenomena at length scales of the order of fibre dimensions with the assumption that material to be locally periodic. However, at the interface of individual plies, there are two different materials that are put together. This disrupts the periodicity in the thickness direction. This disruption leads to a possible loss of local periodicity, as the fully periodic solutions from the two plies may not match at the interface. This requires a correction [2] to the locally periodic asymptotic analysis. This study shows that the effect of the interface is significant.


The temperature dependent synergistic effect of carbon nanotube (CNT)/graphene nanoplatelet (GNP) hybrid nano-fillers on the fatigue strength of the epoxy composites were experimentally investigated. The epoxy composite specimens with various CNT:GNP filler ratios, i.e., 0:0, 0:10, 1:9, 3:7, 5:5, 7:3, 9:1, and 10:0, have been prepared and fatigue-tested at various temperatures (-28, 2, 22, 52, and 82°C) to study the effects of filler ratios and temperatures on the fatigue strength of the hybrid nano-filler composites. A synergistic index was developed in the present study to evaluate the synergistic effect of the hybrid fillers on the endurance limits of the studied nanocomposites with different filler ratios. Experimental results show that the lower fatigue strength of the studied nanocomposites was observed when the studied specimens were tested at higher temperatures. Furthermore, the composites with the CNT:GNP ratios of 9:1 have higher fatigue strengths than those with other filler ratios. The stiffness of the studied specimens with various filler ratios kept unchanged till the last stages of fatigue tests. However, the dynamic creep was clearly observed for the specimens tested at high temperatures. The fracture surfaces show that the crack deflection and the filler bridging are two main mechanisms to enhance the fatigue strength of the studied nanocomposites with hybrid nano-fillers. Moreover, the characteristics of the fracture surfaces change from brittle to ductile when the specimens were tested at higher temperature. The pull-out of fillers verifies that the wrapping and adhesion capability between the fillers and polymer reduces significantly at high temperature, which leading to the low fatigue strength.
Title: IMPACT CHARACTERISATION OF BASALT/EPOXY COMPOSITES AT LOW TEMPERATURES

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Topic(s): - Mechanics of Composites
- NDE and Structural Health Monitoring (SHM)
- Impact and Dynamic Response

Keywords: basalt laminates, low-velocity impact, delamination

Abstract: Recently, basalt fibre composites have gaining significant research interest in several fields such as civil, naval and automotive [1-2] due their environmentally friendly nature, being natural fibres produced with a process similar to that of glass fibres, but without any precursor nor additives. Many authors have investigated the impact and the mechanical behavior of such laminates. In particular, the changes of the material properties as function of temperature was studied in [3, 4] but, very few papers concern about the impact behavior at extreme temperatures, and no one is on basalt fibre laminates.

In this work, basalt fibre reinforced plastic laminates have been obtained by impregnating plain
woven fabrics with an epoxy infusion system. The basalt/epoxy composites have been characterized by mechanical tests aimed to investigate the interlaminar shear strength by short beam shear test). Furthermore, Specimens were impacted at penetration and at increasing energy values, at room temperature and low ones, to investigate the damage onset and propagation. Ultrasonic (US) techniques were adopted to analyze the internal damage and to provide information on the shape and the extent of the delamination. The final aim was to be able to predict impact energy and delamination, in the different test conditions, investigating the influence of the different parameters involved on the phenomenon. These data, together with the results obtained by interlaminar shear strength and indentation depth measurements, have provided useful information on the damage mechanisms.

References
THE INFLUENCE OF TEMPERATURE ON THE LOW-VELOCITY IMPACT RESPONSE OF POLYAMIDE 6/BASALT PLAIN FABRIC LAMINATES

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Topic(s): - Mechanics of Composites
- NDE and Structural Health Monitoring (SHM)
- Impact and Dynamic Response
- Damage, Fatigue and Fracture

Keywords: basalt laminates, thermoplastic resin, low-velocity impact, CAI

Recently, the growing attraction to the development of new eco-sustainable composite materials is driving the research interest toward the replacement of synthetic reinforcing fibers with natural ones and to exploit the intrinsic recyclability of thermoplastic resins even for uses in which thermosetting matrices are well consolidated (eg naval and aeronautical fields).

Among the natural fibers a growing interest of the research, especially on the academic side for now, is addressed to basalt fibers [1]. Basalt fibers, based on volcanic rocks originated from frozen lava, show chemical composition similar to glass fibers but offer better strength and higher elastic modulus characteristics [2]. Moreover, if compared to carbon or Kevlar fibers, basalt ones have wider application temperature range and higher impact performances to be potentially used in a broad range of industrial applications [3]. Understanding the dynamic response of these composites poses several theoretical and methodological challenges due to their inhomogeneity and anisotropy, determining the mechanics of damage formation. These challenges are further exacerbated when considering naval and aerospace applications, where extreme temperatures must be taken into account. Some literature exists about the topic: the changes of the material properties with changing temperature was studied in [5, 6] but, very few papers are about the impact behaviour at extreme temperatures, and no one is about basalt fibre laminates.

Focusing the attention on thermoplastic composites, many experimental findings already available in the literature highlight the outstanding mechanical properties of composite materials including natural basalt fibers and the potentiality of this latter with respect to glass fibers [4].

In this work, symmetric plaques [(0/90)s] (thickness: 2.9 mm-18 plies) based on a neat polyamide 6 (PA6) films and a commercial plain wave basalt fabric are obtained by conventional film-stacking technique and adequately cut to produce specimens for flexural and low-velocity impact tests.

The results of low-velocity impacts at room and higher temperatures allow to predict potential uses of the analyzed composite sample for advanced application. Non destructive and destructive evaluations for damage investigations were carried out. CAI tests were, then, performed to evaluate the residual compression strength. The final aim was to predict the impact energy, delamination and residual strength, in the different test conditions. These data, complemented by flexural tests and indentation depth measurements, have provided useful information about the involved damage mechanisms.

References
Title: Meso-scale modeling of damage in woven composite materials: from experimental characterization to numerical analysis

Abstract: Damage onset and evolution in composites made of a woven reinforcement embedded in a polymer matrix is driven by the multi-scale nature of the material. It starts at the micro-scale with fiber-matrix debonding and plastic stretching of the polymer matrix. The micro-damages then coalesce to form transverse yarn cracks, which are coupled with decohesions between crossing yarns around the yarn crack tips. The meso-scale architecture of the woven reinforcement has a strong influence on the local strain distributions and thus on yarn crack and decohesion initiation and evolution. In order to take into account the influence of the fiber reinforcement architecture on the mechanical behavior of the studied materials, a realistic description of the meso-scale geometry, obtained by modeling the preforming step of the dry fabric, is necessary.

A realistic geometry of the Representative Unit Cell (RUC) of the composite is obtained at the mesoscopic scale by taking into account the relative shifts between the fabric layers and the preforming of the dry reinforcement before resin injection. The geometry is validated using X-ray tomography images. The quality of the consistent mesh of the RUC is ensured using both geometry- and energy-based error indicators.
In this contribution, we present two mesoscale modeling strategies to predict crack initiation and propagation in woven composites. The first one is an approach based on finite fracture mechanics. A criterion coupling stress and energy conditions is used to determine intra yarn damage onset [1,2]. The second approach is based on an adaptive remeshing method for crack initiation and propagation using cohesive zone model. This is a multistage efficient approach to predict and simulate fracture based on elementary tools that have already been tested on metallic structures [3]. This strategy is adapted to woven composite materials to simulate intra-yarns transverse cracking and decohesions at the yarns interfaces.

The locations and the lengths of cracks and decohesions on the edge of woven composite specimens under tension are obtained using global digital image correlation with mechanical regularization [4] performed on optical microscope images. The evolution of the crack and decohesion density as a function of the applied strain are also compared, and the damage scenarios are analyzed and compared to experimental tests in order to evaluate the accuracy of the proposed approaches. The effects of mesoscopic damage on the macroscopic mechanical properties, obtained by periodic homogenization, are evaluated.

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Title: On Modelling Behaviour of Carbon Fibre Reinforced Polymers under High Velocity Impact

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Topic(s): - Mechanics of Composites
General increase in use of carbon fibre reinforced polymers (CFRP) is most prominent in aerospace, automotive, energy and defence. This demand is driving the requirements for the accurate and predictive modelling (consequently dynamic characterisation) of these materials. CFRPs, considered in this work, are composed of stiff, brittle fibres encased in epoxy resin. Predictive modelling and experimental characterisation of these materials, even in basic quasi-static mechanical tests, is challenging due to their anisotropy resulting from the material microstructure. More specifically, the anisotropy and heterogeneity have, as a consequence, complexity in behaviour of these materials including a number of material damage and failure mechanisms that are activated by different loading conditions. Extensive research in this field over the last three decades still has not delivered a widely accepted and reliable failure theory for CFRPs [1][2].

This work presents a new constitutive model developed within the framework of irreversible thermodynamics with internal state variables. The model is based on spectral decomposition of the elasticity and damage characteristic tensors, where the damage evolution is controlled with associative damage model. Two thermodynamic damage potentials formulation were considered: model 1, with decoupled damage modes (without the interaction between the damage modes); and model 2, with the damage modes interaction. Model calibration has been done using extensive mesoscale modelling, whilst the model verification and validation have been based on the modelling physical damage effects defined at the mesoscale level. This is done as part of an effort to produce tools for modelling of high velocity impact on composites in the European project EXTREME*.

References

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Title: Experimental and Simulation Studies on the Crashworthiness of Carbon Fiber Composite Flat Specimens

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Abstract:
Carbon fiber composites have tailorable and superior specific characteristics compared to metal for use in structural components. Higher specific tensile modulus and strength allows designer to reach the desired limits with lower weight. Since CFRPs are less studied than metals they have not been used up to the end of their potentials.

In order to understand them better and be able to simulate them better the building block approach is chosen. Firstly, standard characterization tests, tensile, compression, shear, DCB, and ENF, are performed on the coupons. The results are used to verify the supplier specifications, populate the material card and calibrate the numerical parameters.

The pre and post processing is conducted in HyperMesh and RADIOSS is used as the solver. Moving up the pyramid, saw-tooth triggered flat specimens with length of 150mm and width of 100mm are then tested under impact to understand the energy absorbing capabilities and the failure mechanisms of the material. The force-displacement graph thus obtained is then used to further tune the numerical parameters. Flat specimens are impacted with different velocities and energies using an Instron drop tower machine to simulate different kinds of damage that might happen during manufacturing and/or in service conditions. The damage is, then, studied using X-ray radiography. The FEA model is also damaged in the same way and the response observed. The model is further calibrated to be suitable for both out-of-plane and in-plane impact loadings. Following this, the crashworthiness of these damaged specimens is examined by crushing the specimen along its length both physically and computationally. Energy absorption and failure modes of damaged specimens are compared.

Results show that until the critical delaminations are not occurred in flat specimens the specific energy absorption is not changed drastically but after that point cracks start to propagate in the middle of the specimen affecting sustained crush of the specimen and therefore lower energy absorption.
The analysis of failure in composite laminates usually only covers failure within individual layers (intralaminar failure). Beside that widely noticed failure mode, however another failure mechanism may occur. The individual layers, consisting of high-strength fibers and plastic matrix, are interconnected via thin plastic matrix interlayers. These interlayers may act as weak layers in which cracks may initiate and propagate unhindered yielding a catastrophic failure by separation of the layers (interlaminar failure). This failure mode may be triggered by the so-called free-edge effect. The laminate exhibits layer-wise dissimilar stiffness properties yielding highly localized, theoretically infinite stresses at the bi-material notch along the free edges. In the present work, interlaminar crack onset induced by the free-edge effect is investigated.
Neither strength-of-material criteria, nor fracture mechanics approaches allow for the prediction of interlaminar crack initiation. Hence, a coupled stress and energy criterion within the concept of finite fracture mechanics, as suggested by Leguillon [1], is used to predict instantaneous formation of a finite sized crack. The mechanical laminate model is carried out according to the widespread Pipes and Pagano [2] approach, assuming a generalized plane strain state. For this reason, only symmetric laminate layups can be examined. Martin et al. [3] investigated interlaminar crack initiation in symmetric angle-ply laminates using the coupled criterion. The required quantities have been computed based on the classical finite element method involving high numerical effort. Contrary to Martin et al. in the present work the semi-analytical scaled boundary finite element method, introduced by Song and Wolf [4], is employed in order to determine the required stress and energy quantities in an outstandingly efficient manner. The obtained results are in good agreement to experimental findings from literature.

REFERENCES
Title: Comparison between the mechanical behavior of woven basalt and glass epoxy composites at high strain rates

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Topic(s): - Impact and Dynamic Response
- Textile Composites

Keywords: High strain rate, basalt fibers composites, split Hopkinson bar, digital image correlation

Abstract: The aim of this paper is to study and compare the mechanical behavior of basalt and glass fiber reinforced composites at high strain rates. High strain rate experiments were carried out using a split Hopkinson tensile bar facility. Additionally, reference quasi-static experiments were carried out to compare the behavior at different strain rates. Full strain fields were measured using stereo digital image correlation technique. The effect of strain rate on the in-plane mechanical behavior of both materials was studied. A comparison between the behavior of both basalt and glass fiber reinforced composites at different strain rates was presented and assessed. Results showed that basalt composites do have promising properties for applications requiring impact resistance.
Injection Molding Simulation with Fiber Length Dependent Flow Modeling

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Topic(s): - Composite Manufacturing
- Multiscale Modelling
Keywords: Process simulation, Anisotropic flow, Fiber breakage modeling, Injection molding, Fiber reinforced polymers
Abstract: Discontinuous fiber reinforced polymers are one of the most used materials in mass production, showing a complex behavior, composing a transient chemo-thermomechanical matrix and fiber-induced anisotropic physical properties. The fiber-induced anisotropic behavior occurs not only in structural properties, but also during material flow, which in turn influences the final physical properties by a different mold filling. Therefore, the fibers influence the material flow and vice versa, the material flow causes fiber-reorientation. To account for the fiber-flow interactions, the proposed simulation method for injection molding describes the fiber-induced anisotropic flow behavior by a fourth order viscosity tensor. Furthermore, fiber breakage is taken into account and the calculated fiber length directly influences the modelling of fiber orientation and flow progression. Numerical examples demonstrate the fiber length dependent effects to verify the model implementations.
Study of the Distribution of Rubber Particles in Ground Tire Rubber/Polypropylene Blends

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Topic(s): - Applications of Composites
- Green Composites

Keywords:

Abstract: Goal number 12 of the UN 2030 Agenda for Sustainable Development is sustainable consumption and productions. Recycling has a central role in assuring to meet the target in 2030. Indeed, only in EU, the annual total waste of spent tire is 3.7 million tons [1], this is why it is impelling to find a sustainable way to recycle this material. This article investigates the feasibility of the use of ground tire rubber (GTR) as feedstock for injection molding, by blending it with polypropylene. One of the applications is to create functional anisotropic surfaces due to the roughness introduced by rubber particles.

In order to study the possibility to use GTR rubber as feedstock for injection molding, different blends between ground tire rubber and polypropylene were investigated. In literature is possible to find examples of studies where GTR is used as filler in a thermoplastic matrix [2,3,4,5], in this work, instead, the content of GTR has been increased until 80wt%. In addition the GTR powder used for the blending has a particle size lower than 74 µm (200 mesh), in [2,4,5] the dimension of GTR powder is larger than 0.2 mm. By using a smaller particle size of rubber powder is possible to increase the surface energy of the single rubber particle, improving the overall dispersion of rubber in the matrix, as explained by Xun et al. in [3]. Moreover the use of GTR with small particle size is crucial in order to achieve desired optical properties by micro features on the surface.

The focus of this work is on the investigation of the distribution of GTR particles in a blend between ground tire rubber and polypropylene, because the mechanical property, the surface finishing and the optical functionality of GTR/PP blend are highly related to the distribution. The GTR powder used was produced in a cryogenic grinding implant and subsequently mixed with polypropylene. Three different content of GTR were used: 60wt%, 70wt% and 80wt%. The blending between PP and GTR was done with a tween screw extruder, the extruded material was than shredded and finally injection molded in dogbone specimens and in samples with specific micro-structured surfaces.

The distribution of the GTR powders was visualized by SEM images at three cross sections of one sample. The cross sections were taken near the injection gate, in the center and far from the
injection gate. The cross sections near the gate and far from the gate showed a uniform distribution between PP and GTR. This is not true for the cross section in the center of the specimen (see Figure 1) where it was possible to observe an accumulation of PP near the surface. EDS and sulfur combustion analyses verified the distribution.

The roughness was measured, and correlated with GTR content and particle distribution, in specific positions for each sample: near the injection gate, in the center and far from the injection gate. From the roughness investigation it was possible to observe an increase in roughness when also the content of GTR in the blends was raised, meaning that the rubber powder contributes for the roughness variation of the blends. In addition, a remarkable variation of the roughness was notable throughout the samples, in particular the roughness is higher in the position far from the gate and lower in the center.

The uneven distribution between PP and GTR, showed by the abovementioned analysis, influences the mechanical properties of the blends. Hardness test showed higher hardness in the center of the sample, where the content of GTR is lower, and lower hardness in the local position far from the gate, where GTR is more concentrated.

REFERENCES
The polymerisation reaction or curing of the resin induces internal stresses within the part being produced. During this change of state, the part experiences deformations due to thermal expansion and chemical shrinkage of the resin. These deformations are constrained from developing freely due to the tool-part interaction and result in build up of internal stresses. Those stresses are released upon demoulding and the part deforms. Previous research has shown the significant influence of the tool-part frictional interaction during curing on the final shape of the part [1]. With the development of closed mould processes, the complexity of the moulds have increased resulting in drastic increase in manufacturing costs. Therefore, aluminium moulds are more commonly used to reduce their cost. However, the difference of CTE between aluminium and thermoset resin is significant which results in higher deformations. This brings about an interest in being able to predict these distortions in order to compensate the mould geometry and respect tight dimensional tolerances.

The present study aims at evaluating the model complexity level in term of boundary conditions required to predict cure-induced deformations of composite parts manufactured by the SQRMT process. Several boundary conditions with increasing complexity were tested: freestanding cure, fully constrained cure, deformable opened and closed mould with frictional tool-part interaction.

The numerical methodology consists in performing coupled chemical-thermal-mechanical FE calculations using ABAQUS with user subroutines. The details of the model follow the approach suggested by Svanberg and Holmberg [2] which considers a simplified linear viscoelastic behaviour of the material where time-temperature-degree of cure superposition is applied.

Experimental data was generated measuring gusset angle brackets (Fig. 1) which gives an evolution of the spring-in along the part length. L-parts are made of carbon fibres AS4/8552 prepreg and manufactured on an Aluminium mould. The parts are 550mm long with 150mm long flanges. L-parts of different stacking sequences, symmetric and asymmetric, and
manufactured using autoclave or SQRTM process were measured.

The experimental measurements were compared to the predicted spring-in angle of the different numerical models in order to determine the accuracy required to obtain reliable predictions. Results have shown the importance of an accurate numerical model with representative boundary conditions. Modelling frictional tool-part interaction strongly improves the predictions (Fig. 2).
Multi-scale Finite Element Modelling of Unidirectional Composites under Impact

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Topic(s): Impact and Dynamic Response
Keywords: Multi-scale modelling, Impact, Micromechanics

Abstract: A common methodology to simulate the behavior of composite materials consists in considering the material as homogeneous following a so-called macroscopic approach and modelling it using a progressive damage model [1]. Such macro-scale models describe the behavior of the undamaged material, follow the evolution of different failure onset criteria and progressively degrade the undamaged behavior when the failure onset criteria become larger than some critical threshold values, i.e. when the material is damaging eventually leading to final failure. The description of the undamaged behavior, the failure criteria and the degradation of the material behavior upon damage are typically derived from experimental tests under uniaxial loading conditions. The models then make an assumption about the material behavior under multiaxial loading conditions. This comes with two main disadvantages: (i) a large number of experimental tests is required to identify all model parameters, and, (ii) the model predictions on industrial applications can sometimes be inaccurate since the material is in general seeing multiaxial loading conditions against which the model was not properly validated.

The present paper suggests mitigating these disadvantages by: (i) using a micro-scale model finite element to predict the behavior of the composite material under many different loading conditions, and, (ii) deriving an improved macro-scale model from these simulation results.

The micro-scale finite element model looks at the details of the stress and strain distributions in a so-called representative volume element (RVE), i.e. a typical arrangement of fibers in the matrix which is large enough to be representative of the behavior of the composite material at the macroscopic scale. As in [2], it accounts for different phenomena such as plastic deformation in the matrix material, damage and failure in the matrix and in the fibers or fiber-matrix debonding.

In the paper, the micro-scale model, how it works and how to obtain its parameters will be detailed. Its predictions will be shown for different loading conditions. A suitable macro-scale material model will be derived from these predictions. Finally, the use of that macro-scale material model will be illustrated on a test case consisting of plate impact test.
Acknowledgments
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References
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Title: Flexural strength of carbon fibre composites after impact with and without interfacial non-woven Short Aramid Fibre toughening

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Topic(s): - Mechanics of Composites
- Impact and Dynamic Response

Keywords: Residual flexural strength; Damage tolerance; Short Aramid Fibre

Abstract: Laminar carbon fibre composites contain inherent weak interfaces as there is no cross ply fibre reinforcement. Thus they are prone to impact damage in the form of delamination cracking. In this study, we introduce ultra-thin non-woven Short Aramid Fibre (SAF) veils between carbon fibre plies to provide across ply interface toughening. The effects of SAF veils on flexural strength of carbon fibre composite laminates after impact are investigated, and compared with common unreinforced carbon fibre composites. Samples are first manufactured by hand lay-up of 11 layers of carbon fibre fabric with and without SAF veil reinforcement and then impacted with energies ranging from 0 J to 5.7 J by an in-house drop-weight device. The degradation of residual flexural properties is assessed by three-point bending tests on the impacted side in accordance with ASTM D790 at a span-to-depth ratio of 32. The flexural strength of pristine sample turns out to be 21% larger than SAF sample with no pre-impact while SAF samples give up to 48% larger residual flexural strength after three impact configurations than pristine sample. The reduction in flexural strength is significantly alleviated by SAF veils, decreasing from 70% to 45% in strength loss. X-ray micro-computed tomography is employed to characterize the damage patterns induced by impact and post-impact bending for damage mechanism analysis.
EXPERIMENTAL STUDY OF THE EFFECTS OF LAYERS ORIENTATION ON MODE I INTERLAMINAR FRACTURE TOUGHNESS USING FULLY UNCOUPLED MULTIDIRECTIONAL SPECIMENS

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Topic(s): - Mechanics of Composites
- Damage, Fatigue and Fracture

Keywords: Laminated composites, Fracture toughness, Delamination, Multidirectional, Double cantilever beam, Fully uncoupled specimens

Abstract: Nowadays, composite materials are used for a variety of applications, including safety-critical structures, whose design requires a damage tolerance approach. For laminated composites, delamination is one of the most critical damage modes. In literature, delamination is studied using Linear Elastic Fracture Mechanics (LEFM) concepts, and interlaminar fracture toughness of a material is determined, in pure mode and mixed-mode conditions, by means of standard test procedures [1-3]. However, the validity of such standards is restricted to unidirectional (UD) specimens in which all layers have fibres oriented along the longitudinal direction of the specimen (0°). Real structures, instead, are built using multidirectional (MD) layups and delaminations may occur at any interface. Hence, characterisation of interlaminar fracture toughness of the interface between plies oriented at different angles is required.
Unluckily, experimental characterisation of interlaminar fracture toughness in such interfaces is still an open problem due to the following issues:

- During delamination, additional damage mechanisms may appear such as intra-ply matrix cracking within off-axis plies; this may cause the delamination to jump to another interlaminar plane.
- MD laminates show a complex coupled mechanical behaviour. Due to couplings, thermal residual stresses may appear during curing and they affect fracture toughness evaluation; additionally, couplings induce displacement and strain fields that may introduce undesired parasite modes contributions.
- Most data reduction techniques are based on 2-dimensional theoretical formulations, whose validity for MD laminates is not granted.

To overcome such problems, a special class of stacking sequences, called Fully-Uncoupled Multi-Directional (FUMD), has been developed and presented in [4]. These sequences are conceived to have null coupling terms, in the framework of Classic Laminated Plate Theory (CLPT), for the entire sequence itself and for its upper and lower halves, which form the arms of a typical standard delamination specimen [1-3].

In this study, for the first time, FUMD stacking sequences were used to design Double Cantilever Beam (DCB) specimens for mode I interlaminar fracture toughness characterisation. Five FUMD specimen sets were fabricated with different delamination interfaces (indicated by a double slash):
1. FUMD 0°/0°;
2. FUMD 0°/15°;
3. FUMD 0°/30°;
4. FUMD 0°/45°;
5. FUMD -45°/45°;
where orientation 0° is aligned with the longitudinal direction of the DCB specimen. In addition, standard UD specimens (thus having 0°/0° delamination interface) were fabricated as well.

A glass/epoxy prepreg fabric with 10% fibres in the fill direction was used, as this is expected to reduce matrix cracking problems in off-axis plies and hence prevent delamination jump phenomena.

Sequences FUMD 0/0 and UD have the same delamination interface but different global stiffness: results from their tests allow to assess if, for a fixed delamination interface, global stiffness of the specimen play a relevant role in fracture toughness evaluation, as some authors suggest. On the other hand, sequences FUMD 0/0, FUMD 0/45 and FUMD -45/45 have different delamination interfaces, but identical global stiffness: their tests allow to observe whether fracture toughness is affected by local effects, such as orientation of plies embedding the delamination plane and of adjacent plies at most.

Results show that global stiffness has not relevant effects, while layers orientations plays a major role in changing interlaminar fracture toughness of the interface.

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Microstructure and mechanical properties of Al2O3-Ni-Cu hybrid composites fabricated by slip casting

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Topic(s): Mechanics of Composites, Composite Manufacturing, Hybrid Composites

Keywords: hybrid composites, Al2O3-Ni-Cu, slip casting

Abstract: This work focuses on the developing the method of production and characterization of hybrid gradient composites from ternary systems based on the Al2O3-Cu system with the addition of nickel phase. The Al2O3-Ni-Cu composite were prepared by slip casting technique. The prepared slurries were characterized by high concentration of solid content. In the investigation
ceramic water-based slurries with 50 vol.% solid content and 15 vol.% metal powders with respect to the total solid volume were prepared.

The rheological characterization of the slurries was done. The sintered composites were characterized by X-ray diffraction (XRD), scanning electron microscope (SEM), and energy-dispersive X-ray spectroscopy (EDS). Selected physical proprieties, hardness, fracture toughness, and bending strength were also analyzed. The microstructure was analyzed for its influence on mechanical properties. The results of XRD analysis revealed that obtained composites contained Al2O3, Ni and NiCu phases. The use of slip casting method allowed the production of composites characterized by relative density equal ~96%. An increased in metallic phase concentration caused a decrease in Vickers hardness and increased the fracture toughness of the Al2O3-Cu-Ni materials compared to the Al2O3 samples.

These results with high cognitive value and application potential were obtained. Thanks to this research, the foundations of an innovative method of forming hybrid composite structures was identified, which was combine the best features of ceramics (hardness, resistance to high temperature) with metal properties (crack resistance, good electrical conductivity). This type of composite can be used for temperature, conductivity and flow sensors.

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The paper describes an investigation of explosively welded Mg/Al/Ti multilayer composite. Following the welding, composite was hot-rolled at temperature 400°C with a total relative strain of 30%. The strain rate was 1.0 [1/s]. The composite Mg/Al and Al/Ti bonds were subjected to microstructure analysis using scanning electron (SEM) and transmission electron microscopy (TEM). It has been found that no formation of intermetallic phases was observed in as-welded joints. Applying of hot-rolling process results in formation of a continuous layer in Mg/Al joint consisting of two intermetallic phases Mg2Al3 (ꞵ) and Mg17Al12 (γ). In Al/Ti joint applying of hot-rolling results in formation of a continuous melted layer with locally identified precipitations of the intermetallic phase TiAl3.
Title: Radical induced cationic frontal polymerization for reinforced epoxy composites

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Topic(s):
- Composite Manufacturing
- Applications of Composites

Keywords:
Radical induced cationic frontal polymerization, Frontal polymerization, Epoxy resin, Composites, Fiber reinforced polymer composites

Abstract:
Radical induced cationic frontal polymerization (RICFP) is an elegant technique to cure epoxy resin. Combining advantages of thermal curing and photopolymerization like fast curing, low energy consumption, and long pot-life makes the RICFP beneficial in bulk curing. The formulation for RICFP consists of epoxy monomer, e.g. bisphenol-A-diglycidylether (BADGE), tetraphenyl-1,2-ethanediol (TPED) as a radical thermal initiator, and antimonate or aluminate based diaryl iodonium salts as a photo acid generator. The presence of the two initiators allows the RICFP to be initiated by UV light or a thermal stimulus. The so liberated acid initiates a cationic ring opening polymerization of the epoxy rings of the resin. This exothermic reaction generates the heat necessary to cleave the radical thermal initiator, which provides radicals that can undergo a redox reaction with the photo acid generator causing again acid liberation (Fig.1a, c) [1,2].

Fig.1 Mechanism and scheme of RICFP (a, c), RICFP conducted under water (b), composites cured by RICFP and QR code for video of fiber reinforced composite manufacturing (d). With these advantages, the RICFP deserves to be deeply investigated for manufacturing of composite. Promising results show RICFP was successfully conducted for composites with high...
content of various fillers and fibers (Fig.1d). Furthermore, recently the RICFP can be carried out even when submerged under water (Fig.1b). This invention can be used for applications, such as filling underwater cracks in bridge pillars or dams, or repairing pipes during ongoing operation.
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Title: Impact loaded CFRP aerospace structures with embedded sensors and actuators – Design, Manufacturing and Testing.

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Topic(s):
- NDE and Structural Health Monitoring (SHM)
- Impact and Dynamic Response
- Composite Manufacturing

Keywords: CFRP, embedded sensors, impact, manufacturing

Abstract: Carbon fibre reinforced composites (CFRP) are of rising interest for aerospace and aviation industry to master growing economic and ecological challenges. In contrast to conventional metallic materials, they offer both higher specific material properties, such as the strengths, stiffnesses, and an increased energy absorption capacity in case of impact loading scenarios. Additionally, the possibility of integrating functional elements, such as actuators and sensors, predestine CFRPs for the development of more lightweight structural components. In this study, a generic composite structure is instrumented with integrated piezo ceramic sensor elements. Tailored Embeddable Sensor-Actuator Layers (TEmSAL) are used for autoclave manufacturing. The structure is subjected to a soft body impact event. Aspects of the designing process, manufacturing and instrumentation as well as experimental results will be presented and discussed.
Title: NATURAL RUBBER BASED NANOCOMPOSITE 2D STRAIN SENSORS AND MEASUREMENT OF CYCLICAL SENSING BEHAVIOURS

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Abstract: Elastomer materials like semiconductive rubber are becoming increasingly popular in the automotive, defense industry and industrial process monitoring and control, because of their flexible and hyperelastic properties [1]. The process of compounding of rubbers with conductive additives provides the nanocomposite materials with novel and interesting functions, such as sensing [2]. A detailed experimental study is managed to understand crack initiation within the process zone of GE/rubber nanocomposites under cyclic strain loading [3]. Graphene nanoplatelets (GE) and carbon black (CB) as an effective sensing material for electrical signal identification were used to manufacture an extremely reliable conductive rubber nanocomposite. A strain sensing element was produced by incorporating the rubber, graphene nanoplatelets (GEs), and Carbon black via a double stage mixing method [4]. It was observed that the GE/Rubber was able to perform smooth cyclical strain sensing under all four different constant strain levels. Four different pre-cut dimensions (0, 2.5, 5, 10 mm) and five different constant strain levels (0%, 5%, 10%, 15%, 30%) were used for this study. Resistance measurements were performed by using a four-point probe technique including a high-precision experimental set up (Keithley Instruments Model 6221 as a constant current source, Keithley Instruments Model 6514 as electrometers, Keithley Instruments Model 2000 as a digital multimeter and transferred to a data file via a LabVIEW software). In Figure 1 the measurement devices and electrical conductivity measurement set up were demonstrated.

Fig. 1 (a) Measurement devices and connection set-up (b) Electrical conductivity measurement system.

For each type GE/Rubber nanocomposites, the pre-cut dimensions associated with the constant strain from 0% to 20% were analyzed and discussed concerning the change in electrical signals. Through the conductive structure of the GE/Rubber nanocomposites, during stretching and relaxation, strain and pre-cut length dependent electrical signals have been obtained. Although the electrical response was similar qualitatively at both 4 phr and 8 phr GE/rubber.
nanocomposites, an addition of 1 phr of GE/rubber nanocomposites showed a significantly different response both qualitatively and quantitatively. It was apparent that a regular change in the resistance for each pre-cut dimension was observed when the strain amount was increased further up to %20 except for GE/Rubber nanocomposite at 1 phr. Electrical resistance variation of the GE/Rubber nanocomposites under periodical loading for all four different constant strain cases were presented in Figure 2.

This resistance change is the result of several mechanisms such as separation and stretching of the rubber matrix and filler molecules, the discontinuous network between GE and CB, agglomeration of rubber particles, inhomogeneous dispersion of fillers, reduction of the conductive area due to pre-cut dimension. Finally, GE/Rubber based nanocomposite materials were presented excellent sensing performance under cyclical loading for 4 phr GE addition.

REFERENCES
The last forty years, an escalating usage of composite materials has been observed in aerospace industry for structural performance reasons. Initially, the composite materials were utilized in non-safety critical applications and recently in primary structures including fuselage and wings. Early 1970s, only 5% of airframe structural mass (Airbus A300), including radome fairing, was manufactured by composites. In 2010, when the A350 XWB was produced, it was the first aircraft of Airbus Industry with both fuselage and wings made primarily of carbon fiber reinforced polymer (CFRP). In particular, the A350 XWB airframe is made out of 53% CFRP providing increased structural efficiency and lower fuel consumption. However, the composites are prone to damage occurred by unexpected loads exceeding the design loads of the structure. This vulnerability can lead to extensive damage or even to structure perforation which will eventually degrade the post-impact residual strength of composite structure. The impact threats in aviation range from low-velocity impact, such as a tool drop during scheduled maintenance, to high-velocity one like birdstrike and hail impact. This facts leads to the need to design composite structures that must safely operate under the assumption that damage is present. For the enhanced prediction of damage caused by impact events and the cost saving of
experimental campaigns specified by airworthiness regulations, the current study proposes an
innovative progressive damage material model calibration procedure. The aim of this procedure
is to investigate the influence of each model parameter to quasi-static response of Cycom 977-2
CFRP laminate and, secondly, to approximate the best combination of material model
parameters that will represent the experimental quasi-static response of CFRP material. The
optimization algorithm is based on the comparison of the numerical force-displacement curves
with the corresponding experimental ones. It includes all basic material characterization tests
starting from Tension 0° and closes with Interlaminar shear strength test (ILSS). For
minimizing the parameters combinations, the calibration process was divided into two stages.
The first stage includes the in-plane characterization tests (Tension 0° & 90°, Compression 0°
& 90°, Shear and Open-Hole Tension test) for calibration of orthotropic material. Whereas the
second one consists of the fracture mode I and mode II as well as the ILSS test for cohesive
material calibration. Finally, for validation of material models, the low-velocity impact test
according AITM 1-0010 standard and high velocity one for the impact energy of 30J were
numerically simulated. The experimental and numerical contact force-time curve, time history
of projectile kinetic energy, delamination area and compression after impact maximum force are
correlated.
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Title: FUNCTIONAL STRUCTURAL NANOCOMPOSITES WITH INTEGRATED SELF-HEALING ABILITY

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Abstract

FUNCTIONAL STRUCTURAL NANOCOMPOSITES WITH INTEGRATED SELF-HEALING ABILITY

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ABSTRACT

In the recent years, the development of composite materials has been strongly related to the need to fulfill important requirements in the field of structural materials (aircrafts, ships, wind turbine blades, automotive or electronic devices, etc.). These requirements are: a) weight reduction - to maximize the performance; b) control of pollution during manufacturing process of the materials and their use in service; c) low consumption of fuel and resources; d) reduction of the manufacturing and operating costs (life cycle costs) etc. Aeronautical thermosetting resins show many of the mentioned properties, but their use is still limited because of several drawbacks, such as the absence of electrical and thermal conductivity and the poor impact damage resistance (vulnerability of non-metallic materials to environmental hazards such as such as rain, storms, turbulence, icing, lightning, wind speed, etc.) These limitations can lead to the damage accumulation process, highly compromising the integrity of the structures. An important contribution to increase the composite application in the field of structural materials, can be given by implementing a strategy of autonomous damage-repair and other specific functions integrated in the material structure.

This work proposes a successful strategy in this field, aimed to develop self-healing, load-bearing structures with all functionalities integrated in a single material able to meet many

Keywords:
Self-healing nanocomposites, thermosetting resins

Topic(s):
Repair and Self-Healing
important industrial requirements. Different innovative approaches have been recently considered to impart self-healing function to multifunctional resins. As an instance, for microencapsulated self-healing systems, a new ruthenium initiator for Ring-Opening Metathesis Polymerization (ROMP), which is able to tolerate reactive components, high temperatures during the curing cycles, and preserve its activity at very low concentration in combination with Diaminodiphenylsulfone (DDS) hardener, has been employed in aeronautical self-healing system [1,2]. Very recently, new relevant achievements have been obtained with different supramolecular chemistry approaches [3]. These last systems are usually characterized by repeatable and autonomous self-healing capability, representing interesting candidates, but they have been developed for applications where the high mechanical performance of thermosetting resins is required. Several attempts have also been made to extend these mechanisms to structural systems requiring high mechanical performance and integrated functionalities. In this context, hybrid materials or nanomaterials have been functionalized with hydrogen bonding moieties to activate self-healing mechanisms and introduce additional functionalities [4,5]. In this work, moieties able to act as hydrogen bonding donors and acceptors at the same time have been covalently bonded to multi-wall carbon nanotubes (MWCNT). In particular, MWCNTs have been functionalized with thymine and barbituric acid-based ligands via copper(I)-catalyzed alkyne/azide cycloaddition (CuAAC) “click” reaction. The functionalized carbon nanotubes have been embedded in an epoxy formulation, toughened with the addition of a liquid rubber, with the aim to activate self-healing mechanism in thermosetting aeronautical resin.

Acknowledgments
The research leading to these results has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 760940 – MASTRO.

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CHARACTERIZATION OF CARBON/GLASS HYBRID UNIDIRECTIONAL THERMOPLASTIC COMPOSITE

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004915160117688  
- Mechanics of Composites  
- Applications of Composites  
- Hybrid Composites

Keywords: carbon fibre, glass fibre, hybrid composites, bending, PA6

A tailored use of continuous fibre-reinforced plastics enables application in high volume car body structures. The combination of load carrying unidirectional continuous hybrid fibre-reinforced thermoplastic profiles and injection mold, named “skeleton design”, is a promising approach to meet structural requirements and economical needs.

Profiles with a cross-section of 10 mm x 10 mm made of PA6 with four different unidirectional carbon/glass fibre ratios were characterized. Flexural modulus, strength and strain to failure of profiles were determined using a four-point bending test.

The flexural modulus was 101 GPa (PA6-CF), 93 GPa (PA6-CF/GF), 45 GPa (PA6-GF/CF) and 37 GPa (PA6-GF). This matches the analytical predicted value using parallel axis theorem for all four carbon/glass fibre ratios. The flexural strength was determined to be 613 MPa (PA6-CF), 538 MPa (PA6-CF/GF), 616 MPa (PA6-GF/CF) and 673 MPa (PA6-GF). Thus hybrid profile’s strength depends strongly on fibre type on the outside. The strain to failure is 0,6 % (PA6 CF), 0,63 % (PA6-CF/GF), 1,3 % (PA6-GF/CF) and 1,8% (PA6-GF). Therefore strain to failure shows inverse proportionality to carbon fibre mass fraction.

It is shown that mechanical properties of profiles can be customized by varying the carbon/glass ratio and arrangement of fibres to fulfill the structural and economical requirements.
The human being has always been looking for optimal use of his surrounding materials and over the years, has managed to invent various structures with special properties. Lattice structures are widely used in various applications due to their lower weight and desirable compressive strength. An example of these structures is the honeycomb that is very popular and many studies have been done about it. A new type of lattice structures is auxetic structure that has negative Poisson ratio due to its geometrics. This characteristic has caused auxetic structures to have unique properties such as high shear strength, indentation resistance and energy absorption. Investigation of energy absorption of auxetic structures is a subject that has not been studied in researches. In this study, the ability of some auxetic structure for absorbing energy is investigated at quasi-static and low velocity impact transverse loading. Specimens with three types of geometries (Re-entrant, Arrowhead and Anti-Tetra-Chiral) are fabricated using additive manufacturing method (3D printing). Discussion about energy absorption and failure mechanisms of all three structures were carried out and compared in both types of loading.
Title: PROCESS SIMULATION OF SHEET MOLDING COMPOUND (SMC) USING A DIRECT BUNDLE SIMULATION

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Topic(s): - Composite Manufacturing
- Multiscale Modelling

Keywords: process simulation, μCT, sheet molding compound, discontinuous reinforcement

Abstract: Discontinuously reinforced polymers are widely used in lightweight design, because they can be economically pressed in complex shapes. The manufacturing process induces a re-orientation of fibers during the flow, which is of interest for quality assurance and structural computations. Typically, the re-orientation is described with an evolution equation for the second order fiber orientation tensor, which requires a closure approximation and multiple empirical parameters to describe long fibers. However, we observed in CT scans of SMC microstructures that fiber bundles stay intact during the molding process. Therefore, bundles are directly simulated as 1-D Elements using Stokes’ drag forces on bundle segments and opposing...
forces on the fluid field. The method is applied to SMC specimens with a double-curved geometry and with different positions of initial charges. The results are compared to conventional approaches employing a fiber orientation tensor and to CT scans of accordingly manufactured SMC specimens.
Title: PROCESSING AND DYNAMICAL CHARACTERIZATION OF AN EPOXY FOAM FOR AERONAUTICAL SANDWICH PANELS CORE

Abstract: In order to reduce the CO2 emission and face the global warming, the international authorities are demanding always more efforts to develop new materials with a higher strength to weight ratio. One interesting solution is represented by sandwich panels, combining a very low overall density with an incredibly high stiffness and mechanical strength. Today the most used solution for the sandwich panel’s core is the Nomex® honeycomb, because of its very interesting mechanical properties, low FST (Fire, Smoke and Toxicity) impact and their relative low cost of production. This solution, however, presents some drawbacks, as the low shock and moisture resistance and the so-called anti-elastic-curvature, a problem coming from the high Poisson’s ratio, turning into a difficulty of obtaining 3D complex shapes. One interesting alternative to solve these problems is represented by the use of closed cells foams as core materials. In this frame, this work aims to optimize the processing route and the mechanical properties of a commercial FST compliant epoxy closed cell foam, in order to use it as the core material of a sandwich panel for aircraft cabins applications. According to aeronautical regulations for environmental conditions and test procedures for airborne equipment, all the materials used in the airplanes have to respect standard requirements concerning their vibrational behavior. To
achieve this goal, the study is divided in two parts: from one hand the physical characterization of the system, aiming to evaluate the key process parameters affecting the final mechanical properties; from the other hand, the characterization of the dynamic mechanical characteristics of the final grade of the foam obtained from the first part of the study. The material, a bi-component system composed of an epoxy resin and a hardener, is processed in three phases: expansion, curing and post-curing. The expansion comes directly from the reaction between the two components of the system, because of the presence of a chemical blowing agent (CBA) directly integrated. Free expansion tests, optical microscopy observations and DSC dynamic scans are used to characterize the three phases of the processing route and to optimize the key process parameters. The nominal density after post-curing is around 270 kg/m³. However, the expansion process is very sensitive to room conditions, and small variation in pressure and temperature can strongly affect the final density and mechanical properties. The processing of the final sandwich panel is performed under vacuum bag and can bring the foam to see a higher temperature than during the post-curing. For this reason, TGA analysis are used to evaluate material thermal stability during this fourth phase of material processing, corresponding to the vacuum bagging of the sandwich panel. A final grade of the material is finally chosen for dynamical characterization (stiffness and damping) and to evaluate its vibrational behavior and energy dissipation, as a function of amplitude, frequency and temperature.
USING PIEZORESISTIVE PRESSURE SENSORS FOR RESIN FLOW MONITORING IN WIND TURBINE BLADES

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Topic(s): Composite Manufacturing
Keywords: Vacuum Assisted Resin Infusion (VARI), Piezoresistive sensors, Wind Turbine Blade, Fatigue, Sandwich Structure
Abstract: The production of large wind turbine blades is a costly and time consuming process. In order to get high quality products and to avoid dry spots, it is necessary to monitor the resin flow during the resin infusion process. Using piezoresistive pressure sensors and in-situ measurement of pressure gradient give live information about the textile impregnation status during the manufacturing process and enable instant reaction if some anomalies are discovered. In this work the effect of the used sensors on the static mechanical properties and the fatigue behaviour of the used glass fibre composites was investigated. The sensors were used during the
manufacturing of large sandwich panels similar to that used in wind turbine blades. It was found, that the used sensors don’t degrade the mechanical performance of the used materials and they are able to measure the pressure gradient during the manufacturing of wind turbine blades and to give information about the progress of the resin front.
Development of interphase engineering techniques for the ductility improvement in CF/EP composites

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- NDE and Structural Health Monitoring (SHM)
- Smart Material Structures
- Damage, Fatigue and Fracture

interphase engineering, ductility improvement, 3D printing, DIC

Although endless fiber reinforced composites provide exceptional mechanical performance, high strength to weight ratio, there is still a drawback compared to their metal competitors for structural applications: their limited ductility. Carbon fiber reinforced high performance composites have a tendency to fail instantly upon reaching their maximum load bearing capacity without any warning signs, or ductile plateau, plastic deformation, which could provide some extra safety in their application. Ductility improvement in composites can be addressed from the side of the reinforcing fibers, by hybridization, fiber misalignment or the application of short fibers, or from the side of the matrix material by applying rubber-like ductile matrices, special fillers, for example rubber particles to pin the propagating cracks. In our ongoing research we provide a different approach, interphase engineering, to improve ductility. In our research we locally weaken interfacial adhesion between the fibers and the polymer matrix by the application of a designed interlaminar pattern created by 3D printing from PCL (polycaprolactone), which can be solved in the epoxy resin matrix, leaving low adhesion pattern, but not creating a third phase in the composite. These local weakened zones can help to convert the main failure modes to more energy consuming delamination, creating a ductile plateau in the stress-strain characteristic of the curves. The feasibility of our research has been already demonstrated [1]. In our present research we try to investigate the fundamental processes leading to the ductility improvement. Simple patterns
are created in the tested composite coupons, and the local, designed formation of the
delamination is investigated by acoustic emission (AE), full field digital image correlation
(DIC) and thermography. Based on the results the most suitable interfacial patterning technique
was selected for the further research.

interphase engineering of polymer composites: Concept and feasibility. Express Polymer
Title: Improved Thermal Conductivity of Thermoplastic Polyurethane via Aligned Boron Nitride Platelets Assisted by 3D Printing

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Topic(s): Nano Composites

Abstract: The sample along printing direction at filler loading of 25.9 vol% (40 wt%) exhibits the in-plane thermal conductivity up to 2.56 Wm-1K-1, which is about 10 and 2.8 times enhancement, respectively, compared to the neat TPU and the sample along thickness direction at the same filler loading. The surface temperature distribution of samples with various heating durations is also presented. The effects of some key parameters, i.e. nozzle diameter, printing speed as well as filler loading, on the alignment level of hBN are also investigated. Finally, the alignment level of the platelets, valued as 0.12, is predicted by effective medium approximation, which is consistent with those measured by small angle X-ray scattering.
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Title: Experimental and Numerical Investigation on the Crashworthiness of the Vehicle’s B-Pillar reinforced by Composite Structures

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Topic(s): Impact and Dynamic Response
Keywords: Composite Reinforcement; B-Pillar; Crashworthiness

Abstract: Minimizing the intrusion into the occupant space in side crashes of vehicles is a challenging research topic because the sides of vehicles have relatively little space to absorb energy to keep safe occupants; unlike the fronts and rears which have substantial crumple zones. At side collisions, B-Pillar plays an important role in resisting the load due to the crash. The aim of this paper is to study the functional performance, the crashworthiness and potential mass reduction in the vehicle B-Pillar by attaching different shapes of composite reinforcements to the base structure. Accordingly, the B-Pillar is considered as a hat shape structure, then some different composite reinforcements are fabricated and attached to it. The specimens are tested under quasi-static three-point bending and drop hammer impact loading. The capability of each reinforcement to absorb energy and the different failure mechanisms are discussed upon. Finally, the whole structure is simulated numerically by LS-DYNA software. The results show a good correlation between experimental and numerical analysis.
Summary. In an attempt to further advance the braiding process in terms of productivity and quality, we have developed novel kinds of sensor integrated braiding rings which are able to time-continuously measure the distribution of yarn tension and thus detect braiding defects.

1 INTRODUCTION
The quality of braided textiles from reinforcement fibers and the stability of the process are negatively affected by irregularities that occur during braiding. Previous investigations conducted by Ebel et al. [1] showed that a specific braiding irregularity named fibrous ring causes yarn breakages and can lead to a machine downtime of up to 26 % of the total production time. Moreover, Mierzwa et al. [2] observed a 36 % reduction in tensile and a 33 % reduction in compressive strength when local yarn gaps were oriented perpendicularly to the loading direction of their braided specimens infiltrated by means of the Vacuum Assisted Process.

2 PROBLEM DEFINITION
To avoid the effects of braiding defects described above, there are, on the one hand, systems
which make use of sensors that are attached to the stationary body of the braiding machine [3]. Such approaches can only detect major braiding defects in their final stage (e.g. yarn breakages) or come with an insensitive time until the defective yarn reaches a sensor. On the other hand, there are approaches which include the installation of sensors directly onto the moving bobbin carriers [4,5]. These systems are able to detect even minor process irregularities at short response times. Major drawbacks of this kind of systems are however their high costs and complexity. The abstract at hand outlines a newly developed form of a stationary sensor module (thereby being cost-efficient) which is able to gather quasi time-continuous measurements (thereby realizing short response times) as a way to solve the delineated conflict of objectives.

3 CONCEPT OF THE SENSOR INTEGRATED BRAIDING RINGS
The only component of a braiding machine which is stationary and at the same time continuously in contact with the moving fibers is the braiding ring. Coming from the bobbin carriers, the fibers are deflected by the braiding ring before they form the braid on the tubular mandrel. Hence, each yarn exercises an axial (in production direction) and a radial force onto the braiding ring. During regular operation of a braiding machine, these reaction forces are evenly distributed around the circumference of the ring. Uneven distributions of the reaction forces suggest the presence of a braiding irregularity. Thus, two kinds of braiding rings to measure fluctuations of reaction forces in axial as well as in radial direction were developed, respectively. They both consist of a stationary outer part and a movable inner part. In the first ring, the connection between the inner and outer part is radially stiff but axially flexible. In the second ring, the said connection is axially stiff but radially deformable. By incorporating four force sensing resistors offset by 90° between the inner and outer part along the particular movement axis, the distribution of reaction forces on the rings can be measured.

4 TEST OF THE SENSOR MODULE IN AN OPERATING BRAIDING MACHINE
To validate the functionality of the two braiding rings in a near-production environment, they were tested while overbraiding a cylindrical mandrel (Ø 65 mm) with 12k carbon fiber yarns. Reference measurements were conducted with a regularly operating RF 1/128-100 braiding machine from Herzog GmbH. Subsequently, a defective bobbin carrier was simulated by adding a screw-on barrel tensioner to a single bobbin carrier. To examine several levels of reaction forces, the speed of horn gear rotation was varied between 65 and 130 rpm and the braiding angle was set to 30°, 45° and 60°, respectively. The measurement results obtained from the axially flexible but radially stiff ring at 65 rpm horn gear speed and 60° braiding angle are depicted in Fig. 1. During regular operation, constant sensor signals are observable. By contrast, the simulated defect lead to distinct fluctuations in the sensor signals which were phase-shifted by 90°. Hence, the sensors successfully indicated the presence of a replicated defect. (figure included in extended abstract (pdf))

Fig. 1 Signals from four pressure sensors (red, yellow, green, blue) during regular (dash-dotted lines) and defective braiding (solid lines)

5 CONCLUSION AND OUTLOOK
The authors conclude that the developed sensor integrated braiding rings are well-suited for time-continuously detecting process irregularities during braiding. Future work will include the development of real-time capable data evaluation algorithms to be able to reliably identify the position of the defective bobbin carrier from the measurement signals.

REFERENCES
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Title: Characterization of CFRP mode I and mode II cohesive element parameters for 0/0 and +45/-45 interfaces

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Decades of research on composites showed that delamination is one of the most critical parameters responsible for failure of a laminated composite design. Today, the research community is investing effort in understanding, characterizing and predicting the delamination onset and propagation under static and fatigue loading. Characterization of Mode I (opening) and Mode II (shearing) interface failure mode have been extensively studied for $0/0$ interfaces \cite{1, 2, 3, 4, 5, 6, 7, 8}. However, simulation requires also delamination prediction at “non-zero” interfaces ($\pm \theta$/$-\theta$, $\theta$ being a non-zero angle between two consecutive plies where the delamination occurs). Characterization of such interfaces in static and fatigue are not yet covered by standardized methods but prove to be key for industrial usage \cite{9, 10, 11, 12}. This work presents and proposes a robust process flow to characterize interlaminar static properties for CFRP at $0/0$ and $\pm 45/-45$ interfaces. Initial estimation of the interlaminar cohesive element parameters were derived from a set of testing data via standard analytical formulations (compliance calibration, Modified beam theory …). The onset detection was cross-evaluated using optical method (microscopy) and FEA correlation (including damage intraplies model). Finally influence of the testing method (ASTM, JIS), pre-cracking method (mode I or mode II resulting in different crack front shape), pre-crack length and resin system on the identified parameters were investigated using scanning electron microscopy, dynamic mechanical thermal analysis, FEA correlation and X-Ray. The process flow for parameter identification herein proposed covers static parameters for standard separation law of cohesive zone models used in Simcenter 3D - Samcef and will be extended to fatigue parameter identifications for the interlaminar fatigue prediction models.

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Title: Plate Impact Tests Characterisation of Carbon Fibre Reinforced Polymers for High Velocity Impact

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Abstract:
Materials and structures used for aerospace and automotive applications are designed to exhibit high strength and lightweight, hence the most recent design solutions are dominated by carbon fibre composites polymers (CFRP), rather than traditional metals. The CFRP materials are often exposed to the high rate impact loading, with the range of strain rates from $10^3$ s$^{-1}$ to $10^6$ s$^{-1}$. Typical impact scenarios are: debris impact, hail stone and ice impacts, bird strike, armour penetration etc. These extreme impact cases almost always involve generation and propagation of shock waves within the materials. Equally, the CFRP material behaviour is complex due to their pronounced anisotropy and heterogeneity, and include a number of material damage and failure mechanisms that are activated by different loading conditions. Consequently, the material behaviour under such a complex loading need to be well understood and properly characterised, which remains a challenging task.

The work presented here considers the effect the material orientation has on the material shock equations of state for both through thickness and fibre directions. Among the different architectures of the composite materials, the subject of this investigation is unidirectional fibres impregnated with CYCOM 977-2 CFRP resin provided by CYTEC [1]. The material characterisation is based on the plate impact tests, which has already been used in the investigation of the CFRPs by Millet et. al. [2], Riedel et.al. [3], Dattelbaum [4]. The test consists of coplanar impact of a flyer plate of known properties against a target plate made of the CFRP to be characterised, where the materials undergo uniaxial state of strain. The output of the tests are Hugoniot Elastic limit and EoS parameters for numerical hydrocodes. This is done as part of an effort to support development of the tools for modelling of high velocity impact on composites in the European project EXTREME*.

References
TIME-DEPENDENT FAILURE OF UNIDIRECTIONAL, OFF-AXIS GLASS/IPP COMPOSITES

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The aim of this work is to investigate the time-dependent tensile failure of UD off-axis composites and evaluate its angle dependence. In order to evaluate the time-dependent short-term failure, off-axis angle and strain rate dependence of the tensile strength will be determined. Long-term failure tests will include creep and fatigue tests at various stress levels and off-axis angles at room temperature. A method to predict creep and fatigue lifetime from short-term tests will be proposed, which is based on the plasticity-controlled failure of thermoplastic polymer systems.

Results indicate that off-axis angle and strain-rate dependence of the short-term strength can be decoupled. By doing so, strain-rate dependent strength at an off-axis fiber angle can be determined from a reference angle by using a shift factor. Lifetime under creep and cyclic loading was predicted well with the method proposed. Cyclic loading led failure to be delayed compared to creep loading, which showed that failure is dominated by the accumulation of plastic strain.

Off-axis behavior of the thermoplastic composites is dominated by the matrix. Thus, they exhibit time-dependent short- and long-term failure, likewise neat thermoplastics: tensile strength depends on the applied strain rate and they are highly prone to creep and fatigue failure. Understanding the failure kinetics is fundamental for lifetime predictions under long-term loading. Investigating the failure kinetics of unidirectional (UD) off-axis composites is especially crucial since the failure of more complex laminates is affected by time-dependent damage in the off-axis layers.
The proposed work concerns the evaluation of the behind armour blunt trauma in comparison to witness material measurements. Blocks of ballistic gelatine are commonly used for simulating the dynamic response of soft parts of the human body. Covered with ultra-high molecular weight polyethylene (so called Dyneema®) based ballistic protections, it is possible to observe and assess shock waves and displacement of this transparent witness material during ballistic impact of deformable projectiles. Simulations were realized for evaluating the process and damage mechanisms occurring to the projectiles, composite protection and the gelatine, followed by experimental validation.
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Title: Green clean-up technologies based on functional humic-based materials

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Topic(s): - Hybrid Composites
- Green Composites
- Metal-matrix Composites
- Nano Composites

Keywords: Nanocomposites, Magnetite, Humic acids, Bioactivity, Polycomplexes, Remediation

Abstract: Humic materials have the most striking feature in the context of environmental chemistry due to constellation of such unique properties as non-toxicity, biocompatibility, resistance to biodegradation, and polyfunctionality. As a result, diverse functional and hybrid materials can be derived on the basis of humic materials. These materials can be competitive on the market of biobased products, nominally, green special chemicals as dispersants, flocculants, chelators, etc. We have been formulated a set of nanocomposites containing iron oxide (Fe3O4) and humic acids (HA) to use as sorbents for toxic metals [1] and emerging pollutants (diclofenac and ciprofloxacin). The average particle size calculated tended to decrease from 8.4 to 4.5 nm with...
increasing of HA from 20 to 80 wt%. Mössbauer measurements let identify the nanoparticle core composition as a magnetite. Optical spectroscopy indicated that the fluorescence quantum yield depended on the HA content in the nanocomposite and confirmed that the humic component interacted with ferric ions.

Biosafety of nanocomposites investigated in our laboratory biotest systems using algae, paramecium, and higher plants was allowed to set concentration limits for the NPs. Given that after release into the environment, humics-magnetite NPs undergo various transformations via the interactions with different geochemical and biological components, which ultimately influence their behavior and potential toxicity, we have simulated the oxidation process of magnetite to maghemite in HA and HA-free media. The oxidation is difficult to monitor as both iron oxides polymorphs possess connatural chemical properties, but NPs have various biological activity. The XRD patterns indicate that the crystal phase for magnetite before and after oxidation has not changed. But, Mössbauer spectroscopy as a more powerful tool for the identification of the chemical state and crystal environment of iron species confirms transformation magnetite in maghemite species even so in humic shell.

Mitigating effect of HA on bioactivity of Fe3O4 and γ-Fe2O3 to a green algae and a higher plant (white mustard) were investigated, with a focus on the effect of oxidation state. As a result, the growth inhibition of iron oxides NPs to both test-species increased with an order Fe3O4 < Fe3O4/HA < γ-Fe2O3/HA.

To answer the question − whether the toxicity of iron oxides NPs from the released ions or NPs itself arises, behaviors of Fe3O4-NPs and iron ions (Fe2+ and Fe3+) in the presence of HA, that easily coordinate to iron (II, III) ions and graft to NPs surfaces, were investigated in the aspects of their toxicity to Sinapis alba and Paramecium caudatum in terms of endpoints (EC50) and threshold level (EC20). Fe(II), Fe(III) ions and HA clearly demonstrated increased toxicity with respect to root length of S. alba seedlings and mortality of P. caudatum. Combination of Fe (II and/or III) with HA lead to mitigation of toxicity. The Fe3O4-NPs in some concentrations stimulated the survival of ciliates and the growth of higher plants. In case of the Fe3O4-NPs-HA treatment, the disperse system effect as a whole is affected. For both Fe3O4-NPs and Fe3O4-NPs-HA the toxicity more largely depend on the treatment concentration.

To formation additional protective layer for magnetite-HA from oxidation and to disseminate applications we grafted Fe3O4 with two different alkoxysilanes: tetraethoxysilane (TEOS, as a surface layer) and 3-aminopropyl-triethoxysilane (APTES, as anchor layer with aminogroups) and then HA. The XRD pattern for all samples proved that magnetite is main phase. The bioactivity of samples demonstrated higher toxicity for Fe3O4/TEOS/APTES/HA in compare with Fe3O4/HA. To clarify why composites with humic end-surface in both cases give different bio-responses, the surface charge and other colloidal characteristics for NPs-HA are required to study [2]. Moreover, conditions that lead to stable Fe3O4-SiO2-HA with low iso-electric points is in progress.

The relatively new field of our research is formulation of novel imprinted materials (IIM), incl. magnetic nanoparticles with high recognition for set of metal ions, incl. UO22+ in the presence of competing ions prepared by cross-linking HA with aminocompounds. Removal of the Co (II), Ni(II), Cu(II) from the IIM and creation of cavities for hosting Cu(II) was proved by comparison of the response of IIM to template with that of non-imprinted material (NIM). The thermodynamic and kinetic properties of the adsorption process were studied to explore the internal adsorption mechanism. The relative selectivity coefficients of Me-IIM were determined.

Another part of research of the HA in terms of environmental application is devoted to the design, development and application of a new generation of binders (non-stoichiometric interpolyelectrolyte complexes, NIPECs) for various dispersed systems, incl. soil [3]. The universal binders are formed by interaction of oppositely charged polyelectrolytes (PEI/PDADMAC and PAA and HA), both chemically stable. Numerous results of laboratory experiments and field trials of the NIPEC formulations were obtained. In particular, large-scale tests have been done in the Kadzhi-Say uranium technogenic provinces where the NIPEC binders were shown to be effective means to suppress water and wind erosion thereby preventing a spread of radioactive particles (radionuclides) from contaminated sites. NIPECs are able to bind effectively a majority of toxic metals due to incorporation of metals inside hydrophobic NIPEC fragments generated by mutually neutralized cationic and anionic units.

REFERENCES


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Title: ELECTRORHEOLOGICAL PROPERTIES OF POLYIMIDE NANOPARTICLES SUSPENSIONS

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Topic(s): Smart Material Structures
Keywords: Electrorheological suspensions, Polyimides, Temperature effect, Viscosity

Abstract: Electrorheological suspensions (ERS) under the influence of an external electric field can experience significant changes in their properties: viscosity, yield strength, shear modulus, etc. ERS pass from low-viscosity and liquid-flowing state to solid or viscoplastic. And these changes are reversible and occur within milliseconds. In this regard, ERS are very promising
from a practical point of view and they are referred to as smart materials whose properties can be controlled. It is known that ERSs are used in electrically controlled mechanical transmission devices, for example, in controlled dampers, electromagnetic clutches, various vibration protection devices, etc. One of the most frequently studied dispersed phases in ERS are polymers, in particular polyimides. This possibility is due to the high degree of aromaticity and the ability to form charge transfer complexes both internally and intermolecularly. In this work, the rheological properties of suspensions obtained using various polyimide particles are investigated.

Polyimide particles ERS were obtained in various nonconductive dispersion media based on a series of aromatic polyimides synthesized by the single-stage high-temperature polycondensation method on the basis of 4,4'-diaminodiphenylsulfide and 2,5-diaminobenzenesulfonic acid with different dianhydrides phenyltetracarboxylic acids. The structure and size of polyimide nanoparticles were studied and characterized by methods MALDI-TOF, IR and 1H-NMR spectroscopy, Dynamic light scattering and other. Their electrorheological properties were investigated in nonconducting medium depending on parameters of deformation and external electric field intensity.

It was established that ERS based on polyimide nanoparticles possess a powerful electrorheological response that is ten times greater than the ERS response with a dispersed phase based on traditional microparticles.

It is shown that polyimide ERS, as a result of an increase in the electric field strength, changes the nature of the flow from the Newtonian type to the pseudoplastic one because of the polarization of the particles and the formation of chain structures along the force lines of the electric field. Complexes with intermolecular and intramolecular charge transfer are formed in the medium. Interactions occur between rich electrons (donors) nitrogen atoms and electron-depleted carbonyl groups (acceptors). These random interactions lead to the formation of additional bonds that increase creep resistance and other physical and mechanical characteristics.

The influence of temperature on the change in the rheological and electro-rheological properties of polyimide ERS in constant electric fields was established. It is shown that the electrorheological effect of polyimide ERS is most pronounced at a temperature of about 45°C. It is also shown that the electrorheological effect is more pronounced for the ERS of the polyimide in the transformer oil than in the dibutylphthalate and PMS-500, which, apparently, is due to the lower dielectric permittivity of the medium.

The viscosity of suspensions for polyimides at an equal shear rate increases with an increase in the magnitude of the applied voltage, which is characteristic of electrorheological suspensions. Thus, it is possible to customize the value of the viscosity of the suspension, depending on the practical task.

REFERENCES
Composite structures comprise large parts of modern aircrafts, as they are low in weight in
provide strength superior to commonly used metallic structures. However, the complexity of the
material demands for novel Structural Health Monitoring (SHM) techniques in order to
accurately monitor the state of the material and make statements about lifetime and behavior
[1]. In recent years, efforts were made to integrate sensors such as fiber-Bragg gratings (FBG)
into composite structures. Their advantage over other SHM sensors are their small size and
light weight, immunity to electromagnetic interference and multiplexing capabilities [2]. SHM
applications with FBGs are often restricted by the optical interrogation of the sensors, where
compromises between sampling frequency, resolution and dynamic range have to be made. In
particular, high speed interrogators are limited to strain measurements of only few tens of µε
and complicated tuning schemes have to be employed to overcome these limitations [3,4].
Previously, we demonstrated an interrogator with superior dynamic range of 1,000µε, while
allowing for 1MHz sampling speed and high strain sensitivity measurements of smaller than
1µε [5]. The interrogator is based on a small-scale demultiplexed Mach-Zehnder interferometer
(DMI) manufactured on a photonic integrated chip. In this work, we showcase the multiplexing
capabilities of the tool by monitoring an array of multiple sensors to capture impact events. The
impact location is determined from the measured strain data via a Time Difference Of Arrival
(TDOA) algorithm. The results show good accuracy and prove the suitability of newly
developed interrogator for this SHM task.


WIND TURBINE ONE SHOT BLADE®: DESIGN AND VERIFICATION

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Topic(s): - Mechanics of Composites
- Composite Manufacturing
Keywords: Wind turbine blade, Fiber-glass, One Shot Blade®, Buckling, Composites, FEM

The design of composites-based wind turbine blades manufactured with an innovative process, named One Shot Blade® technology, is the focus of this paper. The One Shot Blade® technology allows the production of a wind turbine blade with no adhesives, with or without shear-webs, in a single infusion process, resulting in a significant reduction of the man-hours, costs, and materials. In the frame of the study presented in this work, a 10-meter long fibreglass blade without shear-web is designed and verified by numerical simulations. Structural performances are evaluated to verify the compliance with the IEC 61400-2 and Germanischer-Lloyd (GL) regulations. Finally, comparison against conventional wind turbine blades, manufactured by means standard processes is introduced to highlight the added value of the proposed technology.
AN EXPERIMENTAL/NUMERICAL STUDY ON THE MECHANICAL BEHAVIOUR OF COMPOSITES UNDER ASYMMETRICAL BENDING LOADING CONDITIONS

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Topic(s): - Mechanics of Composites
- Damage, Fatigue and Fracture

Keywords: Skin-stringer debonding, CFRP, Three-point bending test, FEM, NDI, Asymmetrical load

Abstract: In this work, the mechanical behaviour of a stiffened composite panel subjected to symmetrical and asymmetrical bending load is assessed. The investigated composite structure, representative of a regional aircraft fuselage stiffened skin section, consists of a curved CFRP panel and a co-cured CFRP omega stringer. The structure was undergone to bending loading conditions, which
was simulated by means of 3-point bending tests. The scope of this test is to evaluate the damage status and the skin-stringer debonding under such load conditions. First, a preliminary numerical study has been performed, in order to investigate the influence of the asymmetrical bending loading conditions on the intra-laminar and inter-laminar damage onset and evolution, considering different panel and testing configurations. The obtained numerical results, in terms of stiffness and debonding area, have been integrated by data taken from experimental tests and non-destructive inspections (NDI) in order to exploit the effects of asymmetrical damage distribution on the final failure of the investigated panels.
Multi-Wall Carbon Nanotubes (MWCNTs) have been incorporated in an epoxy resin based on the bifunctional epoxy precursor diglycidyl ether of bisphenol A (DGEBA). The strain sensitivity, in the range between 0.67 and 4.45, may be enhanced by controlling the nanotube percentage. It has been found that the Gauge Factor (G.F.) decreases with increasing the carbon nanotubes percentage. Microscale damages resulted directly related to the resistance changes and hence easily detectable in a non-destructive way by means of electrical measurements. In the fatigue tests, the damage is diagnosticable through the presence of a residual resistivity, which increases with the amount of plastic strain accumulated in the matrix. The piezoresistive property of this nanocharged epoxy formulation has been exploited for imparting self-sensing and Health-Monitoring function to a structural coating for aeronautical Carbon Fiber Reinforced Panels (CFRPs). Mechanical and piezoresistive performance of the CFRP coated with the formulated epoxy resin containing 0.1 wt% of MWCNT has been analyzed for the panel loaded in axial tension. The surface normalized resistivity results linear with the strain highlighting the possibility to monitor the strain in the regime of the elastic deformation. The Gage Factor (G.F.=ΔR/εR0) of the conductive coating was found to be 4.7, which is the highest value found until now for structural coating. Together with the high sensitivity factor of the self-sensing coating, high values in glass transition temperature and storage modulus were found proving that the developed strain sensor result reliable in the normal operational temperature range of the aircraft and automotive components.
ID: 61

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Title: A Multi-Layer Finite Shell Element based on the Generalized Unified Formulation for the Analysis of Hybrid Carbon Fiber Elastomer Metal Laminates

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Topic(s): - Mechanics of Composites
          - Smart Material Structures

Keywords: Generalized Unified Formulation, shell theory, hybrid laminates

Abstract: Due to their high stiffness, thin lightweight hybrid CFRP and metal laminates are usually prone to vibrations. Including additional elastomeric layers in the laminate can significantly reduce those vibrations by means of constrained layer damping. In order to take advantage of this mechanism on component level, knowledge of the deformation behavior is required. Commonly used equivalent single-layer shell and plate theories, however, are unable to account for the strong heterogeneous stiffness distribution of the constituents within the laminate.

Furthermore, the transverse shear and normal deformations in the elastomer layer are expected to significantly influence the deformation of the neighboring laminae. An accurate depiction of these transverse stresses requires a multi-layer shell theory as opposed to commonly used single-layer formulations. Therefore a multi-layer finite shell element based on the Generalized Unified Formulation is developed in order to efficiently analyze and optimize the deformation behavior of such hybrid laminates on a structural level where the computational effort forbids the use of a three dimensional continuum formulation.
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Title: EXPERIMENTAL INVESTIGATION ON FATIGUE BEHAVIOR OF PATCH REPAIRED CARBON/EPoxy LAMINATES

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Topic(s): - Repair and Self-Healing
- Damage, Fatigue and Fracture

Keywords: Patch repair composite, fatigue, digital image correlation, failure modes

Abstract: Composites offer various advantages such as high strength to weight ratio, corrosion resistance, tailored properties etc., which makes them suitable replacement of metals in many structural applications. However, the composites are more susceptible to various in-service damages due to their inherent brittle nature. These damages result in degradation of the strength and life of the composites. Hence it becomes imperative to address these damages. The replacement of the damaged components is one solution. However, the high cost of replacement restricts the extent of usage of composites in various applications. In order to reduce the overall cost of component during its life, the repair of composites is a feasible solution. In this regards, the domain of repair of composites has drawn significant attention of the researchers worldwide.

One of the method of composite repair is the bonding of the patches at the damaged site. The two most commonly used bonded patch repair techniques are scarf repair technique and external patch repair technique. The scarf repair technique involves removal of material from the damaged site of the laminate in the form of a tapered hole and bonding a matching tapered patch into the hole. This technique provides a flushed repaired surface. However, the preparation for the scarf repair involves high skills and is a high cost intensive process. Hence, the external patch repair provides a cost effective alternative to the scarf repair for the applications where the protrusion on the surface due to use of external patch do not affect the functioning of the repaired component. However, the inherent heterogeneity of composite laminate makes the design of the patch a complex task. Various parameters of the patch-parent combination such as stacking sequence, stiffness, patch material, adhesive system etc., play a role in the performance of the repaired laminate. Moreover, during the service, the laminate undergoes various loading-unloading cycles. Thus, it becomes important to investigate the performance of repaired laminates under fatigue loading.

This work investigates the behavior of external patch repaired carbon/epoxy laminates under load controlled constant amplitude tensile fatigue loading. The specimens of laminate configuration [45/0/0/45] are repaired by bonding the pre-cured patches of two configurations viz. [0]2 and [45]2 on the specimens having a hole, which mimic the damage on laminates. Experiments are conducted on three sets of specimens viz. pristine (without hole), drilled (with hole) and repaired (patch-repaired). Digital image correlation (DIC) is employed to capture the
development of strain field. The examination of repaired specimens during tests reveal that the failure initiates in the form of delamination between the plies of parent specimens, which grows further with respect to the number of loading cycles and ultimately leads to a catastrophic failure of the specimen. From the results it is observed that the external patch repair has a significant potential of restoration of fatigue life of the laminates. The work is being extended to study the behavior of more parent laminate configurations having different stacking sequence. The results will provide more insight into determining the suitability of external patch repair for laminates undergoing cyclic loading.
STRESS RELAXATION IN ASYMMETRIC BISTABLE COMPOSITES: EXPERIMENTS AND SIMULATIONS

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Topic(s):
- Mechanics of Composites
- Composite Manufacturing
- Smart Material Structures
- Applications of Composites

Keywords: Stress relaxation, Asymmetric composite laminates, Bistable plates

Abstract: In the last years, bistable composite structures are finding interest in several aeronautic applications such as power harvesting devices or morphing applications on very small aircraft/drones without the need of servo-activated control systems. The residual stresses, leading to warped and bistable shape of these laminates, are considered in this paper. Several batches of unsymmetrical and unbalanced [0/90] laminates were cured in an autoclave according to a standard temperature cycle, following the pre-preg supplier instructions. In order to increase the thermal stresses (and hence the bistability phenomenon), these laminates were removed from the autoclave immediately after the curing reaction and rapidly cooled down in open air instead of following the typical cool rate of 2–5 °C min−1 suggested by the manufacturer. Thermal stresses changed over time, indicating that asymptotic stress relaxation occurs. The first part this work looks at residual stress characterization of bistable composite plates measuring the changes of shape observed during room temperature annealing. Rectangular plates with different aspect ratio were produced and the bistable geometric shape was accurately assessed using a laser scanner system over two weeks, in order to monitor the curvature changes due to stress relaxation. Then a phenomenological viscoelastic predicting model was proposed for a quick estimate for the strain/stress relaxation phenomenon. Furthermore a stress-strain model suitable for bistable materials including time-dependent effects was developed. The loss of bistability was demonstrated with the help of numerical simulation and experimental testing. The final goal was to gain a better knowledge of the
relation between processing and final shape of bistable laminates, accounting for aspect ratio and stress relaxation, in order to make them suitable for application on small air vehicles.
ACTIVE AND PASSIVE SHM FOR COMPOSITE PIPES USING PIEZOELECTRIC SENSORS

Title: ACTIVE AND PASSIVE SHM FOR COMPOSITE PIPES USING PIEZOELECTRIC SENSORS

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Topic(s): - NDE and Structural Health Monitoring (SHM)
- Smart Material Structures

Keywords: Structural Health Monitoring, Ultrasonic Waves, Composite Pipes.

Abstract: Composite materials, in addition to the high specific mechanical properties, are characterized by several promising characteristics enabling the applications in high-pressure, high-temperature (HPHT) and corrosive environment as occurs in deep water. The choice of these materials for manufacturing of pipelines or offshore risers can provide relevant performance advantages over steel such as lower weight, improved fatigue capacity, corrosion resistance and higher strain limits. However, composite materials are more complex to use in design than metallic materials due to their anisotropic properties and lack of accurate failure prediction models. Thus, a continuous in-situ and in-real-time Structural Health Monitoring (SHM) of composite components would be necessary and useful to promote their use in a wider range of operational conditions. In this work, an FRP pipe sample was instrumented with Piezoelectric Wafer Active Sensors (PWAS) used either as passive receivers of acoustic emission signals either as transmitters of guided waves for active health monitoring in pitch-catch configuration. The propagation properties of guided waves in an epoxy matrix pipe reinforced with glass fibres were studied developing Matlab scripts, running FE simulation and experiments. Coupled field numerical analyses were carried out to take into account the PWAS action. The numerical and experimental signals were post-processed in Matlab by Fast Fourier Transform (FFT) and Short Time Fourier Transform (STFT) in order to evaluate the frequency and time-frequency content respectively. The amplitude behaviour of each mode was studied in order to obtain the tuning curves and the frequency with the maximum amplitude. Furthermore, the guided waves were used to detect artificial defects imposed on the structure evaluating their size and location. Several testcases were studied to find out the limitations and the most suitable conditions of using guided waves for defects monitoring in a composite pipe. The work proposes prominent
methods of pipe structural health evaluation by non-destructive techniques and ultrasonic guided waves.
The thermo-structural design of critical components for re-entry vehicles (e.g. nose and wing leading edge) requires the adoption of very detailed and complex finite element thermal and mechanical analyses. Indeed, since very high heat fluxes are expected during the atmospheric re-entry, Ceramic Matrix Composites (CMC) are usually employed because they can guarantee lightness, high damage tolerance, crack/fracture resistance, high tensile, bending and compression strength aside from high temperature stability (1900 °C) and excellent thermal shock resistance. However, such materials, characterized by a complex micro-structure, require demanding numerical tools involving very high computational costs. For this reason, Global/Local approaches need usually to be employed in order to obtain high level of accuracy, especially in the most critical areas of the components, with a significant saving of the computational cost. These efficient numerical tools allow to perform detailed numerical
analyses even in a preliminary design phase where very coarse global models are usually adopted. In the present work, Global/Local finite element models are defined with the aim to improve the design of the Wing Leading Edge of an hypersonic vehicle. The aerodynamic heating, experienced along the re-entry trajectory of the CIRA Unmanned Space Vehicle FTB-X has been used as loading condition for the wing leading edge design. Local models have been defined at the interfaces between the internal and the external structure, where structural criticalities are expected, and the corresponding numerical results have been assessed and compared. Finite element commercial environments have been adopted for the numerical computations (ANSYS and ABAQUS).
Consent: I consent to the collection and use of my personal information, including receiving emails, for activities related to 12th International Conference on Composite Science and Technology (ICCST/12). I have also obtained the consent of all other individuals whose information I provide. (2019-01-30 15:45:43 UTC)

Title: CRASHWORTHINESS OF A GENERAL AVIATION FUSELAGE SECTION: 3D FEM NUMERICAL MODELLING AND VALIDATION

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Topic(s): - Mechanics of Composites
- Impact and Dynamic Response
- Damage, Fatigue and Fracture
Keywords: FEM, Crashworthiness, Fuselage section, Composites, Damage progression

Abstract: Crashworthiness is defined as the capability of a structure to guarantee its occupants safety during a crash event. In the present work, the crashworthiness of a composite fuselage section has been investigated. Indeed, the mechanical behaviour of the investigated fuselage section has been assessed by means of the FE code ABAQUS/Explicit, considering an impact event on a rigid surface. The proposed numerical model, capable to take into account the matrix and fibre traction and compression damages, uses a 3D Finite Element formulation to better predict the deformations and the damages onset and propagation during the impact event. The numerical results, in terms of structural deformation, energy absorption, acceleration, and damage onset and propagation, have been compared with data from an experimental impact test, performed in the frame of the CERVIA PON-DAC project, on a full scale fuselage section. Finally, the effects on the occupants have been preliminary assessed by comparing the accelerations at seat locations with critical thresholds.
THIN VEILS STRATEGICALLY INTERLEAVED TO REDUCE LOW VELOCITY IMPACT DAMAGES ON CFRP

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Topic(s): Damage, Fatigue and Fracture
Keywords: CFRP, Advanced composites, Thin veils, Low velocity impact, Damage

Abstract: In the last decades, polymeric composite materials have been used around the world to perform in highly demanding markets, such as, the aeronautic, aerospace and sports ones. Their outstanding mechanical properties, such as, high stiffness and strength, allied to their low density make them more competitive and attractive for advanced applications than the most common traditional materials. Even though, due to their high brittleness and layer-by-layer inherent nature, they present some weakness when submitted to some specific kinds of loading, such as, impact, dynamic and flexural. Low velocity impacts (LVI) are one of the most dangerous events that composite laminate can face in their life time. These loadings may develop imperceptible internal laminate damages, namely delaminations, which tend of propagate in service, compromising part performance. In order to reduce damage propagation, some works can be founded in literature using interleaved thin veils between laminate layers that enhanced interlaminar fracture toughness in Mode I and II and improve damage tolerance at low velocity impacts. In this work, a theoretical study was carried out on stresses distribution across laminate thickness, when a bending moment is applied, on a carbon/epoxy laminate typical used on aircraft components in order to define where should be better to interleave thin veils of different materials (glass, carbon, aramid and polyester) to improve damage tolerance induced by LVI (a scheme of this approach...
may be seen on Fig. 1). Then, new interleaved carbon/epoxy laminates, made according to the selected structures, were produced by vacuum bag infusion and their mechanical and LVI response were compared with a non-interleaved one produced under the same conditions. All these studied laminates were observed under scanning electron microscopes (SEM) for assessing their processing quality. Interlaminar shear strength (ILSS), flexural and LVI tests at four different energy impact levels were performed in order to evaluate their damage tolerance and impact response.
Composite materials can be potentially considered as an attractive solution for the weight reduction of aerospace structure. Indeed, fibre reinforced composite materials have excellent properties in terms of stiffness/weight, durability, and versatility if compared to metallic alloys; however, they have been found highly sensitive to damages, which may be hardly controlled and predicted. Among all the failure mechanisms that can affect composite materials, delamination can be considered as the most critical one especially if associated to compressive loading conditions. In this work, the effect of the fibre bridging phenomenon on the delamination propagation in CFRP panels is experimentally and numerically investigated. Composite plates, with an artificial through-the-width delamination, have been tested under compression. The results have been correlated to numerical analyses carried out by means of a
robust numerical procedure implemented in the ANSYS® FEM code, which, based on the Virtual Crack Closure Technique (VCCT), has been modified in order to avoid time-step and mesh dependency issues in simulating delaminations’ growth. As a further improvement, this procedure has been made capable to simulate the fibre bridging phenomenon by considering the real variation of the Critical Energy Release Rate associated to fracture Mode I. The main purpose of this research work is to exploit the intrinsic characteristics of the material, in terms of sensitivity to the fibre bridging, in delaying the delamination growth, by analysing different material models with low, medium and highly sensitivity to the fibre bridging phenomenon.
NUMERICAL SIMULATION OF THE MECHANICAL BEHAVIOUR OF SHAPE MEMORY ALLOYS BASED ACTUATORS

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Topic(s):
- Smart Material Structures
- Other

Keywords: Shape Memory Alloys, Actuators, Morphing, FEM

Abstract:
In the last decade, the interest in Shape Memory Alloys (SMA) materials has been considerably increased due to their peculiar morphing capabilities, which can be relevant for many different engineering fields such as automotive and aerospace. The attractive characteristic of shape memory alloys is their capability to recover an initial state, once a deformation has occurred, when subjected to a temperature above a predefined threshold. Possible applications of SMA includes, but are not limited to, switch actuators or morphing structures. In this work, the phenomenology of SMA materials, such as the super-elasticity effect and the recovery due to the heating, is described and numerically reproduced by means of a user material routine implemented in the ABAQUS Standard FEM environment. A test-case representative of a mechanical actuator operated by SMA devices is introduced to assess the robustness of the developed numerical procedure for the simulation of Shape Memory Alloys material behaviour.
NUMERICAL-EXPERIMENTAL INVESTIGATION ON THE TENSILE BEHAVIOUR OF A HYBRID METALLIC-CFRP STIFFENED AERONAUTICAL PANEL

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- Mechanics of Composites
- Composite Manufacturing
- Applications of Composites
- Damage, Fatigue and Fracture
- Other

Keywords: Hybrid structures, Metallic-composite joints, Plasticity, Damage propagation, FEM.

Abstract: In recent years, the use of composite materials for the manufacturing of aerospace primary structures have unquestionably increased. However, despite of the undeniable advantages in terms of weight related to the composites, metal parts are still widely used because of the
damage management criticalities related to the adoption of the new outstanding composites. Therefore, for several structural components, metal-composites hybrid solutions are adopted, due the effective reduction of weights and costs without strong compromises in terms of safety. In this work, the tensile behaviour of a hybrid metallic-composite stiffened panel is investigated. The analysed structure consists of an omega-reinforced CFRP panel joined with a Z-reinforced aluminium plate by means of fasteners. The numerical model, considering geometrical and material non-linearities, has been validated by means of comparisons with experimental test results, in terms of stiffness and strains distributions on both composite and metallic regions. Two numerical analysis reproducing the experimental tests performed on the structure have been carried out, respectively to assess the capability of the hybrid panel to withstand the service loading conditions and to investigate the damage onset and evolution in the composite and in the metallic regions up to the final collapse. Results are presented and critically assessed.
ON THE MECHANICAL BEHAVIOUR OF HYBRID COMPOSITE SAMPLES SUBJECTED TO LOW VELOCITY IMPACT AND COMPRESSION AFTER IMPACT LOADING CONDITIONS

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Topic(s): - Mechanics of Composites
- Impact and Dynamic Response
- Composite Manufacturing
- Hybrid Composites
- Damage, Fatigue and Fracture

Keywords: Low velocity impact, CAI, Damage evolution, Hybrid composites
Abstract: The use of glass and/or carbon fibres-reinforced plastic materials has progressively increased due to growing requirements of reduction in weight and high resistance. However, for this kind of materials, barely visible damages can become very critical for the carrying load capability during life cycle of primary components. This applies, especially for laminates subjected to impulsive loads such as low velocity impacts. In order to check the damage resistance and tolerance of composite panels subjected to low velocity impacts, compression after impact (CAI) test are usually performed. According to CAI tests, the laminate is subject, first, to a low velocity impact that can cause one or more damages throughout the laminate, then a compression test follows to assess its residual strength. In the present work, low velocity impacts and CAI tests have been simulated on hybrid-composite plates. The investigated plates are made of unidirectional carbon fibres central core, with upper and lower skins made of glass fibre cross-ply laminae. Different impact energy values have been analysed on different types of sample panels, in order to assess the influence of the impact induced damage behaviour of the hybrid-composite configuration.
Consent:
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Title:
PALS and nanoindentation as complementary methods for investigating cellulose derivatives (esters and carbamates)

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Topic(s):
- Mechanics of Composites
- Other

Keywords: PALS, nanoindentation, cellulose derivatives

Abstract: The purpose of this study is to show to what extent free volumes affect the mechanical properties of polymer materials. New cellulose derivatives differing in the nature of the substituent, bond with the main chain
and in the presence of halogen atoms and methyl groups with different positional isomers were synthesized. The new cellulose derivatives were characterized by 1H-NMR and subjected to two advanced non-destructive methods: positron annihilation lifetime spectroscopy (PALS) and depth sensing indentation (DSI) (nanoindentation). PALS is a powerful material characterization technique giving quantitative information about dimensions and intensity of the so-called 'free volume holes' (fvh) in polymer materials, which are believed to be related to the molecular and segmental mobility of the polymer chains and therefore to the mechanical properties. On the other hand, the nanoindentation characteristics such as universal, Martens and undentation hardness, indentation modulus, creep, and a number of others give information about the resistance of a material against elastic and plastic deformations, etc. That indirectly leads the interpretation of nanoindentation research to the corresponding structural elements and their changes due to the indentation deformation. It was established that in the cases of cellulose derivatives nanoindentation characteristics were influenced non-uniformly by the different substituent dimensions, their position and degree of substitution. Usually indentation modulus and all hardness characteristics are more sensitive to structural parameters than creep and the elasticity.

The results obtained were discussed individually for every group of cellulose derivatives.
Title: Method for tracking and clustering of fiber bundles within volumetric images

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Topic(s): NDE and Structural Health Monitoring (SHM)  
Keywords: Fiber bundle tracking, image processing, microstructure characterization

Abstract: Due to good formability, good mechanical properties and low density, discontinuous fiber reinforced polymers (DicoFRP) like sheet molding compounds (SMC) are frequently applied in modern lightweight designs. The fiber architecture of DicoFRP on the microstructural level affects the mechanical properties in a fundamental way and therefore, has to be taken into account for designing components. Today, X-ray computed tomography (CT) systems allow to obtain volumetric images of microstructures in a non-destructive way. Using image processing tools, the observed microstructure is analyzed and characterized. Due to the CT geometry, the resolution of volumetric images and the specimen size are directly coupled. In order to characterize all fibers on the microscale in a sufficient way, only small microstructure specimen can be analyzed. The present contribution makes use of the fact that fibers of SMC are arranged as bundles on the microstructural level. To overcome the CT related conflict between specimen size and image resolution, those bundles are identified, tracked and clustered in order to describe the microstructure. This allows to investigate larger specimen on a sufficient region for state of the art modeling approaches. The fiber bundles are tracked by means of orientation data and a suitable integration algorithm facing the challenge of crossing fiber bundles. Afterwards, tracked fiber bundles, which are related to the same mesoscopic fiber bundle are merged using a hierarchical agglomerative clustering method.
The presented method is applied on a typical SMC microstructure. First results showed that the presented algorithm allows to evaluate the fiber architecture in a sufficient way based on the bundle tracking.
Investigation of adhesion properties in load coupling applications for flexible composites

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Topic(s): - Mechanics of Composites  
- Composite Manufacturing  
- Smart Material Structures  
- Applications of Composites

Keywords: flexible composite, fiber reinforced elastomers, fiber bundle pull-out test

Abstract: Due to the increasing demands in high-performance applications, the deployment of specially designed new material classes is essential. The well-known unique material properties of elastomers for flexibility, damping or sealing performance offers the auspicious potential to enhance the limited mechanical properties through tailored anisotropic reinforcement. For these so-called flexible composites, elastomers provide an interesting suitable alternative for classical resin based composite systems in load coupling applications. The fiber-matrix bonding behavior is important to ensure excellent adhesion properties for efficient load transfer between the reinforcement and the surrounding matrix, therefore in-depth knowledge as well as the adequate quantitative investigation of the interface properties is indispensable. To characterize these interactions, several different test methods like the fiber pull-out test can be implemented. In this work, the transferability of different test levels from micro- to macro scale is examined in more detail. The adhesive bonding behavior between one filament and matrix is studied by standardized measurement devices (droplet test, single fiber pull out test). For the investigation of the failure modes and complex stress distributions in a composite part, a novel test setup based on fiber bundles is proposed, which enables an in step with the application, simple as well as economical measurement. The results comparability considering the effects of filament interactions or statistical distributed single fibers inside a bundle is discussed by a designed experimental plan. Various fiber and matrix materials and the effect on the resulting mechanical properties are examined. The main challenges working with flexible composites are the realization of an appropriate technique to manufacture reproducible specimens and the handling regarding the material testing itself, which has a significant impact on the material properties...
and damage behavior. The results reveal, that the performance of flexible composites is dominated by the adhesive bonding between the reinforcement and the surrounding matrix material. A significant different mechanical performance regarding the individual fiber/matrix combinations is observed. All applied test setups reveal the same trends on the adhesive bonding strength, considering the incomparability of the absolute values due to different testing scales. In a test chain, the proposed measurement method on fiber bundles represents the link between the micro- and macro scale measurements and it allows an application-oriented matrix reinforcement characterization. To compare and analyze different interfaces, the costly micro scale testing can be avoided and effective interface properties can derived based on the presented meso scale testing approach. Moreover, it is a suitable tool for an appropriate material selection and the results can be the basis for future work focusing on the calibration of interface material models.
Influence of a marine natural fibre treatments on biocomposites macro- and nanomechanical properties

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Topic(s): Green Composites
Keywords: marine natural fibres, treatment, nanomechanical mapping
Abstract: Wastes from seasonal plants represent a renewable and available source of lignocellulosic fibres which can be used as fillers for composite materials. A sea grass called Posidonia Oceanica (PO) widely spread in the Mediterranean Sea accumulates each fall on beaches. In touristic areas, dead fibres are removed during the summer period and generally burned. The valorisation of these natural fibres for composites materials is discussed here. Their microstructure can increase insulating or specific mechanical properties of composites. Indeed, it presents different cell walls, middle lamellae and a large lumen compared to other lignocellulosic fibres. This complex microstructure contains many interfaces which can impact the composite mechanical and ageing properties. It must then be accurately characterized at sub-micron scale. A nanomechanical mapping technique based on Atomic Force Microscopy.
(AFM) in force mode enables the determination of elastic properties of the different compounds and shows up interphases or interfacial compatibility with the matrix. It can also help in understanding the effects of surface treatments and discuss their relevancy.

In this study, a commercial bio-based epoxy matrix is used with PO short fibres. A classical alkali treatment is compared to a soft sodium hydrogenocarbonate treatment of fibres. Physico-chemical effects are analyzed by infrared spectroscopy (FTIR) and observed with Scanning Electron Microscopy (SEM). The impact on thermo-mechanical properties and water uptake of the composites are evaluated. The difference scales and methods of analysis are then correlated.
Combination of neural networks and acoustic source localization techniques for impact detection on aerospace composites structural components

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Topic(s):  
- NDE and Structural Health Monitoring (SHM)  
- Other

Keywords: chair

Abstract: The aim of this study was to build on the previous work completed to develop a thorough understanding of the influences of dissolved gasses on vacuum assisted resin infusion, and provide a foundational methodology which can be applied in order to develop robust high performance infusion manufacturing processes.
Title: A COMPARISON OF SIGNAL PROCESSING TECHNIQUES FOR IMPEDANCE-BASED DAMAGE CHARACTERIZATION IN CARBON FIBERS UNDER NOISY INSPECTIONS

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Topic(s): NDE and Structural Health Monitoring (SHM)
Keywords: Carbon fiber, Composite, SHM, Impedance, Signal processing, Damage index.

Abstract: The development of inspection techniques capable of enabling safety and integrity of composite structures is an on-going challenge for both industry and the research community. Among several structural health monitoring (SHM) systems, the electro-mechanical impedance (EMI) method stands out as an effective failure detection approach that can be applied in composite components. This technique commonly uses low-cost, small and lightweight piezoelectric transducers operating simultaneously as both sensors and actuators. In the EMI method, damage detection is achieved by comparing the behaviour of the piezoelectric impedance signatures, which are related mathematically to the mechanical impedance of the host structure. More recently, alternative systems to impedance measurements have been proposed. A typical instrumentation system for impedance extraction uses a data acquisition (DAQ) device that applies an excitation signal in the piezoelectric transducer whilst synchronously acquiring its response signal. The damage detection is accomplished by comparing two impedance signatures. The first one is obtained when the structure is considered in its healthy state, being this signature used as reference (the baseline). A second signature is measured after a damage is suspected. The resulting difference between these two signatures can be indicative of failure. Although many studies have proved the effectiveness of EMI on composites, many practical issues such the changes in the environment caused by noise and vibration, have limited its use in real applications. Therefore, several signal processing approaches have been proposed in order to minimise the noise influence on the impedance measurements. This work presents an experimental analysis of the white noise effects on impedance monitoring of a carbon fibre reinforced plastic composite plate, by applying the correlation coefficient deviation metric (CCDM) and cross-correlation square deviation (CCSD) index. Although both indices have been extensively studied in literature, their application is related to the impedance signatures or
wavelet decomposition of the response signal of the piezoelectric transducer. In this work, we applied the CCDM and CCSD indices directly on the response signal aiming to minimise the signal processing and compare their sensitivity to damage detection under noisy environment. Experimental results revealed that, under ideal (no noise) and noisy inspections, the CCSD was more sensitive to damage detection.
Title: IMPACT RESPONSE OF A MANICARIA SACCIFERA FABRIC-REINFORCED PLA COMPOSITE

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Topic(s): - Impact and Dynamic Response  
- Green Composites

Keywords: Impact, FSP, V50, Green Composite.

Abstract: Recently, green composites have gained popularity in industry and research due to the development of novel chemical techniques to produce high-strength composites with specific mechanical properties comparable with the ones of glass-fiber reinforced plastic composites. Amongst green composites, those reinforced with natural fabrics -such as the ones from the Manicaria Saccifera palm, are being actively developed as they feature both enhanced mechanical properties, and easy manufacturing of large sections due to their similarity to textile composites [1]. These attributes have made this kind of composites attractive to develop architectural shells and plates, which can be used to attenuate damage produced by fragments from accidental explosions in buildings and facilities. For example, in a previous paper [2], authors studied the impact response of thin unidirectional Manicaria Saccifera fabric-reinforced polylactic acid composite (MSPLA). In this paper, the response of cross-ply thick MSPLA composites to medium speed impact by fragment simulating projectiles (FSP), is studied.

Cross-ply coupons [±45]5, 90 mm x 110 mm x 10 mm, were manufactured from layers of Manicaria Saccifera fabric plied alternately with PLA sheets, which were subsequently hot-compressed using a Dake Press (190 oC, 13 min). Coupons were impacted by FSPs
manufactured according to the MIL-DTL-46593B standard with straight tail, 7.20mm in
diameter and 2.95 g in mass, which were launched by a gas gun at speeds between 60 m/s and
180 m/s. Every FSP impact was captured by an Olympus i-Speed 2 high speed camera (15000
fps). FSPs striking and residual speeds were measured using the Tracker Video Analysis
software. V50 ballistic limit was estimated using the procedure detailed in [3], and the energy
absorbed by the composite coupon was calculated by a kinetic energy balance using striking
and residual speeds.

Figure 1 shows the V50 ballistic curve for the MSPLA composite. Under the configuration
studied, MSPLA displays a ballistic limit of 120.5 m/s, which is about 71% higher than the V50
found for thin MSPLA composites.

Fig. 1 V50 ballistic curve for the MSPLA composite.

Figure 2 shows the energy absorbed by MSPLA composite coupons, which displays a
seemingly linear relation with FSP’s striking speed, with an average of 20.3 J.

Fig. 2 Energy absorbed by the MSPLA composite.

Finally, in this study it was found that Manicaria Saccifera fabric-reinforced polylactic acid
green composites are a promising alternative to be used in light-weight architectural
applications for shielding against small medium-speed fragments from accidental explosions.

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saccifera Natural Fabric Reinforced PLA Composites to Impact by Fragment Simulating
Projectiles. In Advances in Natural Fibre Composites (pp. 89-98). Springer, Cham.
The adoption of the spread tow technology [1] at industrial level in recent years has allowed the diffusion in the composite market of a novel type of material, the thin and ultra-thin ply laminates. A number of experimental and theoretical investigations over the years have shown the benefits stemming from the new laminate design. Among these, one of the most significant appears to be their ability to drastically delay, and even suppress, the onset and propagation of transverse cracks [2]. The result was not actually surprising, as early studies in the 1970’s on cross-ply glass fiber/epoxy laminates reported that onset of transverse cracking was delayed to higher levels of strain in thinner 90° plies [3]. The effect was since named the ply thickness effect. Contemporary to these early observations was also the identification of microscopic cracking (debonding) at the fiber/matrix interface as the primary driver of transverse crack onset and propagation [4].

Subsequent experimental investigations determined that fiber/matrix interface cracks (or debonds) first grow in a stable manner along the arc direction of the fiber; once they reach a critical angular size, debonds propagate unstably along the fiber longitudinal direction and then coalesce with debonds on adjacent fibers to form through-the-thickness (or transverse) cracks [5]. Theoretical studies have thus focused on understanding debond growth in the arc direction with the aim of predicting the critical size at which unstable longitudinal propagation and coalescence occur. Several analytical and numerical works can be found in the literature dealing with models of: a single partially debonded fiber in an infinite (V_f=0) or effectively infinite (V_f→0) matrix and in a homogenized 90° layer; a single partially debonded fiber with 2 or 6 neighboring, partially or fully bonded, fibers in an effectively infinite matrix and in a homogenized 90° layer. In-situ microscopic observations have nonetheless pointed to the evidence that debond onset and growth occur simultaneously on different fibers. A clear
understanding of the mechanics of the fiber/matrix interface thus requires the investigation of
the effect of more complex microstructural arrangements and damage states.
In the present work, we investigate a family of Repeating Unit Cells (RUCs) which represent
Representative Volume Elements (RVEs) of unidirectional composites with different
microstructural arrangements and different geometric configurations of debonds. This is
achieved by controlling the number of fully bonded fibers appearing in the horizontal, i.e.
loading, direction and in the vertical, i.e. through-the-ply-thickness, direction of the model.
Application on the right and left sides of the RUC of coupling conditions on the horizontal
displacement (which corresponds to the laminate in-plane transverse displacement) ensures a
mirror-like repetition of the solution in the horizontal direction. Vertical displacement coupling
applied to the top boundary guarantees, on the other hand, a symmetric repetition of the
solution in the vertical direction. This implies that, if a debond appears on the right side of the
damaged fiber in the model, the next partially debonded fiber in the vertical direction will
present a debond on the right side as well. Several micrographs reported in the literature show,
however, debonds often appearing on opposite sides of adjacent fibers [2]: if the debond
appears on the right side of a fiber, the adjacent partially debonded fiber has it on the left side
(and vice versa). In order to analyze this configuration, a set of antisymmetric coupling
conditions is proposed which, to the authors’ knowledge, represents the first attempt to model
such configuration in the context of numerical microstructural homogenization techniques. By
applying the antisymmetric coupling conditions on the top boundary of the RUC, we investigate
different configurations in which debonds appear on opposite sides of consecutive (adjacent or
intercalated by undamaged fibers) partially debonded fibers along the vertical direction. The
mechanics of debond growth is analyzed by evaluating the Mode I and Mode II Energy Release
Rate (ERR) at the crack tip. Results for the antisymmetric and symmetric coupling conditions
are compared with each other, and the likelihood of consecutive debonds to grow on the same
or opposite sides in the vertical direction is assessed drawing upon energy-based arguments.

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Longitudinal Splitting Behaviour of Glass and Carbon Fibre Reinforced Epoxy Cross Ply
Laminates and the Effect of Poisson and Thermally Generated Strain. Proceedings of the Royal
for interfacial debonding in composites: 1. Experimental observations. Composites Part A:
The use of composite material in both civil and military aeronautic applications keeps on increasing from the last decades, mainly due to its advantage in terms of ratio mass/stiffness/strengthening in comparison with standard solutions based on metallic material. 3D woven composite is a new kind of composite material, developed to obtain higher out-of-plane mechanical properties and interesting residual properties after impact. Safran Aircraft Engines has thus chosen such a material for the manufacturing of the fan blades of its new generation of civil engine. Moreover, with the continuous improvement of composite design methods during the last decades and the imperative of structural mass and consumption minimization for recent airliners, composite structures are subjected to loadings closer and closer to their static strength during longer periods. Consequently, a robust unified methodology to predict the real lifetime of industrial 3D woven components is expected by Safran Aircraft Engines. The static model named ODM-CMO [1] has been adapted to predict the lifetime of 3D woven composites. A significant effort has been made these last years [2] to build a full kinetic damage model defining multi mechanism kinetic damage evolution laws. This model allows to handle random complex fatigue loadings without using the notion of cycling, the damage law being written in a rate form.
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**Title:** Evaluation of induction and infrared welded CFRP thermoplastic specimens

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**Topic(s):** - Composite Manufacturing  
- Applications of Composites

**Keywords:** Fusion bonding, Thermoplastic welding, PEEK, induction welding, infrared welding, CFRP

**Abstract:** Fusion bonding is a technique that fuses two thermoplastic components together without the need for fasteners or adhesive. This is desirable to reduce cycle times, eliminate additional materials at the join interface and reducing assembly weight for aerospace and automotive composite components. Different fusion bonding techniques are currently available in the market. This paper proposes to look, in particular, at carbon fibre reinforced polyether ether ketone (PEEK) thermoplastic composite specimens (single lap-shear, ASTM D5868) welded using the infrared and induction fusion bonding techniques to evaluate the shear force achieved by the respective methods at five discrete welding pressures. Microscopy was conducted of the bond line and Differential Scanning Calorimetry (DSC) analysis was performed to evaluate and
compare the crystallinity state before and after bonding for these two fusing bonding techniques.
Thermally Assisted Piercing; Manufacture and Properties of Multiply-Pierced Composite

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Abstract:

Perforated metal panels are currently used in many industries and applications including sound absorbing engine components, leading edge de-icing systems and blast protection panels. Due to the increasing demand for ever more lightweight components, the aerospace industry in particular is trying to exploit composite materials. Perforation of composite materials is currently done using the conventional machining techniques such as drilling and abrasive water jet cutting. However, these techniques cut the loadbearing fibres and reduce the efficiency of the composite around the holes.

A project funded by TWI’s Member Companies aims to exploit the benefits of thermoplastic composite materials for perforated structures; a continuation of the Thermally Assisted Piercing (TAP) process that was developed by TWI in 2016 as an innovative mechanical fastening technique. In this technique, the thermoplastic composite is heated up to the melting point and a pin is pushed into the material. Since the matrix is molten, the fibres are free to move around the pin. Mechanical testing of the TAP composite specimens indicated superior mechanical properties compared to the drilled composite specimens.

The new process, “Multiple Piercing Perforation Technique,” has the potential of making one hundred of 2 mm holes at the same time in a thermoplastic composite structure, with fibres displaced around the holes instead of being cut. Mechanical testing and NDT techniques have been used to compare the pierced specimens to the drilled specimens, and results have shown higher strength for the pierced specimens.
ID: 87

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Title: LS-Dyna assessment of composite fan sub-components designed within Extreme

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Topic(s): Other

Keywords: design impact tests

Abstract: This presentation provides an overview of the activities carried out by Rolls-Royce to design impact tests by analysis in support to the EXTREME WP7 validation activities on sub-component specimens. The approach used to build the models, post process them and draw conclusions is presented for two turbofan-related impact events: bird strike and fan blade-off containment. Particular focus was put on understanding how the additional experimental data obtained from the sensors developed within the EXTREME project can be used to validate FE models.
ID: 89

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Title: Simulation of carbon fibre composites in an industrial microwave

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Topic(s): - Composite Manufacturing
Keywords: COMSOL, electromagnetic energy, FE microwave modelling, polymer-matrix composites

The ability of microwave radiation to penetrate and interact directly with materials has led to its extensive use in food and drug industries, and more recently in composites manufacturing. Microwave heating of composites allows rapid heat transfer throughout the material thickness with reduced thermal gradients and processing times as well as energy efficiency. Design of microwave systems to process composite parts with various geometries and sizes demands improved understanding of electromagnetic energy distribution and factors influencing it. Finite-element (FE) models can be efficient design tools in such cases, as real-life experiments could be laborious.

Abstract:

In this study, a fully-coupled FE model of a carbon fibre composite in an industrial microwave environment is developed using COMSOL Multiphysics®. Effects of heating process parameters (the number of active magnetrons, specimen thickness and the variation in the frequency of radiation) on the electromagnetic field distribution are studied. The FE model showed that a substantial difference in the electromagnetic field distribution exists for the frequencies above 1 GHz compared to the lower frequencies in the microwave regime, resulting in non-uniform heating.
Three-dimensional laminated composite components built by fabric plies exhibit complex geometries at various length scales. Finite element simulations of such components up to structural limit loads (and beyond) typically require extreme computational power, in particular when material nonlinearities are to be taken into account. A multi-scale embedding approach is presented which is sufficiently detailed to capture the nonlinear mechanisms inside textile plies and at their interfaces. At the same time the computational effort is kept small enough to be handled by standard PC workstations.

The smallest length scale of consideration is the tow level at which continuous unidirectional fibers are embedded in a matrix. Its composite material behavior is described by a transversely isotropic constitutive law taking into account plasticity, progressive damage, and softening. At the ply level the weaving or braiding pattern of the tows is modeled by shell elements only. Also the unreinforced pure matrix regions are represented by shell elements. Corresponding shell elements are coupled by tie constraints. The laminate level is modeled by stacking a number of such plies with cohesive zone elements in-between to enable delamination. To this end, the entire textile microstructure is resolved. This highly detailed region is embedded in a conventional shell model for which the linear elastic material properties are obtained by homogenization at the laminate scale utilizing the fine scale model. Selected regions of a component in which nonlinear material response is expected are represented by a patch of the
laminate with resolved plies, tows, and matrix pockets. Note that shell modeling is essential to keep the number of degrees of freedom reasonably low.

The approach is demonstrated for a ±30° bi-axial multi-layer braid. It forms a beam with a C-profile which is loaded in four point bending mode. To introduce a stress concentration, a blunt cut-out is realized (Fig. 1). The Finite Element simulations predict the overall load deflection curve, the localized patterns of the various nonlinear mechanisms, and the dissipated energies attributed to these mechanisms. This way, detailed insight to the behavior of structural composite components is obtained. The material and interface nonlinearities which govern the response can be identified. Eventually, such findings can guide the way to improved design of composite components, laminates, plies, and weaving patterns simultaneously, including several length scales.
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**Title:** Metallopolymer hybrid nanocomposites: preparation and properties

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**Topic(s):** - Hybrid Composites
- Nano Composites

**Keywords:** nanocomposite, metallopolymer, metal nanoparticles, epoxy nanocomposites, thermoplastic composites, reduction, curing, sol-gel synthesis, fracture strength, tribology

Recently, hybrid organic-inorganic materials, particularly their structure and functionality, have been attracting intensive research. This interest results from unique combinations of organic and inorganic (metal, oxide, carbide and chalcogenide nanoparticles) component properties. These properties allow their use as magnetic materials for writing and storing information, heterogeneous catalysis, sensing devices, and also for medicine and biology [1–3].

We have developed several ways for producing nanocomposites: one-stage synthesis of metal nanoparticles and stabilizing polymer matrix – conjugated thermal (co)polymerization of metal-containing monomers and following thermolysis of forming polymers; in situ reduction of metal ions either in epoxy resins by curing agents or in thermoplastics by thermal decomposition of metal-containing precursor; and sol-gel synthesis.

Changing synthesis conditions (temperature, precursor ratio, stabilizing matrix) allows manufacturing nanoparticles of required size, shape and composition (for example, core-shell structures) with homogeneous distribution in stabilizing matrix, that is regulating functionality such as magnetic, catalytic, sensing, sorbing properties.

**Abstract:** The obtained metallopolymer nanocomposites exhibit improved mechanical and tribological properties, crack growth resistance, thermal stability, selective catalytic activity for hydrogenation of acetylenes. Nanocomposites containing magnetoactive nanoparticles reveal ferro- and superparamagnetic properties. Their potential as effective magnetically tuned sorbents of heavy metals and radionuclides is being analyzed.

This work has been performed in accordance with the state tasks, state registration No 0089-2019-0008 and 0089-2019-0012.

**References**


The reuse and recycling of carbon fiber reinforced plastics (CFRP) is gaining more and more importance due to the increasing amount of CFRP scrap during production and at end of life. In this work, a processing route is applied to recycle carbon fiber scrap in discontinuous fiber reinforced bulk molding compound. Mechanical tests are carried out focusing on the viscoelasticity and damage behavior by using cyclic experiments with increasing strain. Furthermore, a comparison of the recycling material with conventional long fiber reinforced materials is presented. According to the shown mechanical behavior, an anisotropic viscoelastic model with damage propagation is implemented. The model parameters are fitted to the experimental data utilizing evolutionary algorithms. By comparing both material systems, the results are discussed in terms of viscoelasticity and damage progression. Finally, an example structural component is calculated to show the numerical capability and the practical usability of the material model.
Title: Response of Carbon Fibre Reinforced Polymers to High Velocity Impact

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Topic(s): Impact and Dynamic Response
Abstract:

General increase in use of carbon fibre reinforced polymers (CFRP) is most prominent in aerospace, automotive, energy and defence. This demand is driving the requirements for the dynamic characterisation of these materials. CFRPs, considered in this work, are composed of stiff, brittle fibres encased in epoxy resin. Experimental characterisation of these materials, even in basic quasi-static mechanical tests, is challenging due to their anisotropy resulting from the material microstructure. More specifically, the anisotropy and heterogeneity have as a consequence complexity in behaviour of these materials including a number of material damage and failure mechanisms that are activated by different loading conditions. Extensive research in this field over the last three decades still has not delivered a widely accepted and reliable failure theory for CFRPs[1].

Millet et. al. [2], Riedel et.al. [3], Dattelbaum [4] investigated formation and propagation of shockwaves in unidirectional and woven CFRPs. The work presented further considers the effect the material orientation has on the material shock equations of state for both through thickness and fibre directions. A new algorithm for modelling of shock wave formation and propagation in anisotropic materials is proposed, implemented into a hydro code and validated against new experimental data. This is done as part of an effort to produce tools for modelling of high velocity impact on composites in the European project EXTREME*.

References

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Title: Postbuckling optimisation of a variable angle tow composite wingbox

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Abstract:
The optimisation of the structural behaviour of the wing is one of the key aspects in the design of future aircraft. Enhanced freedom to designers has been offered by the stiffness-tailoring capability of Variable Angle Tow (VAT) laminates. Efficient and robust optimisation strategies are, consequently, of great importance to fully explore such an increased design domain. Simultaneously, taking account of the initial postbuckling behaviour can provide hidden load-bearing capability, leading to reduction in weight and costs. In this work we propose an optimisation strategy of the postbuckling behaviour of a recently-proposed VAT wingbox. Being based on an efficient reduced order model for the evaluation of the equilibrium path and on robust stochastic algorithms for the solution of the optimisation problem, the approach shows its viability as a general design tool for buckling dominated structures. Manufacturing constraints are included and the influence of geometrical imperfections is efficiently handled during the optimisation. Different optimisation scenarios are investigated and results show a much improved solution with respect to the initial VAT design.
The presence of space debris and micrometeoroids particles in the space environment are a serious threat for Earth orbiting spacecraft. Hypervelocity impacts (HVIs) at the typical velocities of ~7-10 km/s can severely damage or destroy satellites, so that debris removal devices are necessary. In the present research work, a “smart” composite detector of orbital debris and micrometeoroids particles is proposed and developed as proof-of-concept for future space missions. The presented detector consists of two thin parallel carbon fibre reinforced plastic (CFRP) composite plates, each instrumented with three piezoelectric transducers embedded into the laminate. The developed algorithm can estimate both directions and velocities of orbital debris and micrometeoroids particles by the knowledge of: (i) impact locations on the two plates, (ii) the time differences of arrival of acoustic emissions generated by impacts and (iii) the wave velocity profile in the composite plates. The localisation of the impact events is estimated by time reversal methods, while the time of arrivals are calculated by using Akaike Information Criterion method. A set of experimental tests were performed to validate the proof-of-concept using a small drop tower. Impact results showed the high accuracy
of the proposed algorithm in the estimation of impact locations, directions and velocities of impact objects.
CO-CURING OF THERMOSET COMPOSITES ON METAL STRUCTURES WITH REDUCED CYCLE TIMES FOR HIGH-VOLUME CAR APPLICATIONS

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- Mechanics of Composites
- Composite Manufacturing
- Hybrid Composites

Co-curing, metal-composite hybrid, glassfiber-reinforced thermoset, prepreg, press-moulding

Nowadays, fiber reinforced plastics (FRP) are used in low series car production (i.e. sports cars). However, there are still obstacles to introducing this technology into the high volume car market, such as process time, joining techniques, and material and manufacturing costs. By locally reinforcing metallic structures of the body-in-white with continuous fiber reinforced composites, the mechanical performance of car structures (i.e. stiffness, strength, energy absorption) can be increased while adding minimal weight. Furthermore, conventional joining techniques can be used to assemble these metal-composite-hybrid parts that are state-of-the-art in the body-in-white manufacturing process (i.e. welding, riveting, gluing).

The VW research group is developing a process where the thermoset composite material (pre-impregnated unidirectional glass fiber reinforcement with epoxy matrix) is directly pressed and cured onto the metallic structure within the cycle times of high-volume car production (< 1min). The focus of this investigation is to define suitable composite materials with sufficient bonding to the metallic structure and a degree of curing of at least 75 % within 30 seconds. Therefore, process parameters (temperature, time, pressure) were identified. The aim is to use the matrix material of the reinforcement directly to bond the reinforcement onto the metallic...
structure. Additional glue films to increase the bonding are also investigated. The metallic joining member is defined as a dual-phase steel with a zinc coating (HX660XD + Z100) contaminated with deep-drawing oil. The minimum bonding strength for a metal-composite-hybrid part is assumed to be 10 MPa. Based on these results, the feasibility is tested on a more complex technology demonstrator to evaluate the potential of a metal-composite hybrid part for an automotive-related use-case. All manufacturing trials are supported by an online degree-of-cure measuring to allow an estimation of the curing process.
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MULTISCALE DETERMINATION OF WATER-SWELLING COEFFICIENTS OF FLAX/EPOXY COMPOSITES AND FLAX YARNS

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Alternate Contact: - Mechanics of Composites
Topic(s): - Green Composites
- Other
Keywords: flax yarns, flax reinforced composites, swelling coefficient

This paper proposes a direct experimental characterization of flax yarns radial swelling coefficient and a three dimensional characterization of the flax/epoxy composite swelling. It was also proven that the composite longitudinal swelling coefficient is negative. Besides, the composite transverse swelling coefficient is smaller than radial swelling coefficient of flax yarns.

Abstract: was also proven that the composite longitudinal swelling coefficient is negative. Besides, the composite transverse swelling coefficient is smaller than radial swelling coefficient of flax yarns.
IMPLICATIONS OF FINITE SIZED TRANSDUCERS ON THE DETERMINATION OF THE VISCOELASTIC TENSOR OF COMPOSITE PLATES WITH THE ULTRASONIC POLAR SCAN

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The Ultrasonic Polar Scan (UPS) is an advanced non-destructive testing technique which is well-suited for the inversion of the full viscoelastic stiffness tensor of anisotropic media, such as carbon fibre reinforced plastics (CFRP) [1]. A UPS experiment comprises the measurement of the reflection and/or transmission signal of an impinging ultrasonic beam at multiple combinations of out-of-plane and in-plane incident angles $\Psi(\theta, \phi)$ on the hemisphere above a single targeted material spot (Fig. 1). The mapping of features such as amplitude, time-of-flight and phase, present in the measured signals onto a polar diagram reveals a local fingerprint of the investigated material (Fig. 2, with $\theta$ the radial and $\phi$ the circumferential direction). The recorded data is subsequently fitted by a numerical model through an evolutionary optimization algorithm based on the particle swarm optimizer. This approach has been implemented as a two stage inversion procedure using pulsed ultrasonic signals as input beams [2]. Despite the success of this procedure, the currently used plane wave model lacks some worthwhile physics. It disregards the influence of the finite size of the ultrasonic transducers and hence overlooks information on for instance leaky wave fields and energy skewing of the propagating waves in anisotropic media. Moreover, the pulsed UPS model fails to account for the influence of typical frequency dependent phenomena (e.g. viscous behaviour) as the performed Fourier analysis requires a-priori knowledge on those relations.

In the present study, we first propose a model for the inclusion of the boundedness of ultrasonic transducers and show on a qualitative level the close agreement of the model with actual pulsed UPS experiments on aluminium and CFRP materials. In addition, a new inversion procedure is proposed using harmonic waves as input for the UPS setup (Harmonic Ultrasonic Polar Scan, H-UPS). The introduced inversion scheme naturally gives access to the potential frequency dependent attenuation of the investigated material, and is tested for numerically simulated H-UPS data of a unidirectional carbon/epoxy plate at different driving frequencies. The accuracy and inversion runtime is compared to the ideal case when the boundedness of the transducers can be omitted (i.e. plane wave experiment). Finally, a model encompassing phased array technology for the reconstruction of the plane wave transmission coefficient for any given transducer is proposed and validated on numerical H-UPS data sets.
Experimental Investigation on the Performance of Fibre-Reinforced Composites as Substrates for the Propagation of Electromagnetic Surface Waves

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Topic(s): - NDE and Structural Health Monitoring (SHM)
- Smart Material Structures
- Applications of Composites

Keywords: microwaves, measurement techniques, surface waveguides, surface impedance, dielectrics, fibre-reinforced composites, modelling, simulation, antennas, communications, non-destructive testing, radars, radar-absorbing surfaces

Abstract: Electromagnetic surface waves can be excited and transmitted along the interface between two dissimilar materials. The surface boundary of a fibre-reinforced part in atmospheric air can thus be used to support the propagation of such wave modes. The investigation of surface wave propagation along the surfaces of composite parts is of great interest for a number of applications, including the design and optimization of conformal antennas for aerospace communications and radars, microwave inspection and condition monitoring and composite material radar-absorbing surfaces. The characteristics of electromagnetic surface waves (attenuation, leakage directivity) in this case would be greatly affected by the dielectric properties of the composite part. The full dielectric characterisation of a fibre-reinforced composite, which is therefore required, is inherently a challenging task as not only the electrical properties of its components but also its microstructure can have a significant effect, often resulting in highly anisotropic behaviour. This work focused on the implementation of novel measurement methods for the dielectric characterisation of composites and complex permittivity values have been derived for a number of composite material types with conductive (carbon fibre) or dielectric (glass, aramid fibre) reinforcement at microwave frequencies. The significance of the measured dielectric properties in terms of the aforementioned applications for composites is also discussed.
Use of polymer appretes and gamma irradiation to improve mechanical properties of LDPE composites

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Influence of polymer appretes on adhesive strength has an important practical value for modern composite materials production. One of the problems the researchers deal with while designing reinforced thermoplastics is poor realization of fibres mechanical properties due to low compatibility of components such as glass fibres and polyethylene. This is where stronger chemical bonding is desirable. Use of polymer appretes along with gamma irradiation allows to enhance compatibility of polymer and reinforcing material, thus improving mechanical properties of composite.

Mixtures of thermoplastic (PE) and carbon-chain polymers (Nitrile butadiene rubber - NBR, polyvinyl alcohol - PVA) were produced by extrusion. Sol-gel analysis and size-exclusion chromatography along with IR spectroscopy were employed to study changing of sol content and molar mass distribution during gamma irradiation of NBR/LDPE mixture. Gamma irradiation with NBR addition improves strength of LDPE by 30%, while gamma irradiation by itself has little effect on LDPE. Elastic modulus increases by 116% after gamma irradiation. Besides that, gamma irradiation only slightly changes melting points and glass transition temperatures of PE/NBR and PE/PVA mixtures.

Dynamic mechanical analysis results are in good corresponding with tensile tests. Gamma irradiation of pure LDPE is shown to increase the dynamic E-modulus from 270 to 295 MPa. Addition of nitrile rubber as polymer apprete and the same irradiation dose increases dynamic E-modulus by 100 MPa. Obtained thermoplastic has high elastic modulus and strain energy. Thus, modification by NBR and gamma irradiation improves elasticity and strength of LDPE matrix. The results allow to suggest the likely strengthening mechanism for the reinforced glass fiber composites modified by polymer appretes and gamma irradiation.
Title: A physically based 3D constitutive law for kink band initiation and crushing accounting for fiber bending failure and neighboring delamination

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Abstract:
Arguably less understood, compressive failure mechanisms of fiber reinforced polymers have posed a significant challenge in the accurate modeling of common industrial problems such as open hole compression. Despite the success of recent progressive damage analyses in capturing the fiber kinking failure mode, the problem is still actively investigated.

This paper proposes a new 3D constitutive law that physically represents micro-scale physics of kink band formation within the framework of meso-scale continuum damage mechanics. The proposed hypothesis for kinking onset is that the following three non-competing requirements need to be met: 1) the matrix around the kinking fibers must have failed locally; 2) the maximum bending stress in a fiber should be large enough to fracture it; 3) the minimum applied longitudinal compressive stress must be sufficiently large to satisfy the previous requirement for a kink plane shear stresses smaller than the ply traverse shear strength. While the first requirement is commonly adopted, the second is new and based on fractographic investigation of kink bands. The third requirement, supported by experimental results, is meant to distinguish fiber kinking from the similar shear dominated fiber splitting phenomenon. After kinking onset, in contrast to using standard linear softening laws, a bilinear cohesive law, obtained via superimposition, is used to more accurately represent the physics behind the softening and assure that the dissipated fracture energy is mesh objective. In the last softening stages, where constitutive laws typically assume that stress converges to a traction free or crushing state, the proposed model assumes that a traction free state can only be achieved if the kink band terminations are able to escape out of plane on either side of the ply through existing delaminations.

The model was implemented within the Floating Node Method discrete crack model with an unstructured mesh. It was validated against experimental open hole compression tests of different sized [0/45/90/-45]s laminates. In all cases the predicted panel strengths did not exceed experimental data by more than 8% while both thickness and in plane size effects were captured.
Abstract: We present the results of distributed fibre optic strain sensing for condition monitoring of a hybrid type IV composite overwrapped pressure vessel using multilayer integrated optical fibres. During load cycle tests material fatigue could be localised and monitored 17000 load cycles before burst. Results have been validated by acoustic emission analysis.
Title: HIGH-VELOCITY IMPACT INVESTIGATION ON T-STIFFENED CFRP PANEL

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Topic(s):
- Impact and Dynamic Response
- Applications of Composites
- Multiscale Modelling
- Other

Keywords: CFRP, high-velocity, damage suppression, impact resistance, TPU

Abstract: Carbon Fibre reinforced polymers (CFRPs) represented an innovative engineering solution in the manufacturing of different parts for several sectors such as aerospace, racing automotive and railways due to high specific properties and contained weights. Although this industrial interest, a crucial limitation that slowed down the diffusion of these materials is their mechanical properties detriment from high velocity impact caused by their fragile and layered nature. An experimental and numerical study of the high velocity impact behaviour was presented in this work analysing a T-stiffened CFRP panel under high velocity loading. After failure phenomena and impact damage was evaluated using high-speed camera and ultrasound techniques (C-scan), a 3D explicit finite element model (FEM) was developed using a commercial LS-DYNA software in which an orthotropic continuum damage-based material model was implemented to predict the complex impact response and relative damage of the structure. The numerical model was calibrated using experimental data at different impact velocities. Experimental and numerical results were then presented showing a good correlation with an error less than 6% in terms of absorbed energy, maximum indentation and damage extension. Afterwards, an optimisation analysis was carried out on the numerical model in order
to identify the best design parameters when a TPU layer is introduced in the lamination sequence of the material for damage suppression purposes. Results were presented reporting a maximum reduction of at least 54% in absorbed energy, damage extension and maximum indentation respectively when 1mm thick TPU layer is applied on the CFRP surface.
ID: 106
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Title: Thermal Properties measurement of single carbon fiber with the 3ω Method

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Topic(s): - Applications of Composites
- Other

Keywords: Thermal Conductivity, carbon fiber, poly-acrylonitrile, sensitivity analysis

Abstract: The thermal conductivity and volumetric heat capacity of poly-acrylonitrile (PAN)-based carbon fiber are measured simultaneously using the 3ω method with a constant current source and two differential amplifiers. In addition to the use of the analytical thermal model developed by Lu et al. in 2001 for the measurement of longitudinal thermal conductivity, an analytical model for the measurement of the radial one was developed. For both thermal conductivities, a sensitivity analysis was performed to find the best experimental conditions in order to increase the accuracy of their measurements. The experimental tests were carried out under vacuum and at atmospheric pressure with a chromel wire to validate the method and then with a PAN-type carbon fiber.
Morphology and Characterisation of Novolac/LDPE Based Mixtures as Matrix for Injection Moulded Green Bodies for Bio-Based SiC Ceramics

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Abstract:
In this work the influences of the thermoset-thermoplastic ratio, additives and processing conditions of novolac/LDPE based mixtures, which serve as matrix for the green bodies for bio-based silicon carbide (C/Si/SiC) ceramics, on the morphology and mechanical and thermal properties were investigated. The green bodies were obtained through compounding and subsequent injection moulding and were characterised by scanning electron microscopy (SEM) and mechanical testing. Differential scanning calorimetry (DSC) was performed to estimate the degree of hardening of the novolac after processing. The thermal decomposition behaviour of the pure substances and compounds was investigated by thermogravimetric analysis (TGA). Selected formulations were later reinforced with natural fibres and afterwards pyrolysed to yield porous carbon templates, which were then converted into C/Si/SiC ceramics via liquid silicon infiltration. The carbon and ceramic specimens were characterised by light optical microscopy (LOM) and mechanical testing.

Without further additives, very coarse morphologies of the novolac/LDPE mixtures were obtained, but the miscibility could be improved by the addition of a coupling agent and a lubricant. The temperature and screw speed during compounding directly affected the degree of hardening of the novolac and thereby had a very strong influence on the morphology. The pore structure of the carbon specimens was dependent on the phase distribution in the green bodies, and in turn influenced the morphology of the C/Si/SiC ceramics. In all steps of the process chain (green body / carbon / ceramics) the morphology had a very strong influence on the mechanical properties. From green bodies with a homogeneous phase distribution ceramic specimens with a SiC content of up to 75 vol% could be obtained.
ID: 108

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Title: USE OF SILICA-BASED SHEAR THICKENING FLUID IN CFRP STRUCTURES FOR INCREASED IMPACT RESISTANCE

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Topic(s):
- Impact and Dynamic Response
- Smart Material Structures
- Hybrid Composites

Keywords: CFRP, low-velocity, STF, impact resistance, FEM

Abstract: In the last decade, the interest of several industries including aerospace, automotive and defence was attracted by laminated composite structure for their high specific mechanical performances and low weight. However, due to their layered nature, they are susceptible to out-of-plane dynamic loading that generates damage within the structure causing a drastic mechanical properties detriment. The stacking sequence hybridisation with a secondary reinforce is one of the solution to overcome this issue that allows to absorb large amounts of impact energy with a minimal damage generation. This work investigated the impact response of Carbon fibre Reinforced Polymers (CFRP) when a silica-based Shear-Thickening fluid (STF) is embedded within the structure and used as a secondary reinforcement. An experimental impact campaign is carried out and results are used to calibrate a Finite-Element Model (FEM). This numerical model is developed using an Arbitrary Lagrangian Element (ALE) approach in an interaction-fluid structure analysis to determine the best mechanical properties in function of the STF position along the thickness of the part. Good results were obtained when STF is placed in the centre and in the upper portion of the laminate where impact solicitations are more influent on the structural integrity.
Title: Automated laser-based bonded repairs of aeronautic composites

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Keywords: laser-based repair, automated repairs, CFRPs, statistical optimization

Abstract:
The present study proposes a highly automated solution for the bonded repair purposes of carbon fibre reinforced composite structures. A robotic manipulator which carries the laser head is designed and assembled. The process parameters such as the scanning speed, the pulse frequency, the hatching distance and the hatching pattern are investigated as to their influence on the material removal rate as well as the quality of adhesion as characterized by a novel composite peel test. The use of a green laser, if properly implemented and optimized, turns out to offer a series of advantages. Not only it allows the precise, controllable and automatic - without human intervention- material ablation but it can change the morphology of the CFRP surface through micro-machining effects such as the creation of novel highly regular micro-structural formations that significantly enhance bonding. We provide with experimental evidence that this is not always the case but happens only for specific levels of the process parameters. A design of experiments approach is implemented to search as effectively as possible the process parameters space. We utilize a Box-Behnken four-level factorial design to define the minimum number of experimental trials and build an appropriate test matrix. Finally, the set of parameters that optimize the objective of simultaneously high peel strength and material removal rate are identified following a response surface methodology.
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Title: Core-shell nanocomposites produced from metal acetylenedicarboxylates

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Topic(s): Nano Composites

Keywords: Nanocomposite, acetylenedicarboxylate, thermolysis, magnetic properties

Abstract: Metal-containing nanocomposites of core-shell structure were produced via simultaneous synthesis of metal-containing nanoparticles and stabilizing polymer shell during solid-phase polymerization and thermolysis of Zn(II), Co(II), Fe(III) acetylenedicarboxylates. DSC and TGA curves were recorded to define the main stages of thermal transformations. Temperature of polymerization was found to be in the range of 160–190 °C [1,2]. Polymerization process was shown to occur simultaneously with decarboxylation. Further
kinetic studies showed that these complexes can be polymerized under much lower temperatures, but decarboxylation nevertheless takes place [3]. Composition, morphology and microstructure of nanocomposites were studied by XRD, SEM and TEM. Narrow size distribution was shown by TEM. Metal ions were found to determine shape of nanoparticles and, therefore, morphology of nanocomposites. Co and Fe acetylenedicarboxylates as precursors lead to spherical nanoparticles, while Zn acetylenedicarboxylate provides flat rectangle nanoparticles. EPR spectra revealed conjugated system in polymer shell of nanocomposites, which had formed during solid-state polymerization of metal acetylenedicarboxylates. Fe-containing nanoparticles were found to be of a smallest average size, and that corresponds with their magnetic behavior. Co-containing nanoparticles show strong ferromagnetic properties, and Fe-containing nanoparticles exhibit superparamagnetic properties [4]. Co-containing nanocomposite was tested as sensing material for liquefied petroleum gas (LPG) and shown to have good response time and sensitivity at room temperature [5]. Small additions of Zn-containing nanocomposite was found to improve crack resistance of epoxy resins by 22%.

References.
Development of active composite dish surface for radio astronomy application

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Topic(s): Smart Material Structures
Keywords: Composite, piezoelectric, active surface, radio astronomy, shape correction

Abstract:

Composite reflector based radio telescopes are next generation instruments for radio astronomical observation which provide several benefits over traditional metal-based radio telescopes. These benefits include: improved thermal characteristics, increased surface efficiency, reduced structural weight, etc. One of the challenges in radio telescope design is maintaining the performance of the optical system throughout its operating range of elevation angles and temperature, and under the influence of wind forces. At lower frequencies, and for smaller sized dishes, this has typically meant making the structure as rigid as possible, while at higher frequencies and for larger telescopes the need for active structures is understood. Traditionally, to realize reflective surface shape correction, electric actuators such as screw jacks have been used on panelized elements which require additional support structures at a large cost in complexity and weight.

Shape memory alloy (SMA) wire actuators were embedded into a 1 meter composite reflector to compensate for global and local shape changes. Different orientations of wires have been tested. Although, it demonstrates promising results in terms of surface deformations, there are a few challenges of using shape memory alloys, such as hysteresis non-linearity, adhesion to composites, thermal activation, slow response, limited to one direction movement and fatigue life etc. In this study, piezoelectric patch actuators will be used to create surface deformation. A 1 meter fibre glass based composite dish is manufactured using vacuum infusion technique. Piezoelectric patches are connected to the surface. The dish surface will be measured using a precision laser tracker to obtain the shape of the dish at various actuation of the piezoelectric patches. In addition, fibre optic strain sensors will be mounted on the surface to measure the strain due to the actuation. The primary objective of this study is to characterize the dish under various piezoelectric actuation. Based on the experiments, a mathematical model will be developed to model the hysteresis behaviour for control purposes.
Iron and cobalt-containing nanoparticles (NPs) are promising candidates for use in information recording devices due to a high coercive force and magnetic susceptibility. But, a significant drawback of NPs is the tendency of nanoparticles to rapid oxidation till formation of antiferromagnetic oxide CoO in case of CoNPs, that causes a sharp change in the magnetic properties.

Heterometallic metal polymer nanocomposites were obtained by co-crystallization of the acrylamide complexes of Fe (III) and Co (II) and their subsequent polymerization in the frontal regime and controlled thermolysis of polymer products. Electron microscopy data suggests that as a result of thermal transformations of acrylamide complexes with a given ratio of
components, nanoscale particles of alloys stabilized by carbonized polymer matrix are formed. Studies of the magnetic properties as well as the EPR and FMR spectroscopy data indicate that the paramagnetic centers are not isolated, but form ferromagnetic domains as in case of the product of cocry stallize of acrylamide complexes of Co (II) and Fe (III) nitrate. Analysis of the phase composition of the nanocomposite forming by the XRD method (Figure) indicates the formation of a CoFe nanocrystalline alloy (CoFe-44-1433). Polymer-mediated synthesis of nanocomposites is an effective way to obtain nanocrystalline alloys with controlled sizes and properties of nanoparticles.
ID: 114

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Title: COMPOSITE GRID STRUCTURE TECHNOLOGY FOR SPACE APPLICATIONS

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Abstract:

Mass reduction of primary structures is a constant driving design parameter in the space business. Innovations in design, materials and manufacturing processes are permanently assessed and applied to get mass optimized solutions at low cost. Primary structures provide the necessary structural strength and stiffness to the launch vehicle or in more general terms to space systems. Interstage structures, cone adapters for payload, central tubes for satellites and boom segments for deployable antennas are some examples. Very often these types of structure are axi-symmetric shell structures that must retain their strength and stiffness despite being subjected to very high loads during launch.

Manufacturing these structures using conventional architecture such as monolithic laminates or sandwich structures offers a reasonable compromise between meeting structural and mass requirements. However, they incur mass penalties as material from continuous plies is also present in low stress areas and additional reinforcement is needed at locations of discontinuities (such as access holes, equipment support points, etc).

Whilst Automated Fibre Placement and similar techniques enable a more precise layup of tows that minimizes unnecessary mass in conventional architectures, a more efficient solution to defining heavily-loaded axisymmetric shell structures, is found using CFRP grid structures based on Filament Winding. This technology consists of a regular and dense system of interlaced hoop and helical ribs that take advantage of the axi-symmetric support from the rest of the structure, to provide the required structural stiffness and strength, but with a much lower fibre volumetric fraction (except at the nodal intersections), and lower structural mass than for conventional applications of composite material.

This paper presents the general aspects of the technological development of three applications of grid structures for payloads and launch vehicles, in the frame of ESA projects. Two unique applications for satellite structures: a Central Tube for medium-class satellite platforms and Boom segments for antenna deployable reflectors, and a third application on the Interstage 2/3 of the new European launcher VEGA C that CIRA is developing in partnership with Avio. The project is now in its qualification phase.

In all these applications, a specifically developed design process integrated with a patented manufacturing process is used to provide the skinless, open grid architecture. Other than providing mass benefits, it provides improved accessibility to the inner volume of the structure, thereby enabling easier integration of internal hardware, and it provides passive thermal stability by enabling temperature homogenization between inner and outer surfaces.
EXTREME shearography: high-speed shearography for measurement of impact strains on composites. Development, testing and validation

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Topic(s): - NDE and Structural Health Monitoring (SHM)
- Impact and Dynamic Response

Keywords: High-speed shearography, Double-pulse shearography, Flexural waves, Impact damage, Surface strain, Spatial phase shift

Abstract: This work presents the design, development and the steps towards the validation of results obtained with the developed EXTREME high-speed shearography instrument for the surface strain measurements during an impact event. The work is carried out within the “EXTREME
Dynamic Loading – Pushing the Boundaries of Aerospace Composite Material Structures” Horizon 2020 project.

The shearography technique is used in this project to provide a quantitative measurement of the surface strain development at the first moments of the impact event (μs time scale). Experimentally measured surface strain components over the field of view will be used as input and validation data for developing numerical and analytical models of the impact response of composites. Within the project, the shearography data is compared with in-situ impact data from various techniques as high-speed digital image correlation, ultra-fast Lamb waves interrogation and piezo-electric sensors.

The developed shearography instrument can be configured for the measurement of the in- or out-of-plane surface strain components with two or one shearing interferometers, respectively. The experimental results were achieved with two common interferometers schemes, namely Michelson and Mach-Zehnder which implement a spatial phase shift in a double-frame regime to assess the strain components during the dynamic loading. The speckle pattern is produced by illuminating the field of view of 120×120 mm with an expanded beam from a pulsed laser (SpitLight 600 by InnoLas Laser GmbH) in a double pulse regime. The synchronisation in real-time is based on the approaching impactor using a set of optical interrupters which results in a reliable prediction of the impact event. The instrument uses a gas-gun which is adapted for the impact speeds up to 200 m/s. The experiments included measurements of the flexural waves occurring during the impact in metals (aluminium, steel) and composite laminates. The validation was based on a comparison of the measured surface strain components corresponding to the propagating waves with piezo-electric sensors and numerical predictions.

Comparison of the actual parameters of the EXTREME shearography instrument with previous developments makes it one of the most extreme applications of shearography for dynamic material characterisation.
Abstract: It is generally regarded to be a difficult task to model multiple fractures leading to fragmentation in materials subjected to high-strain rates using continuum mechanics [1]. Meshless methods such as smooth particle hydrodynamic (SPH) [2]-[3] are well suited to the application of fracture mechanics, since they are not prone to the problems associated with mesh tangling, see for instance [4]-[8]. Consequently, this investigation presents alternative approach to modelling damage in SPH, based on the weakening the interparticle interactions combined with the visibility criterion. The main aim of this work is development and implementation of the algorithms for treatment of damage and fracture in SPH method. The focus here is on alternative approaches to modelling free surface and crack opening, its propagation and branching, through a weakening the interactions between the particles. The SPH momentum equation can be rearranged and expressed in terms of a particle-particle interaction area, where the damage acts to reduce this area and is ultimately set to zero, indicating material fracture. The current implementation of the model makes use of a simplified Cochran-Banner description for damage parameter evolution and incorporates a multiple bond break criterion for each neighbourhood of particles.
The model was tested on a 1D and 3D flyer plate impact tests and the results were compared to experimental data. The test showed that the model can recreate the phenomena associated with uniaxial spall to a high degree of accuracy.

References
Data driven approach for 3D Green’s function determination in composite structures: Guided Wave Imaging application

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Topic(s): NDE and Structural Health Monitoring (SHM)

Keywords: guided waves, machine learning, Green's function

Abstract: The aerospace industry is intended to use lightweight and high-performance materials in order to increase the reliability and profitability of aircraft. From this perspective, composite materials, including Carbon Fiber Reinforced Polymer (CFRP) plates and Honeycomb Sandwich Structure (HCSS), are particularly attractive due to their exceptional directional mechanical properties, strength-to-weight ratio, stiffness and corrosion resistance. Nevertheless, these structures are susceptible to hide damage defects such as face sheet delamination or core-sheet debonding that may appear due to impact forces or thermo-mechanical aging and can degrade the mechanical properties. Guided Waves (GWs) -based Structural Health Monitoring (SHM) systems are referred as promising solution for inspecting such structures. GWs are sensitive to surface and subsurface...
flaws and can explore large areas. In general, a sparse array of PZT transducers is used to excite and to sense propagative GWs. GWs Imaging algorithms such as Excitelet can be further used to process the measured signals. This imaging technique allows forming high-resolution images representing the integrity of the structure so that a flaw can be detected as well as localized and, in some cases, sized. This technique is accurate and robust but requires the knowledge of GWs propagation in the structure, namely 3D Green’s function. For structures of simple shape, e.g. plates, pipes, rails, 3D modal Green's functions can be computed by means of various modeling methods. For joined of stiffened structures, or for honeycomb sandwich structures, the accurate and efficient prediction of additional complexity in GW propagation becomes very challenging and of no practical use.

As an alternative to the computation of modeled 3D Green's function, we propose in this work to develop a data-driven approach for the experimental determination of 3D Green's function in composite plates. It implements guided modes filtering in the wavenumber - frequency domain using machine learning methods, so that the modal components of the 3D Green's function can be sequentially deconvolved from the spectrum. The 3D Green’s function is determined over the region of interest and further used for defect imaging.
Abstract: Summary. This paper deals with an overview of innovative UT control procedures, related to defect investigation on advanced CFRP composite elements for aeronautical structures; the inspection procedures are optimized in terms of probe selection, experimental techniques in direct contact condition or water stream method and finally probe manipulation and linear scanning procedures and C-scans. For these aims, artificial defects are englobed in state of art production CFRP plates at different depths and inspections are optimized and compared to combined thermographic acquisitions with active pulsed techniques, in order to calibrate UT tools and procedures for best results. In a second stage, improved UT scanning investigations are applied on real parts, containing real production defects in terms of small delaminations, diffused porosity and resin/matrix excesses between layers, localized in the thin cap and web of structural civil aircraft stringers and T-shaped co-cured jointed elements of considerable thickness, directly provided from actual industrial production.

1 INTRODUCTION
Ultrasonic ND inspections are conducted on CFRP laminates with artificial defects and real CFRP structural components; calibration methods and setup improvement are studied using
special supporting tools, designed for probe positioning and contact conditions on inspected components. Axial probes are used at different frequencies, together with Phased Array 64 elements probes. At same time, Thermographic inspection represents an important solution in order to integrate inspection of composites, in particular for sub superficial defect or extended delaminations. Recent research shows possibility of combining IRT technique with most accurate UT method for a complete characterization of real damage on CFRP parts under service or after production issues. Data processing of UT procedures, coupled with recent advances conceived by authors in merit of pulsed thermographic analysis allows comparing detection sensitivity of different probes and procedures for various type od defects. Direct contact and immersion or water stream techniques are found to be efficient in particular with 2.25 MHz frequency and with PA 4MHz probe. Statistical study is performed for validity demonstration and repeatability of some UT inspections on composites, as function of contact conditions and probe movements by operator. Ultrasonic scan inspections with both traditional Pulse Echo and Phased Array probes are performed initially on reference CFRP plates equipped with 0.2 mm thin artificial defects od different size and NDT control operations are successively performed on T-shape stringers produced by industrial partners and discarded by the quality control procedures, because of diffused porosity presence. Several thermographic set-up tests allowed to identify optimal configurations for defects detection and custom post-processing algorithm is developed for better defect shape mapping, achieved with a full-field contrast automated mapping on larger areas. More inspections are successively experimented on other real components in the form of co-cured CFRP T-jointed thick laminates, in which Resin accumulation spots and sparse small delamination, formed in the interface between skin and stiffener junction after curing process. Thermal and UT inspections are not always in agreement in some cases and defect typology plays important role in exact determination of damage severity, especially in case different probes or set-up procedures are implemented. The experimental activity includes both the optimization of experimental tools in case of ultrasonic probes and development of specific data processing method for thermal control. Finally, microscopic analysis with the stereomicroscope is executed and allowed to observe internally the damaged section, correlating results with data emerged also from thermographic investigations. Thermal PT and UT data are analyzed for different CFRP specimens and verified on damaged structural aeronautical component with internal production anomalies and better computation method is found to be useful for simultaneous defect detection and identification of defect boundaries, on the base of absolute thermal contrast measurements and rearranged with automated mapping algorithms.
ID: 120
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Title: NUMERICAL FAILURE PREDICTION OF GFRP/STAINLESS STEEL HYBRID LAMINATE BOLTED JOINTS

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Topic(s): - Mechanics of Composites
- Hybrid Composites
- Damage, Fatigue and Fracture

Keywords: Finite element method, continuum damage, hybrid laminates, bolted joints

Abstract: For many technical applications, the joining of composite laminates is required, either to realize a combination with other materials, modular manufacturing techniques or simply due to dimensional limitations during transport. In this context, bolted joints are favored compared to bonded joints by many industries, since bolted joints can be manufactured with relatively low-cost tools, are reversible and therefore easy to inspect. Though, the joint efficiency for such joints using composite materials is comparatively low due to the brittle material behavior of the composite [1]. One way to increase the joint efficiency for composite bolted joints is by introducing metallic inlays in the periphery of the bolt. These so-called fiber metal laminates (FML) behave much more ductile than common composite materials, which is one of the main reasons for their increased performance under bolt bearing loading conditions [2].

However, to design a robust and at the same time efficient FML joint, additional laminate characteristics, like the position of the metallic plies in the composite layup, the thickness of the metallic plies, as well as the type of metal used, have to be defined properly. In this context, the ultimate joint strength is one of the most important design parameters. Therefore, the knowledge of the joint’s failure behavior during an early design stage is of fundamental interest for the industry. Numerical tools can be used to predict the onset of damage and its progress till ultimate failure of the joint and are hereby able to reduce the design costs significantly.

In this contribution, a finite element (FE) based test rig for bolted FML joints is presented. The FE-model is segmented into different sections, to provide specific damage modeling ap-
proaches for the FRP material in the bolt’s periphery and in the far field of the bolt. Thus, a mechanically sound representation of the complete damage process till failure of the joint is achieved. The modeling approach is applied and validated for a large variety of different FMLs as well as pure composite bolted joints, to show the available range of application.

REFERENCES
Title: Big data management to guarantee the traceability of material characterization process

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Keywords: Big data management, traceability, material characterization

Abstract: The introduction of composite materials in the aerospace field, with the aim of reducing the aircrafts’ weight and contextually improving their performances, is directly linked to a building block approach in order to characterize the material’s mechanical properties. This kind of approach allows to progress step-by-step and in a pyramidal way starting from the lowest level of analysis concerning the single coupon till arriving to the highest level concerning to the aircraft’s entire structural component. Starting from the base of the pyramid, the designer engineer’s main goal is to investigate how the single specimen mechanical properties vary on varying the test condition. This means that, once the material system has been chosen, it needs to analyze all the various configurations in terms of environment settings, stacking sequence and type of test, all factors which can influence the coupon global strength. Speaking about the strength of a certain composite material in a particular testing configuration, means to speak about the allowable value that is the value which statistically ensure of not having failure under it. Having said all this, it is clear that the allowable campaign’ main need is to collect the allowable values for all the different configuration in which a structural part has to deal with once it is assembled on the aircraft: this is the designer’s highest goal during a material characterization campaign. Nevertheless, it must be considered that such a type of campaign is often hindered by the high costs and long time span. In this scenario, what can help to support and accelerate this type of experimental work is a virtual solution completely dedicated to the allowables’ calculation that can to save time and money.

Globally, both in physical and virtual cases, to optimize the whole process, it is necessary to track material behavior both at lamina and laminate levels and identify all the process and testing parameters needed to fully characterize the whole test matrix. A system which supports
comprehensive data collection, management, and traceability across multiple batch is required to address these challenges. This enables the correlation between the physical and the virtual test results, collecting the process data can provide predictive part performance using statistical models. Finally, the data traceability can be used to collect all the data used in the preliminary phase of part design.

In recent years, the introduction and the increasing emphasis to process management has enabled the industry to shift towards interactive applications, batch automation, new web-based technologies, and the ability to monitor the full data lifecycle of high-quality corporate data. A system as such sets forth several key benefits in the engineering community. In order to support, comprehensive data collection, management, and traceability, it is necessary that a system be able to:

• Capture data, including: process information, qualification material data, inspection data, mechanical testing and characterization
• Provide controlled access for modification, review, and approval workflow
• Maintain traceability and pedigree information from the manufacturing process to the tested part
• Execute/automate processes such as statistical tools and visualization of data
• Maintain, data across the lifecycle of the part in service
• Provide critical information to establish inspection cycle planning

All these requirements define the next generation materials process and management system which must be provided as a COTS (Commercial Off-the-Shelf) solution. First, it allows the dissemination of large quantities of physically-tested and virtually-simulated material data. Second, the automation of data capture and analysis of material test data becomes possible throughout the material lifecycle. Third, the definition of workflows and approvals can apply best practices to efficiently manage the flow of business information. Lastly, integrations with commercial or proprietary CAE, CAD, and PLM tools with scalable web-protocols enable intellectual property protection through process control and traceability.
Title: High Rhodamine B and Methyl orange removal performance of graphene oxide/carbon nanotube hybrid nanocomposites

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Topic(s): Nano Composites

Keywords: 3D nanostructures, High surface area, Cationic and anionic dye removal.

Abstract: In this study, a novel three-dimensional structure of graphene oxides (GOS) and carbon nanotubes (CNTs) forming hybrid nanocomposites have been prepared via a facile freeze drying method. The subsequent N2 adsorption and desorption isotherms has indicated a high surface area of the prepared products, especially the GNT1-5 sample, which had a weight ratio of GOS : GNTs of 1 : 5, with a surface area of 257.6 m²/g. The organic dye removal experiments have demonstrated that the GNTs hybrids adsorb both cationic (Rhodamine B, RhB) and anionic (Methyl orange, MO) dyes in aqueous solution, and the maximum adsorption capacity can reach as high as 295 mg/g with RhB and 67 mg/g with MO. The study also reveals that the adsorption kinetics of both dyes follow a pseudo-second-order model, while the Langmuir adsorption isotherm could be adopted to explain the equilibrium during adsorption. Therefore, these 3D GNT hybrid nanostructures have shown potential as an efficient absorber capable of removing organic dyes in wastewater.
Guided wave imaging of a composite plate using passive acquisitions by Fiber Bragg gratings

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In this talk are presented imaging results of defects in composite CFRP panels using guided wave imaging algorithms such as Delay and Sum (DAS) and Excitelet. Guided wave imaging is commonly applied to active data: each sensor acts successively as a source whereas other sensors measure the propagated signals. In this work, the imaging is obtained from passive data, that is, the signal corresponding to each emitter-receiver couple is reconstructed thanks to the cross-correlation of the ambient noise measured simultaneously by every couple of sensors. The passive imaging approach allows the use of sensors unable to generate guided waves, namely Fiber Bragg Gratings (FBG). FBG present a much smaller intrusiveness compared to traditional piezoelectric sensors, while allowing dense multiplexing and being robust to harsh environments. Results are shown for two instrumentations, the first one uses piezoelectric transducers while the second uses FBG sensors only. The imaging results presented here show the feasibility of passive imaging in composite panels and the possibility of using FBG at ultrasonic frequencies, reducing the intrusiveness of the sensors integrated on the structure in the context of Structural Health Monitoring (SHM).
In recent years, a number of studies within the field of structural health monitoring have focused on the localisation of micro-damage locations in materials. These non-invasive methods are widely used for damage characterisation in materials employed in aerospace and automotive fields, such as steel, aluminium and carbon fibre-reinforced plastic (CFRP) composites. Damage such as micro cracks, layer delaminations, corrosion or barely visible impact damage (BVID) can compromise the integrity of structures. Common inspection techniques based on ultrasound cannot detect small defects. However, many techniques focused on nonlinear wave behaviour have recently been developed to improve the sensitivity of ultrasonic methods. The nonlinear acoustic approaches proposed in this work rely on the production of further harmonics which generally occur at multiples of the fundamental (driving) frequency. This phenomenon is related to the strong nonlinear dynamics of flaws due to the friction between crack surfaces. A damaged sample was excited by an Air-Coupled Ultrasound (ACU) device consisting of 88 transmitting sensors and 1 receiver element. The sensor has a central frequency of 40 KHz and focused at a certain point (F=80 mm). Results confirmed a linear vibration of the intact part of the inspected sample, which results in no higher order harmonic production in the frequency spectrum. On the other hand, a small cracked defect behaves as an active radiation source of a
new frequency, twice the value of the input frequency, known as second harmonic (2f₀). For nonlinear imaging and damage characterization, the second order nonlinear parameter was studied to quantify these nonlinear features. In conclusion, this research work demonstrated that nonlinear techniques are suitable for numerous classes of defects, such as fatigue cracks and corrosion (micro-cracks).
Fatigue Testing and Damage Evaluation using Smart CFRP Composites with Embedded PZT Transducers

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Topic(s): - NDE and Structural Health Monitoring (SHM)
- Impact and Dynamic Response
- Smart Material Structures

Keywords: Composite materials, Smart structures, Fatigue test, Nonlinear ultrasound

Abstract: An increasing number of carbon fibre reinforced plastic (CFRP) composite parts are used in the aerospace industry as they offer high strength and stiffness, as well as lightweight properties. The major challenge with CFRP materials is their susceptibility to micro-cracks and delamination that may occur at the manufacturing stage or during assembly and in service. These defects can lead to component’s failure as they evolve with repeated loading. Over the last few years, the idea of developing smart composite materials with integrated sensing systems for real-time ultrasonic inspection of aircraft parts has become very popular. This is because traditional non-destructive inspection methods such as X-ray scanning and thermography require expensive equipment and the component to be taken out of service for long period. In previous studies, the authors proposed a novel design of smart CFRP composites with embedded piezoelectric Lead Zirconate Titanate (PZT) transducers, in which glass-fibre patches were used to electrically insulate the sensors from the conductive carbon fibres. The results from static mechanical tests including compression, flexural and interlaminar shear tests indicated that this specific configuration of embedded PZTs had no effect on the material strength. In addition, a nonlinear ultrasonic campaign proved the suitability of the proposed smart composites in detecting material damage based on the second harmonic generation and the nonlinear wave modulation techniques. This paper presents the results from dynamic loading tests and nonlinear ultrasonic experiments on the smart CFRP composite subject to fatigue-after-impact testing. Specifically, CFRP specimens with pairs of internal PZTs were initially impacted and then subject to tension-tension fatigue tests to compare their endurance under cyclic loading against plain specimens. The electrical capacitance of transducers was
recorded to confirm their functionality during the test. The PZTs were also used to examine the variation of the nonlinear material response with increasing the number of fatigue cycles. This ultrasonic analysis enabled both the detection of the impact flaws and the monitoring of damage evolution.
DETERMINATION OF THE FRACTURE TOUGHNESS AND THE CRITICAL INTERFACE OF HISTORICALLY BASED MULTILAYER COMPOSITE BY DOUBLE CANTILEVER BEAM TEST ON WOOD

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Keywords: Multilayer composite on wood, Mode I fracture toughness, Critical interface, Double-cantilever beam, Delamination, Painting

Topic(s):
- Mechanics of Composites
- Applications of Composites
- Damage, Fatigue and Fracture
Abstract: The aim of this research is to determine how the initiation of cracks leads to delamination in a historical coated surface on a wooden support, such as in panel paintings. An experimental methodology to measure the fracture toughness of the multilayer coating on a wooden substrate using the double cantilever beam test is developed. The location of failure, i.e. the position of the critical interface, is shown to depend on the concentration of animal glue used. The focus of failure has been interpreted, and the mode I fracture energy values of these materials have been determined.

Comments:
RESIZING OF THERMALLY RECYCLED GLASS FIBRES

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Topic(s): - Mechanics of Composites
          - Other

Keywords: fibre recovery, thermal recycling, resizing, composite

Abstract: European regulations require the recovery and recycling of composite materials. In thermal recycling of glass fibre (GF) reinforced composites, sizing is removed from the fibre simultaneously with resin. The function of the sizing is to improve the interfacial properties between the fibres and matrix. The sizing consists of several components, of which most
essential are film former and coupling agent. The film former provides good processing characteristics, protection against damage and bonds the fibres in a bundle. The coupling agent is responsible for increasing adhesion between the fibres and matrix. Most used coupling agents are organosilanes since they contain both silica and organic functional groups and thus, are capable of forming bonds between the surface of glass fibres and polymer matrix. The aim of the work is to understand the effect of different sizing parameters on the final properties. Construction parts, wind energy blades and automotive parts containing GF were recycled by pyrolytic process. Thermogravimetric analysis (TGA), scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FT-IR) and tensile strength measurement were used to analyse the outcome. SEM images showed no fiber surface damage. Organic substances were not detected during FT-IR measurements.

For the resizing process, polypropylene and polyurethane dispersions were used as the film former and aminosilanes (3-Glycidyloxypropyl)triethoxysilane) as the coupling agent. The process was developed by varying the concentration of sizing components, pH, temperature and immersion time. As a result, the rGFs (Fig.1) had similar amount of sizing on the surface to what reference virgin GF had. Thickness and composition of the sizing layer was evaluated as well as mechanical properties of resized GF.
LONG-TERM MOISTURE ABSORPTION AND DURABILITY OF FRP PULTRUDED REBARS

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Topic(s): - Applications of Composites
- Other

Keywords: Pultruded rebar, anisotropic diffusion, edge effects, ageing, short beam test
Up to 15-years long moisture diffusion into CFRP, GFRP, and AFRP rebars is studied. Uncertainties in identification of the radial and axial diffusivities are discussed. A methodology for unique determination of the axial diffusion coefficient is proposed by introducing concepts of apparent diffusivity and edge effects. Durability performance of the rebars is estimated by comparing their interlaminar shear strength before and after exposure in humid environment.
ID: 131

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Title: Design approach and finite element analysis of a hybrid composite material cleat as nautical spar

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Topic(s):
- Mechanics of Composites
- Composite Manufacturing

Keywords: FEM; FEA; Hybrid composites; Natural fibers; Mechanical behavior

Abstract: In this study, it was firstly analyzed through finite element analysis the behavior of a cleat modeled to be manufactured in natural fiber and glass fiber reinforced polymer. The proposed model consisted in the use of Curauá fiber reinforced polymer in four conceptual fiber-layering laminates. The polymer chosen was an epoxy reinforced with curauá fiber and one lamina of glass fiber. The fiber volume ratio was about 60%. The fiber ratio was selected by the rule of mixtures and the failure chosen from the lower between Tsai-Wu, Hashin and Von Mises failure criteria. Next, it is shown that the stacking design in composites can play an important role on strength, according to the fiber direction referred to stress. Then, the final model was simulated to compare the results achieved from a simulation with the theoretical ones. The analysis had shown how much the natural fibers could be used in certain circumstances with environmental advantages, against conventional composite combination. As a conclusion, it can be noted that the curauá fiber can be used with thermosetting polymers to produce nautical spars that are Eco-friendly, rather than the traditional materials. It was also remarked that the next step on this research would be the production of cleat specimens, and carries out flexural tests to confirm or refuse the theoretical and the finite element analyses.
ID: 132

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Title: Development of functionally graded materials from thermoplastic elastomers waste

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Topic(s): - Composite Manufacturing
Abstract: This work presents thermal and chemical characterization of EVA waste, and their potential to produce functionally graded materials. Moreover, it was also tested the use of blowing agents and PU foams in order to promote better properties in terms of thermal resistance and different type of mechanical properties along its thickness.

1 INTRODUCTION
In a constantly changing world, the main trends of innovation development are guided by societal challenges, such as climate change, low carbon economy or green transport, in order to meet the components weight reduction desires, decrease of waste generation, reduction of components manufacturing costs, among others. In this context, the development of graded materials allows to decrease the amount of components production steps. Functionally graded materials can be defined as a class of advanced materials characterized by variation in properties as the dimension varies [1].

So, in this work, the main objective is to develop graded materials from thermoplastic elastomers waste, namely ethylene vinyl acetate (EVA), having been studied and optimized the processing parameters, according to its intrinsic properties, previously determined.

2 MATERIALS AND METHODS
Firstly, EVA waste was characterized in order to determine some properties which can be relevant for the development of the referred materials, namely its melting point (Tm), enthalpy of phase changing (ΔH), content of vinyl acetate (% VA) and crystallinity degree (Xc). This study was carried out through a Fourier transform infrared spectroscopy (FTIR), Simultaneous Thermal Analysis (STA) and Differential scanning calorimetry (DSC) tests.

In the next step, materials were processed through a compression moulding technology, being studied several processing conditions. The use of blowing agents and polyurethane (PU) foams was also tested. The obtained samples were subsequently subjected to some mechanical and thermal tests, according to ISO 3386 and using an Alambeta device, respectively, in order to evaluate the performance in compression and thermal insulation properties.

3 RESULTS AND DISCUSSION
From the preliminary characterization results of EVA waste, it was verified that the EVA waste presents low concentration of vinyl acetate, around 13%, which means that this material is mainly composed by monomers of ethylene, a simpler molecule than vinyl acetate one. However, despite this fact, the low values of Tm, ΔH and Xc, 81°C, 16.41 J g⁻¹ and 5.6% respectively, indicates that the crystalline regions in the thermoplastic elastomer are reduced. Table 1 shows the obtained results of characterization tests performed. Analyzing these results, it can be verified, in first place, that the EVA Waste (sample 2) presents better compression strength than EVA (sample 1), which can induce that EVA Waste has a higher amount of ethylene monomers than virgin EVA. Moreover, it was verified a decrease of compression strength with the blowing agent incorporation and, in this case, a trend to increase this property for higher temperatures (Samples 3 to 7 and 8 to 12). Relatively to thermal resistance results, it can be verified that larger amounts of blowing agent in the samples promotes higher thermal resistances. Finally, the use of PU foam (sample 13) promotes the best results of thermal resistance and with the compression strength value between those verified for the samples with 1.2 and 2.2% of blowing agent.

4 CONCLUSIONS
Overall, the use and recycling of polymeric waste plays an important role in actual innovation trends. From this study, it is possible to verify that the use of EVA waste allows the production of new materials. Besides that, through the blowing agents and PU foams use, it is possible to obtain a functionally graded materials with good properties of compression strength and thermal resistance, that can be applied in several sectors, such as automotive.
ACKNOWLEDGEMENTS
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REFERENCES
A Comparative Study of FEM Constitutive Material Model Laws For Simulation of Low Velocity Impact Damage to Composite Plates

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Keywords: low-velocity impact, LS-DYNA, CFRP, Failure Criteria, Interlaminar damage, Intralaminar damage

Abstract: The modes of failure in fiber reinforced plastic (FRP) laminates resulting from low velocity impact are quite complex typically comprising of intralaminar and interlaminar damage interaction. It is this in-situ interaction of the damage mechanisms that makes the validity of numerical simulation results of low velocity impact damage with Finite Element Analysis (FEA) error prone. It is well known that the constitutive failure criterion of a material model law significantly influences the overall prognostic effectiveness, yet the technical literature seems to lack a clear consensus pertaining to the prognostic effectiveness of the different material model laws based on damage evolution characterization (i.e., progressive failure and/or continuum damage mechanics). Experimental data obtained from carbon fiber reinforced polymer (CFRP) unidirectional (UD) laminates subjected to transverse impact at different energy levels was utilized to assess the robustness of the failure criteria and damage evolution pertaining to a defined material model law. The study also assessed the influence of both two and three dimensional elements on the damage evolution for a given material model law. To minimize bias with the numerical results, the modeling methodology was kept both simplistic and consistent, omitting advanced element discretization techniques such as the implementation of cohesive element formulations, contact law induced failure criteria, and user defined algorithms. The material model law selection criteria for the study comprised of literature review, damage evolution characterization and conduciveness to adoption of lamina macromechanics. The lamina being characterized by homogenized stiffnesses and strengths since most failure criteria are based on stresses or strains calculated on the lamina level. The
computational impact simulations were conducted using the commercial FEA software LS-DYNA with constitutive material model laws that meet the defined selection criteria being obtained from the pre-processing material library. The comparative study of the material model laws revealed mixed results depending on the failure mode interactions induced from the impact energy levels independent of element type. For matrix dominated damage the numerical results yielded poor correlation with experimental data. Conversely, numerical results of the continuum damaged based material models where fiber rupture was the dominant failure mode were in satisfactory agreement with experimental data.
Title: Comparison of radome sandwich composite structures with finite element method

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Topic(s): - Mechanics of Composites
- Composite Manufacturing

Keywords: sandwich structures, composite radomes

Abstract:
Today, composite sandwiches are used in almost all areas. One of the areas of use are radomes that protect the antenna structures from external influences. The sandwich composites used in radome structures generally consist of monolayer, two-layer, three-layer (A-type radomes) and five-layer (C-type radom) structures. The number of layers and the materials to be used vary according to the mechanical requirements. In this study, mechanical strength of radomes made from three-layer and five-layer sandwich composites was compared with FEM (ANSYS) method. The analyzes were performed for the case where the radome was not damaged under 75 bar pressure. In both sandwich structures, surface film, prepreg and foam core material were used. The three-layer structure was laid in a glass fabric-foam core-glass fabric configuration, and the five-layer structure was laid in a glass fabric-foam core-glass fabric-foam core-glass fabric configuration. First, the analyzes were made by keeping the total foam core thicknesses constant for the two sandwich structures. Then the five-layer structure was repeated using a thinner foam core material than the three-layer structure. Characterization tests were carried out to provide material input to ANSYS program and material properties were determined. Characterization tests were performed according to determined ASTM standards. According to these results, the five-layer sandwich composite structure with two layers of foam was found to have better mechanical strength.

Comments:
ID: 136

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Title: DESIGN AND OPTIMIZATION OF A COMPOSITE SCALED WING MODEL FOR AEROELASTIC WIND TUNNEL TESTING

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Topic(s):
- Applications of Composites
- Multiscale Modelling
- Other

Keywords: Aeroelasticity, Composite structure, Optimization, Finite element analysis

Abstract: In this paper, a numerical method was developed to investigate the aeroelastic similarity between a full-scale wing structure and a scaled wing model for wind tunnel testing. The Full-Scale wing was based on the wing developed for Clean Sky 2 turboprop Regional Aircraft. The Full-Scale wing aerodynamic surfaces, the full-scale finite element model and the operational requirements were used as a starting point. Using the aeroelastic scaling laws and the Buckingham-π theorem, a scaled finite element model, was developed including all the scaled aeroelastic data (testing conditions, inertias, masses etc.) for the WT model. The finite element model of the scaled down wing was matched to the full scale one relative to static aeroelasticity laws and was further used for the 3D WT model structural optimization. Composite materials and aluminum were the primary selection for the 3D WT model. Following the aeroelastic scaling laws, the 3D higher fidelity model of the scaled wing was structurally optimized to match the aeroelastic behavior with the full scale one whereas ensuring its structural integrity using multi-objective genetic algorithms.
Four different structural layouts were investigated considering criteria such as strain limits, scale similarity, manufacturability, assembly process and manufacturing cost. The scaled down model is designed to be used in wind tunnel test conditions, an additional static/dynamic aeroelastic analysis was performed securing the normal operation during wind tunnel test. The wind tunnel composite wing was modeled with Doublet Lattice panels for the aerodynamic calculations and layered shell elements for the structural components. The aerodynamic panels and the structural mesh were coupled using the rigid/flexible spline method, to secure accurate load transfer.

Acknowledgement

This work has been supported by Horizon 2020 Clean Sky 2 Joint Undertaking under the acronym GRETEL (GREen Turboprop Experimental Laminar Flow Wind Tunnel Testing). The Authors would like to acknowledge the support of the Topic Manager Dr. R. Gemma from Leonardo SpA for his technical advice and data.

Comments:
Title: Development and characterization of innovative carbon-based ashes/epoxy composites

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In this study, carbon-based ashes have been produced by the wooden biomass pyro-gasification plant CMD ECO20. CMD ECO20 is a micro-scale combined heat and power system powered with biomass, under development by the Italian company Costruzioni Motori Diesel S.p.A. (CMD). It is an integrated system combining a downdraft gasifier, syngas cleaning devices, a spark ignition internal combustion engine and an electric generator, and it is able to produce electric and thermal power up to 20 kWe and 40 kWth, respectively. Three different types of fillers have been produced from ashes starting from innovative green waste: the first type (MA) has been obtained by mortar milling, while the second (DBA) and the third (WBA) have been produced by dry and wet ball milling, respectively. MA, DBA e WBA fillers have been characterized by several techniques including Wide-angle X-ray diffraction (WAXD), Fourier transform infrared (FTIR) spectroscopy, Scanning Electron Microscopy (SEM), Multi-angle light scattering (MALS), Energy Dispersive X-ray (EDX) Spectrometry, Organic Elemental Analysis (OEA) and Inductively Coupled Plasma – Optical Emission Spectrometry (ICP-OES).

Each filler has been added to epoxy resin EC01 in an amount equal to 1, 3, 5 wt % and has been tested as possible catalyst for crosslinking of epoxy resin, as already observed for oxidized carbon black. This study has been mainly conducted by rheometry and Differential Scanning Calorimetry (DSC).

The curing agent (22phr) has been added to the resin that has been cured for 1 h at 60 °C and 2 h at 150 °C.

Finally, the flexural properties and the glass transition temperature of cured neat epoxy and ashes filled epoxy composites have been measured.

The elastic modulus of the epoxy resin containing an amount of fillers of 1 and 5 wt% is higher in comparison to that of the neat epoxy. The flexural strength of the epoxy resin containing an amount of DBA of 1 and 5 wt% is also higher than that of the neat epoxy.
NATURAL FIBERS REINFORCED INORGANIC FOAM COMPOSITES FROM SHORT HEMP BAST FIBERS OBTAINED BY MECHANICAL DECORTATION OF UNRETTE STEMS FROM THE WASTES OF HEMP COLTIVATIONS

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Topic(s): Green Composites
Keywords: natural fibers, geopolymer, inorganic foam composites

Abstract: Global interest in the use of plant fibers in natural fiber reinforced composites (NFCs) is growing rapidly. The increased interest is primarily due to the advantageous properties of natural fibers including biodegradability, low cost, low density and high stiffness and strength to weight ratio. In order to achieve NFCs with suitable mechanical properties, well separated and cellulose-rich fibers are required. Hemp is taking a center stage in this regard as a source of suitable natural plant cellulose fibers because natural hemp bast fibers are long and inherently possess high strength. Classical field and water retting methods have been used for centuries for removal of non-cellulosic components from fibrous plant stems including from hemp, but they
carry a risk of reducing the mechanical properties of the fibers via damaging the cellulose. For NFCs new targeted fiber pre-treatment methods are needed to selectively and effectively remove non-cellulosic components from the plant fibers to produce cellulose rich fibers without introducing any damage to the fibers. A key feature for successful use of natural fibers such as hemp fibers in composite materials is the optimal interfacial contact between the fibers and the hydrophilic inorganic material. Focused modification of natural fibers for NFCs must also be targeted to optimize the fibers surface properties.

Natural plant fibers such as hemp and flax fibers are currently receiving high research attention due to their potential as reinforcing agents in composites to substitute for synthetic fibers. Hemp bast fibers are defined as the continuum of primary and secondary cell walls of the cells that form the cortex sclerenchyma layer of the hemp stem. These bast fibers are particularly long and contain highly crystalline cellulose fibrils. These characteristics make hemp plants a promising source of natural cellulosic fibers for use in biocomposite materials. More importantly, compared to synthetic materials (e.g. glass fiber), hemp fibers also have other advantages such as low cost and low density together with their high stiffness- and strength-to-weight ratios.

Hemp fibers, similarly to other plant fibers, essentially contain 5 major components: (1) structural polysaccharides: cellulose and hemicellulose (the hemicellulose mainly being xyloglucan); (2) structural protein; (3) other polysaccharides, notably pectin (homogalacturonan); (4) lignin; (5) waxes, and (6) minerals. Hemp fibers are generally composed of 53–91% cellulose, 4–18% hemicellulose, 1–17% pectin, and 1–21% lignin (all in % by weight, wt%), but the chemical composition of untreated hemp bast fibers varies with cultivar, harvest year, harvest time (or growing stage), location of fibers within the stems, and the final composition of fibers used for composites also depends on the type of fibre processing. The density of hemp fibers is 1.4–1.6 g/cm3, whereas the mechanical properties of fibers from different hemp varieties, i.e. tensile strength, stiffness and failure strain range from 200 to 1000 MPa, 18–66 GPa, and 2–4%, respectively. In comparison, synthetic fibers including glass fibers and carbon fibers have higher tensile strengths of ~2000 and up to ~4000 MPa, respectively, as well as higher average stiffness of 80 and 238 GPa, respectively. Glass fibers have much higher density (2.55 g/cm3) and carbon fibers somewhat higher density (1.8 g/cm3) than hemp fibers. Thus, the specific tensile strength (1.3–6.7 × 105 m2/s2) and stiffness (1.2–4.4 × 107 m2/s2) of hemp fibers are comparable to the specific tensile strength (approx. 7.6 × 105 m2/s2) and stiffness (approx. 3.0 × 107 m2/s2) of glass fibers. Hemp fibers therefore have potential as replacements for glass fibres as reinforcements for composite materials.

This work has been mainly focused on cryogenic, mechanical and chemical treatment to increase the wettability of hemp fibers and make them suitable for the application inside inorganic materials such as cementious matrices. Chemical treatments have included the traditional alkaline treatment and a more innovative green treatment with sodium ascorbate. Untreated and treated fibers have been characterized through Fourier Infrared spectroscopy (FTIR), measurement of the contact angle, Optical Microscopy, Thermogravimetric analysis (TGA) and Differential Scanning Calorimeter (DSC). In addiction, differentiate thermogravimetric analysis (DTG) is used to evaluate the shift of the significant peaks related to the maximum oxidative decomposition rate and the thermal stability of the materials. The aim is to investigate the influence of the physical, mechanical and chemical treatments on hemp fibers properties in order to prepare lightweight fiber reinforced inorganic diatomite-based insulation foam, characterized by low density (350 kg/m3), thermal conductivity (0.05 W/mK) and suitable mechanical properties. The insulation foam was obtained by using a natural source as matrix, suitable amount of Si powder and vegetable surfactant as chemical and physical foaming agent and a polysilicate solution as reactive crosslinker. Hemp short fibres were added in order to improve flexural mechanical properties. The foamed systems were cured at defined temperature.
**Title:** Experimental study of Thermoplastic-RTM process using ε–caprolactam for the carbon fiber reinforced nylon 6 composite fabrication

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**Topic(s):** Composite Manufacturing

**Keywords:** Thermoplastic resin transfer molding (T-RTM), CFRTP, Nylon 6, anionic polymerization, anionic polymerization of nylon 6 using activator, catalyst and ε-caprolactam has advantages of fast curing, excellent impregnation, impact resistance and recyclability.

**Abstract:** Thermoplastic resin transfer molding (T-RTM) is the most promising process for mass production of carbon fiber-reinforced thermoplastic polymer (CFRTP) composite, applicable to automotive applications. Anionic ring-opening polymerization of the nylon 6 using activator, catalyst and ε-caprolactam is the most promising resin system for the T-RTM process. The T-RTM process using anionic polymerization of nylon 6 has advantages of fast curing, excellent impregnation, impact resistance and recyclability.

The only two parameters that can be controlled in the T-RTM process are resin temperature and molding temperature (curing temperature) before and after mixing the activator, catalyst and ε-caprolactam. In this study, the anion polymerization process of nylon 6 was studied to optimize the T-RTM manufacturing process in relation to the process temperature. The curing process of the T-RTM (polymerization and the crystallization of the nylon 6) was analyzed by cure monitoring using dielectrometry. The mechanical properties and impregnation quality of the nylon 6 and CFRTP were measured with respect to the process temperature. The effect of cooling process on the mechanical properties of CFRTP produced by T-RTM process was investigated. As a result, the optimal process conditions for the T-RTM process were suggested by the quality and processing capabilities of CFRTP composite.
EXPERIMENTAL MODAL ANALYSIS AND VIBRO-ACOUSTIC TESTING AT LEONARDO LABORATORIES

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Abstract: This work deals with Experimental Modal Analysis and vibro-acoustic testing performed on several composite panels tested at Leonardo Laboratories, Pomigliano site. The main objective of this paper is to investigate the dynamical behaviour of the structure under test and to evaluate its acoustic properties. Several tests have been performed at the Transmission Loss Facility of Leonardo. In a modal test, both the applied forces and vibration responses of the excited structure are measured in one or more locations. Exploiting this data, a Modal Model, that essentially contains the same information as the original vibration data, is derived by means of frequency-domain system identification techniques. A home-built Matlab algorithm, named “uMan”, is developed to perform a full Experimental Modal Analysis. Its performances, in terms of capability to build a useful stabilization chart and to curve-fit measured FRFs, are shown. Moreover, a comparison with respect to the state-of-art “Polymax” algorithm in LMS Test.Lab is provided. Finally, the numerical-experimental correlation is performed to verify consistency. The proposed algorithm identifies first mathematical polynomial models, rather than estimating the modal parameters directly from the measurements. Subsequently, these mathematical
models are related to the modal parameters. Finally, the obtained Modal Model is compared to the analytical dataset.

An acoustic test has been performed to experimentally investigate sound transmission. Two experimental methods have been adopted to evaluate the transmission loss. First, the method that includes measurements of the sound pressure levels using microphones is exploited. Then, the sound intensity method, in which the transmitted sound intensity is measured with a sound intensity probe, is used. By comparing both experimental techniques, the first showed better performance with respect to the other method at low frequencies, while the sound intensity method is more applicable in the medium and high frequency regions in order to predict the noise transmission characteristics.
Title: Contribution to mechanical fasteners for composite structures - an automated industrial approach

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Topic(s): Applications of Composites

Keywords: automated, interference-fit, car body, composites, fastener, pullout

Abstract: Current fastening technologies implemented in composite structures for car body application show various disadvantages compared to an interference-fit joint. For example adhesive bonding requires clean and pre-treated surfaces and metallic parts are prone to galvanic corrosion. This work is investigating the system of an interference-fit joint ("connection") consisting of a fiber reinforced thermoplastic insert which is pressed into a pre-drilled hole in a composite structure. With the insert being oversized and the hole undersized respectively, interface pressure is generated. Pressure in circumferential direction is leading to friction which in turn is giving the insert resistance against pullout. The connection is functionally evaluated by comparing both the pullout force curves and the injection force curves for three different levels of interference. Major target is a precise prediction of resulting pullout force based on the injection process. Futhermore a process capability figure of the connection is worked out whereby the pullout force curves are characterized and curve sketches are performed. Since the environmental conditions of a car manufacturer’s body shop require highly automated processes, the connection is implemented fully automated within a cycle time of approx. 5 seconds. Furthermore the process is conducted by a robot controlled device fulfilling relevant targets of process reliability, capability and reproducibility. Additionally the whole equipment is designed with regards to body shop facilities allowing to transfer the testing facility into
production environment. As the car body structure is the intended application, possibilities to attach parts to the body are required. Therefore the hybrid insert is shaped like a Stud, composed of a M6 stainless-steel thread insert which is covered by a fiber reinforced thermoplastic, produced through injection molding.
Effect of matrix modification using cellulose nanofibers on strength recovery in self-healing carbon fiber/epoxy laminates

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Topic(s): Repair and Self-Healing

Keywords: Short beam shear testing, Composite material, Microcapsule, Cellulose nanofiber, Interlaminar shear strength, Self-healing

Internal damage can cause a reduction in strength and stiffness of laminated composites and is extremely difficult to detect and repair by conventional methods. Thus, self-healing has the potential to mitigate the internal damages. Recently, Sanada et al. evaluated the interlaminar shear strength and self-healing of spread carbon fiber (SCF) /epoxy (EP) laminates. This study examines the effect of addition of cellulose nanofibers (CNFs) to the matrix on the strength recovery in self-healing SCF/EP laminates. The results indicated that as the addition of 0.05wt%CNFs to the matrix, the apparent interlaminar shear strength decreased and the healing efficiency increased.
The effect of the addition of a combination of rigid nanofillers and core-shell rubber nanoparticles on the fracture mechanics, tensile, electrical and thermo-mechanical properties of epoxy resins were studied. SiO2 nanoparticles, multi-walled carbon nanotubes (MWCNT's), as rigid nanofillers, and core-shell rubber (CSR) nanoparticles, as soft nanoparticles were used with bisphenol-A based epoxy resin. Further, the rigid fillers were added systematically with core-shell rubber nanoparticles to study the combined effect of rigid nanofillets and soft CSR nanoparticles. The resulting matrix will be extensively characterized by standard methods. This includes a thorough characterization of fracture mechanical, mechanical, electrical, and thermal properties. The resulting formulations led to a significant increase in fracture toughness, critical energy release rate and electrical conductivity. The analysis of the fracture surfaces revealed the toughening micro-mechanisms. The obtained results to be used as the matrices for the
development of innovative low-, mid- and high-pressure tanks based on advanced composite materials and processes.
Title: MECHANICAL AND THERMAL BEHAVIOUR OF PHBV COMPOSITES REINFORCED BY NATURAL FILLERS

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Topic(s):
- Mechanics of Composites
- Composite Manufacturing
- Green Composites

Keywords: PHBV, wood fibres, basalt fibres, injection moulding, biocomposites

Abstract: Biodegradable poly (3-hydroxybutyrate-co-3-hydroxyvalerate) based composites reinforced with 7.5 or 15 wt. % of wood or basalt fibres were fabricated by injection moulding. The study of mechanical properties of composites showed differences in the characteristics of the reinforcement of composites depending on nature of fibre’s type. Basalt fibre reinforced composites showed improvement in all properties, whereas wood fibre composites showed an increase in Young modulus values, while a drop in strength and impact properties. In comparison with the unmodified polymer, an increase of 174 % of Young modulus and 41 % of impact strength has been noticed for composites with 15 wt. % of basalt fibres. Furthermore, the experimental results of Young modulus were compared with various theoretical micromechanical models. It was found that Haplin-Kardas model was in near approximation to the experimental data. A morphological aspect of the bio-composites was studied using scanning electron microscopy due to describe distribution and interfacial adhesion of fibre. Additionally, biodegradation tests of the biocomposites have been performed in saline solution at 40 °C through weight loss and mechanical properties studies. It has been observed that the presence of fibres affect water absorption rate and the higher was for composites with 15 wt. % of wood fibre, what is connected with nature of fibre. Both after the first and second week tensile strength, flexural strength, Young modulus and flexural modulus decreased slightly. Due to the poor adhesion confirmed by SEM photos, further work will concern its improvement by adding compatibilizer.
SIMULATION OF COMPOSITES NAVAL PLATES SUBMITTED TO GEL PROJECTILES IMPACTS

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Topic(s): Impact and Dynamic Response
Keywords: Composite, Fluid Structure Interaction, Intra-laminar damage, Gel impact.

Abstract: Underwater Explosions (UNDEX) and slamming are two of the most important design loads to be taken into account in naval engineering especially in the field of composites materials. Two main challenges are faced in designing this type of structure: to be able to model the behavior of naval structure submitted to these loads with computational costs compatible to industry needs and to characterize the material behavior under UNDEX or slamming. Indeed, performing experimental tests of these events is not only a costly but also a complicated and hazardous process. On the other hand, methods such as gas cannon testing are used in the
aerospace industry, especially for bird strike tests. These soft body impact uses gel impactor that exhibit a behavior similar to the one of water and therefore can be of use in the field of ship design. Furthermore, this kind of tests is able to be used in combination with simulation to characterize the behavior of composite materials up to failure.

This work presents the results obtained in characterizing the behavior of several naval composite plates submitted to gel impacts. The plates studied are made of CFRP and GFRP laminates as well as sandwich panels made of GPRP skin and PET foams. The nonlinear explicit finite element simulation that has been validated against experimental tests is based on Fluid Structure Interaction between an impactor with water properties which is modeled using an Arbitrary Lagrangian Eulerian approach and a shell composite plate. An orthotropic material law with a failure criteria is then used for evaluating the different intra-laminar failure modes that may occur in the impacted plates such as fiber rupture, fiber kinking, matrix cracking and matrix compressive failure. The Chang-Chang Criterion is used as it enables to separate the different failure modes in the composite plate.

The results obtained with this model present a good correlation with the experimental gas cannon tests performed during the project campaign. It is then possible to determine, for the different material tested, different levels with respect to the impact energies: elastic response, initiation of matrix cracking due to tension loads and finally fiber rupture.

**Comments:** Composite, Fluid Structure Interaction, Intra-laminar damage, Gel impact.
CFRP materials used for aerospace and automotive applications can be exposed to high rate impact loading, with the range of strain rates from $10^3 s^{-1}$ to $10^6 s^{-1}$ during impact scenarios such as debris impact, hail stone and ice impacts, bird strike, armour penetration etc. These extreme impact cases almost always involve damage and failure of the materials. When modelling the response of CFRP structures to impact loading the treatment of failed material is major challenge.

The work presented here considers the coupling of the Finite Element Method (FEM) and the Smoothed Particle Hydrodynamics (SPH) Method, a meshless method. The purpose is to make
use of the inherently non-local nature of SPH [1] and treatment of damage based on particle to
particle interactions [2] for dealing with composite failure, and at same time to use the
efficiency of FEM in areas away from the failure zone. The coupling algorithm of regions
discretised with SPH and regions discretised with FEM uses a transition element based on
previous work [3], [4].
This is done as part of an effort to support development of the tools for modelling of high
velocity impact on composites in the European project EXTREME*.

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Modelling failure in solids using inter-particle interactions in SPH, Proceedings of 13th
The development of renewable energies is a critical need to meet the ambitious energy goals set by the European Union in the coming years. Particularly, offshore wind energy face certain limitations due to its relative youth and limited technological development. The latter determines that, at present, the cost per KWh is too high as compare as to alternative energies. This high cost is, to a great extent, related to the maintenance, repair and overhaul operations (MRO), aggravated by the current trend of moving wind farms further away from the coast. Thus, the present work deals with the development of a new design of transition piece. This component located in the splash zone is one of the most demanded structures both from the mechanical and corrosion perspectives. As such, it is currently made of steel with high corrosion allowances and a low efficiency in terms of corrosion resistance.
The work presented herein shows the developments from the lab-scale to a demonstrator scale of a multimaterial transition piece. Hence, a component combining an inner shell of steel with a protective thermoset composite outer shell has been accomplished. In order to do so an extensive and thorough study of material selection (fibers and resins) and stacking sequence has been done. The structure is completed by a coating system to provide the biofouling resistance as well as improving the corrosion resistance. Finally, one of the key features of the new solution is the possibility of performing real-time monitoring based on Fiber Brag Grating (FBG) sensors. These fiber optic sensors have been fit for the purpose by developing ad-hoc coatings follow by the corresponding sensitivity study. The results are currently being validated under real conditions in a demonstrator at a 1:5 scale in an experimental area located in the Atlantic Ocean.
Title: Non-Destructive Method for Evaluation of the In Plane Elastic Modulus of Composite Materials

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Topic(s): - NDE and Structural Health Monitoring (SHM)
- Other

Keywords: Young’s Modulus, Non-Destructive Testing, Ultrasound, Material Evaluation

Abstract: The rapid and precise assessment of component material properties is of high importance in multiple industries due to material safety requirements. Furthermore, easily adaptable testing methodologies, which provide quick and accurate non-destructive measurements of material properties can result in large savings in terms of material, time and cost. This work presents a non-destructive testing method to measure the in-plane Young’s Modulus of composite materials using sound waves. A piezoelectric transducer of multiple elements was developed and used to transmit a plane wave through composite samples in order to calculate the in-plane speed of sound. By calculating the time-of-flight between pairs of transducers the in-plane material properties of various composite panels was assessed non-destructively. Following this, various tensile tests were conducted on the tested samples in order to validate the calculated in-plane Young’s Modulus. The Young’s Modulus measured using the proposed method were in good agreement with the values obtained by the destructive tensile tests. The proposed method has potential to allow for rapid inspection of composite structures during and after the manufacturing process.
DAMPING ASSESSMENT OF NEW MULTIFUNCTIONAL EPOXY RESIN FOR AEROSPACE STRUCTURES

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Title: DAMPING ASSESSMENT OF NEW MULTIFUNCTIONAL EPOXY RESIN FOR AEROSPACE STRUCTURES

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Keywords: Nano Composites
Title(s): Nanocomposite, damping, aerospace

Abstract: The increasing of the demand of more advanced materials, particularly in the aerospace field, has led to an increase of the use of the resources dedicated to the scientific research on carbon-fiber reinforced composite materials including the application of nanotechnology strategies. The presence of CNTs reinforcements allows the modulation of the characteristics of a polymer matrix composite which become suitable for more extreme operating conditions and resistant to environmental damage. The advantages of the use of carbon nanotube reinforcement are many. They allow to improve the mechanical characteristics of the composite. The most relevant aspect, however, lies in the electrical properties that make these composites suitable for the
design of self-sensing materials. Composite materials reinforced with CNTs have the potential to be used as sensors as well as structural materials and this is a highly sought after goal in recent times. Techniques using electrical properties, are the non-destructive way to monitor damage in composites subjected to static and dynamic loads. However, this approach is still not applicable to composites where the fibers are non-conductive, such as glass and aramid fibers. Damage detection through conductivity measurements offers many advantages when compared to traditional glass fiber optic sensors. In fact, because of their high cost, it is not possible to create a dense network of these fibers to inspect large parts of the composite and especially if the damage spreads in the material without crossing the fiber could also not be detected. Therefore, the use of carbon nanotubes may provide an effective solution to go under the many aspects described. As part of an intensive research activity aimed at studying the performance of innovative smart resins, the authors will show in this article the outcomes related to some of their dynamic properties.
Abstract: Composite materials may reduce the final weight of the aircraft structural components, in addition to improve fatigue performance and corrosion resistance. In order to achieve the optimization of air transport systems, making them increasingly sustainable, the structural design must be surely reviewed, starting to follow the "composite thinking" philosophy. The present research provides some relevant outcomes concerning the design of a composite sample for the main landing gear bay of a large commercial airplane (EASA CS25 category), within ITEMB (InTEgrated Full Composite Main landing gear Bay Concept) project, a program of Clean Sky 2 EU research framework. The most ambitious goal is to develop a new generation of Lower Center Fuselage (LCF) with an innovative integrated landing system in the fuselage, which is considered the next frontier in the development of landing systems for medium-haul aircraft, such as the Airbus A320 aircraft family. The development of a different architecture, with the landing gear integrated within the related fuselage bay, could lead to a simplification of the whole sub-assembly with potential advantage in terms of construction and assembly times. Final target of the project is the manufacturing of an innovative monolithic composite structure that will replace the actual configuration (a mixed structure of metal and composite sub-assemblies) reducing or actually removing all the cost of assembly and increasing the...
production rate. This paper presents the main results of the work, introducing the main processing steps and prototype results; in the last part of the work, also some experimental tests on significant elements are introduced as first assessment of the technology readiness level that has been achieved.
I consent to the collection and use of my personal information, including receiving emails, for activities related to 12th International Conference on Composite Science and Technology (IC CST/12). I have also obtained the consent of all other individuals whose information I provide. (2019-02-15 08:35:38 UTC)

**Title:** CELLULOSE FIBER BASED COMPOSITES FOR AUTOMOTIVE APPLICATIONS

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Topic(s): - Mechanics of Composites
- Green Composites
Keywords: renewable resources, bio-based performance polymers, lightweight material, automotive application

Abstract: Reducing a vehicle’s weight is a primary objective as well as a major challenge for the automotive industry. This is the main reason why plastics have been used to substitute heavier materials such as metals. A further challenge faced by the industry is the use of renewable resources in order to minimize the environmental impact of car production. Innovative materials derived from renewable sources help to save energy, reduce reliance on fossil fuels and drastically reduce the carbon footprint. Our research and innovation are focused on natural fibers reinforced polymer composites can offer the same performance as traditional materials but with lower weight and environmental impact. In this article the performance of cellulose fibers was analyzed and compared with traditional filler. From this point of view, cellulose fibers are probably the most interesting for their availability, price and constancy of properties. Recent investigations at SAPA have shown that, compared to other natural fibers, they can guarantee excellent mechanical properties in the molded parts. Experimental activities were carried out within the LIFE Biobcompo Project, whose objective was to reduce the environmental footprint of new vehicles through innovative low density thermoplastic composites derived from renewable (bio-based) sources. The specific objectives of BIOBCOMPO is to develop at industrial level very low density thermoplastic materials which allows to save up to 8% in weight by using natural fillers. The project aims to demonstrate these new technologies at industrial scale, aiming to overcome the problems related to industrialization of the newly proposed solutions. In this paper the application of cellulose-reinforced polypropylene composites for automotive parts is evaluated. Key parameters such as fiber-matrix adhesion, moisture, thermal stability and mechanical properties, are discussed in detail. The results show that the presence of inorganic fillers can improve the dispersion of the cellulose fiber within the polymer matrix and the processability of the composite. A small percentage of talc can help the melt flowability while enhances the composites in stiffness and strength. These bio-based composites are suitable for applications ranging from interior door panels and pillar covers to underbody aerodynamic shields.
Composite materials based on porous matrices.

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Sodium borosilicate glasses with and without iron are the subject of intensive study. This is connected with the new practical applications in optics, microelectronics, solar energy and immobilization of radioactive wastes. Recently these glasses are used as a host material for porous matrices with controlled porosity. Some publications concerned an introduction of different ferroelectric materials into porous dielectric matrix and a determination of physical properties of these nano-ferroelectrics appeared. Embedding of a ferroelectric material into the pores of a magnetic porous matrix provides opportunities to obtain a new multiferroic material. The properties of nano-composites based on the dielectric or magnetic porous matrices are dependent on the structure of initial glasses and porous glasses produced from them.

The subject of this work is a technology and investigation of the properties of the ferroelectric (KNO3) nanocomposite materials based on porous matrices as sodium borosilicate glasses with...
and without iron and porous glasses obtained from these glasses. The TEM, FTIR, X-ray Diffraction methods were used to study the morphology and structure of the materials. All investigated glasses contain inclusions of the iron-containing phase in the two phase-separated structure. The electrical measurement results show the ionic conductivity for glasses and dielectric porous matrices and mixed electronic and ionic conductivity in magnetic matrices and glasses with iron. The electronic conductivity is due to polaron hopping between iron ions and the ionic conductivity is related to the motion of sodium ions. The results of investigations of the electrical properties demonstrate the correlation between glass structure and polarization mechanisms occurring in these glasses.
EFFECT OF FREEZE-THAW ON COMPRESSIVE AND FRACTURE PROPERTIES OF CNT-MODIFIED CEMENT MORTARS

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Topic(s):
- Smart Material Structures
- Damage, Fatigue and Fracture
- Nano Composites

Keywords: CNTs, mortars, fracture, acoustic emission, freeze-thaw

Abstract: The last two decades carbon nanotubes (CNTs) have received great attention as a result of their unique properties in the context of smart-multifunctional materials. It has been observed that CNTs exhibit a bridging effect among micro-cracks within the cementitious matrix which delays their propagation [1, 2]. As a result CNTs lead to an improvement of the fracture behavior of cementitious composites [3-6]. At the same time, addition of CNTs may result in improved electrical conductivity, piezo-resistivity and/or acoustic emission behavior, features that enhance the health-monitoring capability of the nano-modified matrix [7-10]. A critical parameter of CNT-modified cementitious materials behavior is the dispersion of the nano-phase without affecting the physical characteristics of the nano-modified cement paste [11-13]. Thus, the effect of CNT-dispersing medium should be taken into consideration.

It is well accepted that the durability of a building material under severe operating conditions is a key parameter for its design. Freezing and thawing conditions encountered in cold climates can cause serious damage or even destruction of cement-based structures. Therefore, it is imperative to study the compressive and fracture properties of CNT modified cementitious mortars as a function of dispersion quality.
For this purpose aqueous CNTs suspensions were sonicated using surfactants and/or plasticizers with the CNT content varying between (0.2-0.8 wt. % cement). Suspensions then were incorporated in cement and sand. Cured specimens were subjected into low freeze/thaw cycles according to ASTM C666. Temperature in low freeze was set at -18 ± 2 °C and in thawing at +4 ± 2 °C. The compressive strength was evaluated using BS EN 196-1 standard. The fracture toughness was determined using the CMOD (crack mouth opening displacement) under three point bending test configuration [14]. Damage monitoring ability was determined using critical acoustic emission (AE) parameters, such as hits, AE energy, and other parameters of the AE waveform [15-17]. The strength, fracture toughness and AE parameters were assessed as a function of nano-modification, dispersion agent and environmental loading.

ACKNOWLEDGEMENTS
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Topic(s): - Composite Manufacturing
- Nano Composites

Keywords: Porous glasses, ferroics, multiferroics, size effect

Abstract: Nowadays materials science becomes an unusually intriguing research field due to extraordinary novel materials, more advanced fabrication and uncommon challenges. Among them, nanomaterials, in which qualitatively novel properties emerge upon decreasing material size below certain limits, play a special role. A great number of materials have been shown to exhibit a coupling between magnetism and ferroelectricity. Multiferroic nanocomposite technology seems to be a field full of challenging and interesting problems both for scientists and engineers. The past decade confirmed a positive evaluation of efforts in development of multifunctional nanostructures with properties controlled by their size, morphology or the host matrix. Borosilicate glasses have achieved great attention due to the presence of an irregular network in which different ions can be introduced and moreover embedded ions does not destruct the glass structure [1-3]. In many cases, such iron-contains SBS glasses exhibits ferromagnetic properties, interesting for applications in areas of multiferroics nanocomposites, optics, nanoelectronics, sensors, biotechnology and medicine. Studies on ferroelectric and multiferroic nanocomposites obtained by embedding a ferroelectric material into the pores of a dielectric and ferromagnetic porous glass matrix will be presented. It was shown that the ferroelectric nanocomposites obtained on the basis of ferromagnetic porous glasses exhibit both ferroelectric and ferromagnetic properties. Ferroelectric-like behavior were observed for all nanocomposites. The hysteresis loops and temperature dependencies of resonance field ultimately prove ferroelectricity and ferromagnetism in nanocomposites under study. The specific heat was measured using the DSC method and the anomaly of the ferroelectric phase transitions was indicated. The particle-size dependent magnetic, dielectric and thermal
properties of the obtained multiferroics nanocomposites were presented.


MODE I FRACTURE TOUGHNESS OF ASYMMETRIC METAL-COMPOSITE ADHESIVE JOINTS

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Topic(s): Damage, Fatigue and Fracture
Keywords: Fracture toughness, Metal-composite adhesive joint, Double cantilever beam

In this work, the mode I fracture toughness behaviour of dissimilar metal-composite adhesive joints for aerospace applications is studied by means of the double cantilever beam (DCB) test. A generic joint configuration is studied; the metal and composite adherents have different thicknesses, while also two aluminium backing beams were applied in both sides of the metal-composite joint to ensure the non-yielding of the metallic adherents. Data reduction was performed using an analytical model recently developed by the authors which takes into account the residual thermal stresses as well as the bending-extension coupling of each sub-laminate. Experimental results were compared with numerical ones using the Virtual Crack Closure Technique (VCCT). Fractographic investigations were performed to study the involved fracture mechanisms.
This work focuses on the rheological and morphological properties of epoxy composites loaded with two very similar graphene-based nanofillers, i.e. GNP56 and GNP60, differing fundamentally for the exfoliation degree (56% and 60%, respectively) and consequently for the concentration of carboxylated groups on the nanoparticle edges. The morphological analysis by Atomic Force Microscopy (AFM) allows to observe the distribution of the nanofillers inside the epoxy matrix, highlighting the effect of exfoliation degree and the capacity of edge-carboxylated graphite layers to create self-assembled structures embedded in the polymeric matrix which promote the interfacial interaction between polymer and carbon layers. The chemistry of edge structures of graphitic blocks can be controlled for improving the performance of nanocomposite in order to achieve the wanted goals, thus markedly influencing the physical properties of the resin where the graphene based nanoparticles are inserted.
Design and characterisation of hybrid hemp/carbon laminates with improved impact resistance

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Topic(s): - Textile Composites
- Hybrid Composites
- Green Composites
- Damage, Fatigue and Fracture

Keywords: Composite materials, Hybrid Hemp/Carbon composite, Impact resistance, Damping properties, Non-Destructive test

Abstract: Composite materials, thanks to their mechanical properties and lightness, are widely used as
structural parts in marine, automotive and aerospace fields. Although composite materials are characterised by high in-plane properties, their performances to out of plane loads are not remarkable. During operating conditions they could be involved in accidental impacts at low velocity by runaway debris or tool drop during maintenance operations that could cause invisible damage by visual inspection. For this reason many research paper are focused on low impact characterisation; in particular, during the last decade, the researchers are focused on hybrid laminates characterisation.

The hybridization process is one of the main and efficient way to merge the mechanical properties of synthetic fibres with the natural ones. In this way, thanks to the lower modulus of the natural fibres, it is possible to improve the impact performance of composite materials while the higher modulus of the synthetic ones contribute to the resistance and stiffness. Thus the hybridization process reduces the critical drawbacks of composite materials.

On the basis of the hybrid laminates research trends, the aim of this work is to evaluate the impact behaviour of Hemp-Carbon composite panels. Hybrid laminates were produced using natural fibres and synthetic ones laid up by using combination of hand lay-up and compression moulding technique, with more detail Carbon, Hemp and Hybrid configuration were tested. Damping tests and Low Velocity Impact tests at 10 J and 20 J were carried out in order to evaluate the Hybrid configuration damping properties and impact behaviour. Moreover, in order to have a better interpretation of the internal damage for each impact energy, Non-Destructive tests were carried out.

The results shown improved damping properties for the Hybrid configuration and a slightly more ductile behaviour if compared to CFRP composite. The Non-Destructive tests carried on the Hybrid composite showed, for the same amount of absorbed energy, a smaller damage extension localised at the interface between Hemp and Carbon fibres.
THE EFFECT OF AN AROMATIC HYPERBRANCHED POLYESTER IN AERONAUTICAL EPOXY COMPOSITES

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Topic(s): Nano Composites
Keywords: Hyperbranched Polymer (HBP); Epoxy Resin; Fracture Toughness; Thermosetting Matrix; Polymer Matrix Composites (PMC); Thermal Stability

A glassy hyperbranched polyester (HBPG), was synthesized and dispersed within an aeronautical graded epoxy matrix as toughening agent. This filler is a polyester characterized by a higher glass transition temperature (Tg) then room temperature (~90°C) and obtained by means of bulk poly-condensation reaction starting from a diphenolic acid as precursor. HBPG/epoxy systems were prepared considering two concentration levels, respectively 0.1 and 5 wt%, and the effects on thermal stability, mechanical properties and fracture toughness were investigated and analyzed in respect to the corresponding neat epoxy. HBPG induces optimal results with a limited reduction of the Tg and a higher increase of degradation activation energy along with enhanced fracture behavior as indicated by an enhanced critical stress intensity factor (KIC) and critical strain energy value (GIC).
EFFECT OF SIO2@POLYDOPAMINE CORE/SHELL NANOPARTICLES AS MULTIFUNCTIONAL FILLER FOR AN AERONAUTICAL EPOXY RESIN

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Topic(s): Nano Composites

Keywords: Epoxy resin, Core/shell nanoparticles (CSNPs), Polydopamine (PDA)

Silica@polydopamine nanoparticles were considered as filler for an aeronautical graded epoxy matrix and their effects on the composite matrix mechanical and thermal behaviour were investigated respect to the neat epoxy. A simplified procedure for synthesis of the Core/shell nanoparticles was implemented allowing the production of necessary amount for future development and characterization of corresponding carbon reinforced composite. The NPs were synthesized by a modified one-step procedure, based on the nucleation and growth of SiO2 NPs followed by the growth of a thin PDA layer on the silica surface. TEM observations have revealed that CSNPs are characterized by approximately 250 nm core and a PDA surrounding shell of about 15 nm. Nanocomposites with different SiO2@PDA contents (0.1, 1 and 5wt%) were manufactured and samples will be tested by thermal and mechanical techniques with particular attention to the thermal stability and fracture toughness properties.
TEMPO oxidized cellulose nanofibers (T-CNF) was prepared from cellulose pulp which is extracted from bagasse, cultivated in Egypt. T-CNF was grafted with soy protein hydrolysate (SPH) via the amidation reaction between the carboxylic groups of T-CNF with the amino groups of SPH for preparing new bioactive material. Then, T-CNF-graft-SPH was soaked in simulated body fluid (SBF) to initiate the calcium phosphate mineralization. It was demonstrated that T-CNF-graft-SPH, with a structure similar to the humane protein, promotes the biomineralization process in analogy with hydroxyapatite mineralization in collagen based natural bone tissues. FT-IR spectroscopy showed that successful formation of amide bonds and the introduction of amino groups during the TEMPO oxidized cellulose/SPH hybrid formation. The growth of calcium phosphate was confirmed by the presence of different vibration modes of $PO_4^{3-}$ groups. EDXs and XRD also shows the presence of the calcium and phosphate with Ca/P ratio 1.63, similarly to the native hydroxyapatite of bone.

TGA calculation showed that the residual weight of the T-CNF-graft-SPH and T-CNF-graft-
SPH/calcium phosphate hybrid are 20.8 and 42.9%, respectively. T-CNF-graft-SPH were in vitro tested with human Mesenchymal stem cells to validate the biocompatibility of nanocomposites. In particular, cell morphology was qualitatively evaluated by SEM microscopy, proliferation tests were performed to quantitatively evaluate cell proliferation, while Alizarin red stain was used to detect the presence of newly formed calcium deposits in the “ex novo” formed extracellular matrix. All the results are promising to fabricate bioactive platforms, via electrofluidodynamic technologies, for the repair and/or the regeneration of hard tissues such as bone.

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Title: HEAT CONDUCTION IN POLYPROPYLENE-BASED COMPOUNDS REINFORCED WITH BASALT OR GLASS FIBERS

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Abstract: Basalt and glass fibers were used as fillers in polypropylene(PP) to verify their effect on the thermal transport of the neat resin. In particular, formulations containing up to 30% in weight of filler content were prepared by melt blending and analyzed in terms of thermal conductivity and rotational rheology.