BOOK OF ABSTRACTS

ICSAAM 2023

The 10th International Conference on Structural Analysis of Advanced Materials

10-14 September 2023, Zakynthos, Greece

Composite Materials Group,
Department of Mechanical Engineering & Aeronautics, University of Patras, Greece

10th International Conference on Structural Analysis of Advanced Materials

Zakynthos, Greece

10 - 14 September 2023

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NOMENCLATURE		
A: HALL A: Leschi of Zakynthos	**PL:** Plenary Lecture	*PAID BY the CONFERENCE 25-30 Ps max
B: HALL B: Public Historical Library of Zakynthos	**KNL:** Keynote Lecture	**PAID BY the CONFERENCE 250 Ps
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ABSTRACTS: Session 1A

Monday 11 Sep. 2023	**SESSION 1A** Plenary Lectures **Advanced Composites-Modelling and Behavior**
Session 3A Co-Chairmen:	**Antonio Torres Marques,** LAETA/FEUP – Faculty of Engineering of University of Porto, Porto, Portugal. **Danny Van Hemelrijck**, Professor, Mechanics of Materials and Constructions, VUB, Belgium

AEROSPACE COMPOSITES WITH BUILT IN FUNCTIONALITY: ACHIEVEMENTS & LIMITATIONS

Constantinos Soutis

The University of Manchester, UK, E-mail: constantinos.soutis@manchester.ac.uk

ABSTRACT

The growing use of multi-layered composite materials has arisen from their high specific strength and stiffness when compared to the more conventional materials, and the ability to tailor their structure at the fiber and ply level to produce aerodynamically more efficient structural configurations [1, 2]. Ideally though, we would like to build a material system from scratch, atom by atom engineering. Then you would be able to build in functionality on a material level. Imagine, you create a hetero structure such as say the top layer acts as a sensor, the next few work as amplifier and interconnects, few layers act as mechanical reinforcement. Somewhere there would also be a solar cell to generate power to run the whole circuit. Multilayered carbon fiber reinforced composites together with 2D materials such as graphene will enable such structural configurations to be tailored according to needs. In this context, applications of modern composite systems are presented and achievements, but also challenges and limitations are discussed.

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DELAMINATION AND BRIDGING IN COMPOSITES: EXPERIMENTS AND MODELING

John Botsis
John Botsis, Institute of Mechanical Engineering, School of Engineering, Ecole Polytechnique Federale de Lausanne, EPFL, Lausanne, Switzerland. E-mail: john.botsis@epfl.ch

ABSTRACT

It is well known that large scale bridging in fracture of layered composites is one of the most important toughening mechanisms. The resulting resistance to fracture, however, is dependent on specimen geometry, material and microstructure rendering its experimental characterization and modeling difficult. In this presentation, experimental results and modeling of fracture in DCB specimens are discussed. Selected specimens are equipped with wavelength multiplexed fiber Bragg grating (FBG) sensors to monitor crack propagation and strains over several millimeters in the wake of the crack. The modeling involves an iterative scheme to calculate traction separation-relations, due to bridging, using the strains from the FBG sensors, parametric finite elements and optimization. The results demonstrate an important effect of specimen thickness in the fracture response and allow deducing scaling relationships due to large scale bridging. The obtained traction-separation relations are employed in cohesive zone simulations to predict very well the corresponding load-displacement and fracture resistance curves for each thickness. To elucidate further the phenomenological response, computational micromechanics models are developed to predict the specimen thickness effects on bridging and the large differences in inter- and intralaminar fracture. Analysis shows that when the traction separation relation is enriched with the local crack opening angle, the observed experimental response can be easily reproduced thus, suggesting traction separation relations with two-kinematic parameters as a physically sound model. Using real microstructures, the micromechanics models demonstrate that the matrix material between and within the composite plies plays important roles in fracture response and suggests a vast field of future research opportunities to predict toughness in composites [1-6].

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SELF LEARNING MATERIALS FAILURE MANAGEMENT SYSTEM

N. Melanitis [1], P. Giannaris[1], G. Giannakopoulos[2], K. Stamatakis[2], A. Sideras[2] , D. Mouzakis[1], G. Melagraki[1], A. Koutsomichalis[3]

[1] Hellenic Naval Academy, Leof. Chatzikiriakou 48, Pireas 185 38, Greece
[2] Institute of Informatics & Telecommunications, NCSR Demokritos, 27, Neapoleos str &, Patriarchou Grigoriou E, Ag. Paraskevi 153 41, Greece
[3]Hellenic Air-Force Academy, Acharnes 136 72, Greece

ABSTRACT

The H.F.R.I. funded project (no 822) with the acronym NAVMAT intends to develop a knowledge-based system for the support of decision making and knowledge management of naval materials (NAVMAT) failures. The work aims mainly to erase disruptions in the flow of knowledge in a versatile environment such as a fleet, to support the decision making in maintenance and supply of marine spares, to train and educate the engineers and the operators of an organisation with distributed unis and points of presence, to contribute to operational readiness, by developing a materials failure ontology and utilising artificial intelligence algorithms in data handling [1].

The key data of the system is the failure incidents. Each one is associated with a component, which belongs to a system of a naval (and not only) platform. Once the failure incident is recorded in NAVMAT system by the authorized and trained users, should a failure analysis be commissioned, is then associated with a failure mode, and a root cause of failure, together with other characteristics of the material and the conditions of operation [2].

The NAVMAT application supports several types of users, from the incident contributor to the materials expert through appropriate workflows. Multiple types (and language) of information are incorporated securely to the system such as text, files, images, and videos. They are classified by using a dedicated materials, components and systems failure ontology developed, and subsequently indexed and retrieved upon request by employing Artificial Intelligence and machine learning tools.

The prototype application is developed in a web environment and has been fed with 40 failure incidents and associated failure analysis reports. A User Group of 30 volunteer experts has been formed and thoroughly examined the system, reported bugs, and provided suggestions to improve the user experience of the application. The application is expected to be fully operational by the end of the current year.

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ABSTRACTS: Session 2A

Monday 11 Sep. 2023	**SESSION 2A** Plenary Lectures **Bio-Mechanics and Biocompatibility**
Session 2A Co-Chairmen:	**Corrado Piconi,** Italian National Research Council, Institute for the Science and Technology of Ceramic Materials (CNR-ISTEC), Faenza (RA), Italy. **Georgios Psarras,** Professor, Smart Materials & Nanodielectrics Laboratory, Department of Materials Science, School of Natural Sciences, University of Patras, Greece.

TEXTILE SCAFFOLDS FOR TISSUE ENGINEERING OF TENDONS AND LIGAMENTS: PAST AND ACTUAL PERSPECTIVES

Rui Miranda Guedes

LAETA, UMAI-INEGI, Department of Mechanical Engineering (DEMec), Faculty of Engineering of the University of Porto (FEUP), Rua Dr. Roberto Frias s/n, 4200-465 Porto, Portugal

ABSTRACT

Tissue engineering relies on scaffolds with tissue-like properties [1, 2]. This approach allows the regeneration of irreversibly damaged tissues. Tendons and ligaments possess limited healing ability implying an invasive surgical procedure to repair or replace them if irreversibly damaged. Significant contracture of the ruptured tendon ends prevents a direct primary repair. Longer intervals between injury and repair reduce the viability of this repair. Augmentation techniques to bridge the gap between tendon ends use autologous, synthetic, or allograft graft materials [3, 4].

The use of synthetic materials for augmentation avoids sacrificing other active tendons. Moreover, it circumvents the associated morbidity with large incisions and dissections necessary in autologous techniques. Textile technology delivers singular advantages mimicking tendons and ligament hierarchical organization and attaining similar mechanical properties such as anisotropic and strain-stiffening features. Driven by this, a novel hybrid synthetic augmentation device using a textile technology was developed after testing different textile structures based on polypropylene, poly (ethylene terephthalate), and poly(lactic acid) multifilament yarns, attempting to mimic the fibrous structure of tendons [5-7]. Those structures are based on a core/shell system, being the core composed of several sub-components (braids) and the shell based on braided yarns enclosing the core structure. Starting from non-degradable simple fibrous structures (braids) produced with PP or PET multifilament yarns, it led to hybrid-braided structures composed of PET and PLA multifilament yarns [8-10]. The PLA yarns incorporated in the braids will gradually degrade, allowing integration within the host environment without compromising the mechanical performance.

Textile patterns influence the porosity, architecture, and mechanical properties of scaffolds. Exploration of various textile patterns is critical to achieving mechanical properties matching the target tissues. Thoroughly investigating the effect of different textile patterns on scaffold properties remains relevant in biomedical engineering.

Modelling fibrous structures imply capturing the complex interactions between fibres, knowing the initial and actual geometrical arrangements, the constitutive nonlinearities, and the hygrothermal and mechanical loading interactions. For this purpose, the continuum mechanics approach needs specific adaptations to model the heterogeneity and discontinuity between fibres with slender and deformable geometry [11]. It requires advanced simulation methods to capture these features. Dedicated Finite Element code can simulate multilayer braided scaffolds considering contact/friction interactions between fibres represented by a beam model accounting for cross-sectional strains in the finite strain domain [12-14]. Future developments involve designing and producing textile patterns efficiently.

In silico models for virtual manufacturing and testing will substantially reduce the time-consuming and costly manual textile production followed by mechanical testing [15-18]. The efficient and precise manufacture of complex textile-based scaffolds requires more advanced textile machines.

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MODERN METHODS AND TECHNIQUES FOR TESTING ARTIFICIAL SUBSTRATES BIOCOMPATIBILITY

Minodora Dobreanu[1], Doina Manu[1], Diana Portan[1,2]

[1]Center for Advanced Medical and Pharmaceutical Research George Emil Palade University of Medicine, Pharmacy, Science, and Technology, Targu Mures, Romania, Corresponding Author: minodora.dobreanu@umfst.ro

[2]Department of Mechanical Engineering and Aeronautics, University of Patras, Patras 26504, Greece

ABSTRACT

Biocompatibility is a measure of how an artificial substrate interacts in the body with the surrounding cells, tissues and other factors. A biomaterial is considered to have good biocompatibility if it does not trigger cytotoxic effects and / or too strong of an immune response, resists build-up of proteins and other substances on its surface that would hinder its function and is resistant to infection. Seven major type of methods are in use:

a) ***In vitro* cell culture assays:** This method involves exposing artificial substrates to different types of cells in a controlled laboratory setting and assessing their response, viability and metabolic activity. The cells are then observed for any adverse reactions (apoptosis/necrosis), or changes in their behaviour, such as cell differentiation, proliferation, adhesion, migration and any adverse reactions. [1-3].

Cytotoxicity testing. These assays evaluate the potential toxicity of artificial substrates on cells. Various cell lines can be used, such as bone-derived mesenchymal stem cells (BDMSCs), fibroblasts or epithelial cells, and different assays can be employed to measure cell viability, such as flowcytometry, fluorescence microscopy (MTT 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide), lactate dehydrogenase (LDH) release assay or the Neutral Red uptake assay can be employed to measure cytotoxic effects.

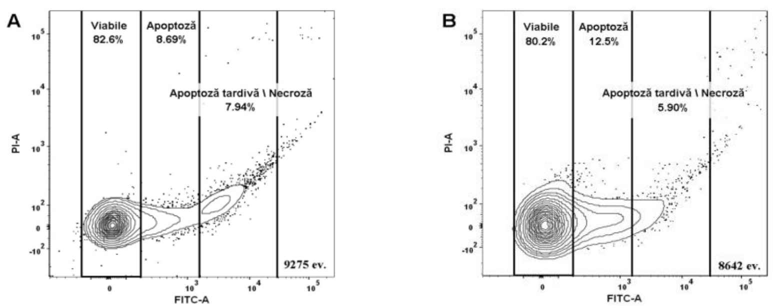

FIGURE 1 A, B - contour plots (FITC-A vs PI-A, that is, Annexin-V vs Propidium Iodide) for determining cell's viability. The double negative cells are viable, the Annexin-V positive ones are apoptotic, and the double positive ones Annexin-V / Propidium iodide are in late apoptosis or necrosis. Figure caption reproduced from an open acces source [1]

Cell Adhesion/Migration Assays: These assays assess the ability of cells to adhere/migrate to /on artificial substrates. Techniques such as the crystal violet staining assay or the CellTiter-Glo Luminescent Cell Viability assay, or confocal microscopy can be used to measure cell dynamics (diferentiation, development, adhesion and migration) [2,3].

***In vitro genotoxicity testing**:* This assesses the potential of the material to cause DNA damage in cells. Common tests include the Ames test, micronucleus assay, γH2AX and Comet assay.

Gene expression analysis: Gene expression profiling can provide valuable information on the cellular response to materials. Techniques such as quantitative real-time polymerase chain reaction (qPCR) and microarray analysis can be used to measure the expression levels of specific genes involved in inflammation, tissue regeneration, and immune response.

b) **Animal models:** Animal models, such as rodents or larger animals like pigs or non-human primates, are used to assess the biocompatibility of artificial substrates. The substrates are implanted or applied to the animals, and their physiological responses, such as inflammation, fibrosis, tissue integration, and immune reactions, are monitored.
c) **Histological analysis:** The immunohistochemistry methods involve examining tissue surrounding the implantable material in samples collected from animals or humans after implantation of artificial substrates. The samples are stained and observed under a microscope to assess tissue integration, inflammation, fibrosis, necrosis and other indicators of biocompatibility.
d) **Blood compatibility tests:** Artificial substrates are tested for their interaction with blood components, such as platelets, red blood cells, and plasma proteins. Tests include measuring hemolysis, platelet adhesion/activation, coagulation and/or complement activation.
e) **Immunological assays:** These tests evaluate the immune response to artificial substrates, including activation of immune cells, the release of inflammatory cytokines, and assessment of potential hypersensitivity reactions. Techniques such as flow cytometry, RT PCR, multiplex, ELISA, can be used to assess the activation or proliferation of immune cells (lymphocytes and macrophages), to measure inflammatory markers.
f) **Surface characterization techniques:** Advanced surface analysis techniques to evaluate the degradation of artificial substrates over time. There are several modern techniques used for the evaluation of advanced materials biocompatibility:

Imaging techniques include scanning electron microscopy (SEM) allows the visualization of material surfaces at high magnification. It can be used to assess cell adhesion, morphology, and interaction with the material. Atomic force microscopy (AFM) allows for the visualization of material surfaces at the nanoscale. It can be used to assess surface roughness, topography, and mechanical properties of the material and can be employed to assess changes in the substrate's morphology or chemical composition.

Chemical analysis includes X-ray photoelectron spectroscopy (XPS) - a surface-sensitive technique that can provide information about the elemental composition and chemical bonding of a material. It can be used to assess the surface chemistry and changes in the material due to cellular interactions. Fourier-transform infrared spectroscopy (FTIR) can be used to analyze the chemical composition of a material. It can provide information about the functional groups present and changes that occur due to cellular interactions.

g) **Computational modelling:** Computer simulations and modelling techniques can predict the interaction between artificial substrates and biological systems (4.5). These models can simulate the behaviour of cells, tissues, and biomolecules, helping to predict the biocompatibility of the substrate before actual testing.

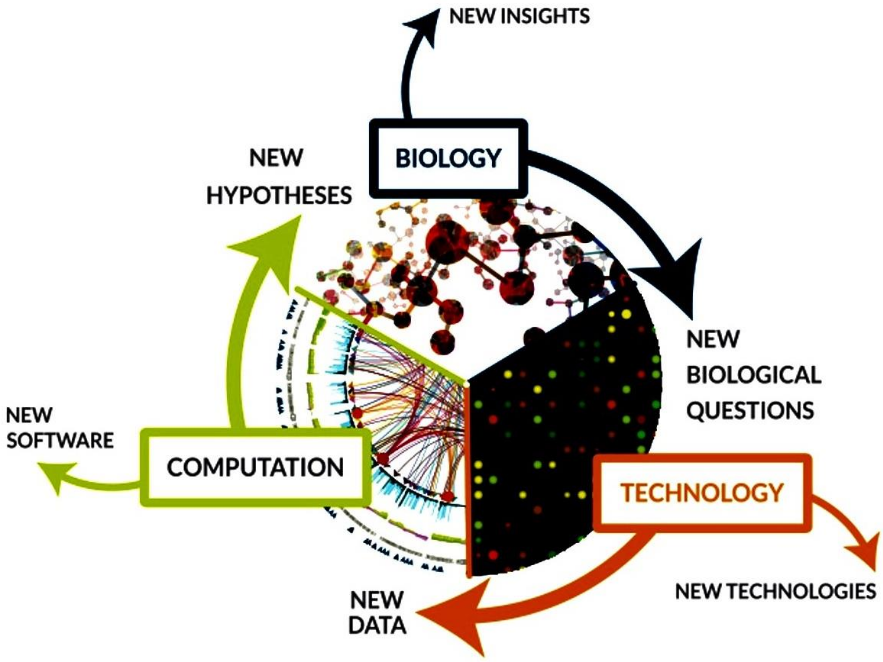

FIGURE 2 Computational models are used to simulate and study complex biological systems; Image Courtesy ISB [5]

The specific methods used for testing biocompatibility may vary depending on the type of artificial substrate, intended application, and regulatory requirements. Researchers often use a combination of techniques to obtain a comprehensive understanding of the biocompatibility of artificial substrates.

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TOWARDS THE DEVELOPMENT OF SINGLE AND MULTILAYERED PACKAGING FILMS WITH ADVANCED BIOACTIVITY

Nektaria-Marianthi Barkoula

Department of Materials Science and Engineering, University of Ioannina, 45110, Ioannina, Greece

ABSTRACT

Until now petrochemical-based plastics have been used as packaging materials because of their large availability at relatively low cost and their good mechanical performance, good barrier properties, heat sealability and so on. However, consumer’s increasing demand for minimally processed foods that maintain freshness, quality, and safety has directed the plastic packaging industry towards the development of active packaging. Active packaging is defined as the kind of packaging that contains substances which interact either with the food or with its environment to extend food’s shelf life. Numerous methodologies have been proposed for the transformation of conventional to active packaging. This can be achieved through various routes, including the incorporation of bioactive substances in the form of bioactive patches, coatings, capsules, or through grafting or blending of such substances with the polymer matrix. The use of biopolymers with enhanced bioactivity to replace conventional synthetic polymers has also been suggested as a viable alternative.

The current study will provide insight into two different strategies. One is focusing on developing and elaborating alternative polymer films based on biodegradable, biobased hybrid nanocomposites produced from renewable resources. As packaging materials, these materials target to expand their added value by providing quality preservation and extending the shelf-life of a variety of food products, by material minimization due to the nano reinforcement (reduced amount of the required material for the same performance), or even by providing additional functionalities, i.e., antimicrobial action and biodegradability. The second strategy is based on the transformation of conventional packaging materials into active packaging with minimum intervention in terms of materials addition. The target here is to maintain the mechanical performance and high barrier of synthetic polymers and at the same time add bio functionalities.

In the first direction, the current research explores the potential of chitosan-based packaging films. Chitosan is a natural polymer derived by the deacetylation of chitin. It is the second most abundant biopolymer in nature after cellulose. Next to its availability in nature and biodegradability its antimicrobial activity against a wide variety of microorganisms makes chitosan one of the most promising biomaterials to replace synthetic plastics, particularly for packaging applications. The main limitations for the widespread use of chitosan are linked with its strongly hydrophilic character, dilution in acidic pH, and brittleness. Based on the above, we explore in the current study the effect of the addition of layered silicates in chitosan, since polymer/layered silicate (PLS) nanocomposites have recently become quite important for both industry and academia due to their superior performance compared to virgin polymer or conventional micro and macro-composites.

Improvements of the elastic moduli, strength, and barrier properties are documented here, in conjunction with the effective protonation of chitosan in appropriate acidic environment, the use of placticizers, and selection of suitable processing methodologies [1, 2]. The incorporation of lipid compounds, such as fatty acids and oils, into chitosan-based films and the role of blending with synthetic polymers have also been investigated [3, 4, 5]. The current study has also put effort to growth ZnO nanoparticles (NPs) in chitosan to create active packaging films with enhanced performance [6]. ZnO has been proposed as an attractive 3D-nanostructure additive in various applications due to its photocatalytic activity, high stability, antibacterial property, and non-toxicity. Overall, in this part of the work, we aimed: (a) to create chitosan-based nanocomposites with enhanced mechanical, barrier properties, thermal stability, and additional functionalities (biodegradability, antimicrobial activity); (b) to assess the durability of the produced films and (c) to optimize the proposed processes.

In the second direction, the current research explores the potential of developing active films based on low density polyethylene (LDPE). LDPE is widely used in food packaging applications because of its exceptional properties, such as light weight, low cost, and easy processibility. For the transformation of LDPE to bioactive packaging, we focus on natural food preservatives from plants, which demonstrate quite significant bioactivity and may contribute to the circular economy and sustainability. To keep the intervention in terms of material modification to a bare minimum, we propose the development of a multi-layered structure, with the main part of the packaging being based on neat LDPE. To enable time-controlled bioactivity and higher thermal stability, we propose to entrap the bioactive substances into the interlayer space of effective adsorbents such as layered silicates [7]. Bioactive substances are also applied in the form of coating for direct interaction with the packaged food and immediate antimicrobial and antioxidant action [8].

Acknowledgements

Part of this research was co-financed by the European Regional Development Fund of the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call 'Aquaculture'—'Industrial Materials'—'Open Innovation in Culture' (project: AntiMicrOxiPac, project code: T6YBΠ-00232).

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BIOMATERIALS FOR MEDICAL DEVICES

Corrado Piconi

Italian National Research Council, Institute for the Science and Technology of Ceramic Materials (CNR-ISTEC), Faenza (RA), Italy

ABSTRACT

This lecture is aimed to give an historical perspective on the development of biomaterials, of the present state-of-the-art and of the development now in progress in this field.

Over the past years in European Union countries life expectancy at birth has increased greatly thanks to advances in medicine and improved general hygienic conditions. The proportion of the population over the age of 65 is increasing, associated with a general trend of prevalence of chronic over acute diseases, giving rise to an increased demand for medical devices safe, effective, long lasting.

The use of medical devices during clinical treatment of whatever anatomical district is a standard practice today. The success rate of medical devices is so high in some areas that sometimes neither the limitations arising from their use, nor the complexity of the problems associated with their design and production cycle are perceived by the general public.

The use of medical devices has enabled several remarkable therapeutic innovations, of which we can mention a few examples. Today, femoral neck fractures in the elderly are treated with the implantation of a hip prosthesis and resolved in a few days of hospitalization on average. Before, the treatment consisted of performing osteosyntheses that forced the patient into immobility for weeks, with complications consisting of phlebitis and pressure sores. With no certainty that the fracture would consolidate, hip fractures were one of the main causes of death in the elderly. Cataracts, opacification of the crystalline lens that could lead to blindness and otherwise severe visual impairment, are now treated in 97% of cases on an outpatient basis with the insertion of an intraocular lens. Pacemakers are implanted in more than one million individuals each year [1], while the implantation of a prosthetic valve to treat stenosis or insufficiency of heart valves, of a stent to restore patency to a vessel, of a coronary bypass is part of daily clinical practice. Hemodialysis filters and circuits are essential to the survival of countless patients. Patient-specific implants made by additive manufacturing are the solution in many critical cases. All these developments have been possible thanks to the availability of biomaterials.

It is difficult today, to think that only some decades ago the very word ‘biomaterial’ made no sense: in fact, the term dates to the first symposia organized by Clemson University in the late 1960s. The very definition of the term ‘Biomaterial’ was established in 1991 during the 2nd International Consensus Conference on Biomaterials (Chester, UK,) as ‘a material designed to interface with biological systems to evaluate, support or replace any tissue, organ or function of the body’ [2].

Biomaterials have fulfilled humanity's atavistic need to replace or supplement parts or functions of the human body damaged by pathological or traumatic events, crowning with success a long series

of attempts dating back to the dawn of medicine. Egyptian, Babylonians, Greek surgeons were able to treat many diseases, as well as Phoenicians and Etruscans, who left us several fixed or movable golden dental appliances. Written sources from Roman times inform us refined surgical techniques were part of clinical practice, and instrumentation found in the tombs of physicians [3], like the one consisting of more than 150 different pieces found in Rimini (Italy) [4], testify to the developments achieved in surgery during the Roman Empire. Famous was a Greek manufacturer, whose instruments marked ‘Agathangelus’ were found in Pompeii, Herculaneum and Vindonissa (near Zurich) [5].

All these devices were confined outside the human body, until during the second half of the 18th century the discovery of anesthesia, asepsis, and X-rays paved the way for the implantation of materials into the human body. Only the wide availability of penicillin in the early 1950, discovered by Sir Alexander Fleming in 1928, changed the surgery outcomes defeating infections.

Then, some pioneers in Europe and the U.S. to think about how to transfer to their patients the surgical techniques developed during the war in military hospitals. Many of them were orthopedic or cardiovascular surgeons, who with the help of mechanical engineers started using materials once restricted to military applications, such as low-carbon stainless steel (AISI 316L), Polymethylmethacrylate PMMA (Perspex®, Plexiglass®, Lucite®) and new polymeric materials such as PTFE (Teflon®) or high-density Polyethylene. Parachute fabric (Vinylon N) was used for the first vascular prostheses. Since then, the number of applications of biomaterials in medical devices has grown steadily, with important clinical spin-offs in all branches of medicine, enabling a very large number of patients to survive, or restore impaired function of their bodies.

Today biomaterials are the result of concurrent developments obtained in the field of medicine, of material science, of microbiology, of mechanical engineering, of electronics. Orthopedics and Cardiovascular surgery are still the main users of biomaterials. The main development in orthopedic devices can be represented by the new metal-free devices for resurfacing of the femoral head, either for the condylar component in total knee replacements. In cardiovascular surgery, transluminal techniques allow today the implant of cardiovascular stents and heart valves, and ventricular assistance devices (VADs) sustain hearts affected by heart failure. Heart transplantation is the gold standard for end-stage biventricular heart failure. However, this therapy is subject to the scarcity of donors, which limits the number of transplants to around 5,500 patients per year [6]. The development of a Total Artificial Heart (TAH) as a bridge-to-transplant or as a long-time replacement was for long time the Holy Grail in cardiovascular surgery. Today, two devices are available, the SynCardia CardioWest™ Total Artificial Heart that obtained FDA approval on October 2004 and the Carmat Aeson®, that obtained the CE marking in November 2020.

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ABSTRACTS: Session 3A

Monday 11 Sep. 2023	**SESSION 3A** Oral Presentations **Damage and Failure**
Session 3A Co-Chairmen:	**Alkis Paipetis,** Professor of Experimental Mechanical Behavior and Non-Destructive Testing of Composite Materials, Department of Materials Science & Engineering, University of Ioannina, Greece. **Michalis Georgallas,** Quality Assurance Manager at AmaDema (Advanced Materials Design & Manufacturing Limited), Cyprus.

DURABILITY PREDICTION OF POLYMER COMPOSITES: THE ROLE OF HYDROTHERMAL AGEING

Olesja Starkova

Institute for Mechanics of Materials, University of Latvia

ABSTRACT

The growing use of fiber-reinforced plastics (FRP) and polymer composites in various industries such as energy, transportation, and civil engineering emphasizes the importance of comprehensively understanding how these composites perform when exposed to environmental ageing conditions. Polymer composites normally absorb a small but potentially damaging amount of moisture from their surrounding environments. The polymer matrix, being highly sensitive to moisture, is often considered the weakest part of the composites [1,2]. This sensitivity contributes to the degradation of the interface and the inefficient transfer of stress between the matrix and fibers. When subjected to elevated temperatures and moisture, these combined factors can significantly reduce the service lifetime of the composites. Therefore, the investigation of hydrothermal ageing effects on the physical and mechanical properties of the composite constituents is of great importance for comprehension of the degradation mechanisms and prediction of the long-term durability of composite structures. Moisture absorption in polymer composites is a slow process, complicated by diffusion anisotropy, which can take several decades; thus, it is often modelled without experimental verification and can lead to erroneous long-term projections [1].

To estimate the design lifetime of structural composites, predictive models are commonly employed using short-term data. Accelerated testing methods involve intentionally exposing composites to conditions outside of their normal operating range in order to control the rate of degradation. This approach shortens the time needed for experimental testing and enables reliable simulation-based lifetime assessment. Among the most widely applied methods for predicting the durability of composites are superposition principles, Arrhenius-type models, and parametrization techniques [3]. These methods operate under the assumption that the material's behavior under extreme conditions for a short duration is comparable to its behavior under moderate operating conditions over an extended period. By applying this assumption, it becomes possible to extend the observed range of viscoelastic behavior as a function of time under specific conditions and make predictions regarding environmental ageing within shorter time frames that are experimentally inaccessible [4].

In recent years, there has been an increasing demand for the development of sustainable biocomposites with customized durability and biodegradability characteristics, which is essential for the growing circular economy. One of the greatest challenges of bio composites for their wide use in structural applications is their susceptibility to moisture and high hydrothermal impact on the reinforcement and adhesion efficiency of biobased reinforcement [5].

The current study provides a comprehensive overview of methods used to predict the durability of polymers and polymer composites when exposed to moisture and elevated temperatures. The results

of some recent studies investigating water absorption and its impact on the (thermo)mechanical properties of nanocomposites, bio composites, and structural FRP are presented. Special emphasis is placed on identifying the uncertainties and challenges associated with predicting long-term behavior and ensuring reliable forecasts.

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DELAMINATION FATIGUE ACCOMPANIED BY LARGE SCALE BRIDGING

John Botsis

John Botsis, Professor Emeritus, Institute of Mechanical Engineering, School of Engineering, Ecole Polytechnique Federale de Lausanne, EPFL, Lausanne, Switzerland. e-mail: john.botsis@epfl.ch

ABSTRACT

Delamination growth under fatigue in composites is accompanied by large scale bridging (LSB) providing important resistance to crack growth. Characterization and modeling of bridging in fatigue, however, is not trivial because it depends on the laminate geometry, loading conditions (load vs displacement controlled), material and microstructure [1-3]. In this presentation, results of fatigue delamination under load control as well displacement control in carbon-epoxy DCB specimens are presented. The distinctly different crack growth response is highlighted and explained in terms of the energy release rate (ERR) at the crack tip. This latter parameter is obtained at selected points by accounting for the ERR due to bridging. Microscopy and embedded fiber Brag gratings are used to obtain crack growth data and strains along the birding zone. The results in load-controlled tests show three distinct delamination growth regimes: deceleration, stable and acceleration followed by specimen fracture. The results also confirm that fatigue delamination growth strongly depends on the specimen geometry when LSB prevails. It is shown that both the extent of bridging and critical ERR at failure increase by increasing the specimen thickness while the maximum bridging traction at the crack tip is found independent of the specimen thickness. The identified traction-separation relations serve to establish a power correlation, between the crack growth rate and ERR at the crack tip.

In displacement-controlled testing, delamination of two unidirectional carbon/epoxy systems is investigated under monotonic and displacement-controlled fatigue loading. One material (CP004) presents a random distribution of fiber clusters and matrix-rich zones while the other (SE-84) has an ordered microstructure. The results show that monotonic and fatigue delamination of CP004 present similarities, with smooth crack growth and significant bridging. The SE-84 shows no bridging, but matrix cohesive failure related to *stick-slip* growth under monotonic load and adhesive/cohesive failure with limited fiber-bridging in fatigue. Data from strain sensors show that bridging under monotonic and fatigue are similar in CP004. The identified traction-separation relation under monotonic loads is used in a cohesive model to approximate the traction-separation and identify the bridging. The results demonstrate that depending on the microstructure and material properties, monotonic and fatigue delamination may have important similarities (or differences).

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ABSTRACT: Session 4A

Monday 11 Sep. 2023	**SESSION 4A** Oral Presentations **Experimental and Manufacturing Techniques**
Session 4A Co-Chairmen:	**Evi Kontou,** Professor Emeritus, Mechanics Department, School of Applied Mathematical and Physical Sciences, National Technical University of Athens, Greece. **Olivier Dalverny,** 1LGP, INP/ENIT, University of Toulouse, France

DEVELOPMENT OF A SUSTAINABLE, CREEP-RESISTANT MAGNESIUM DIE CASTING ALLOY BY AVOIDING RARE EARTH ELEMENTS

Hajo Dieringa

Helmholtz-Zentrum Hereon, Institute of Material and Process Design, Max-Planck-Str. 1,

21502 Geesthacht, Germany, E-mail: hajo.dieringa@hereon.de

ABSTRACT

In addition to AZ- and AM-series magnesium alloys, typically used at ambient temperature, there are also die-cast magnesium alloys developed for use at elevated temperatures. This work examines the compressive creep resistance and mechanical properties of several aluminium-containing magnesium high-pressure die-cast alloys, including the commercially available AE42, AE44-2, AE44-4, MRI230D alloys and newly developed DieMag series, i.e. DieMag211, DieMag422 and DieMag633. Unlike commercially available alloys, this new family of alloys was developed eliminating the use of rare earth elements. These are considered critical raw materials by the EU, 60% of which are mined in China and 90% of which are refined in China [1]. The use of these elements should be avoided for economic, environmental, and social reasons. Compressive creep is the common load case for automotive powertrain components such as transmission housings, engine blocks or oil pans, which are typically mounted with steel or aluminium bolts that have lower thermal expansion than magnesium alloys. When the component heats up, there is a compressive load in the area around the bolt, which can lead to creep of the component. It is shown that MRI230D and the two high concentrated DieMag alloys have the best creep resistance at 200^0 C. Similar results are also observed in the tensile tests at room temperature and 150^0 C, with DieMag633 showing outstanding strength.

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ACTUAL STATUS OF ACCELERATED TESTING METHODOLOGIES FOR LONG-TERM CREEP AND FATIGUE PREDICTIONS APPLIED FOR COMPOSITE MATERIALS

Rui Miranda Guedes

LAETA, UMAI-INEGI, Department of Mechanical Engineering (DEMec), Faculty of Engineering of the University of Porto (FEUP), Rua Dr. Roberto Frias s/n, 4200-465 Porto, Portugal

ABSTRACT

Engineers in the industry employed accelerated test experiments for many decades. The purpose is to acquire reliable information more rapidly. Typical accelerator factors are temperature, stress, and humidity levels. Increasing the intensity of each experimental variable at which the material or structure operates and employing different level combinations can accelerate the mechanical and chemical degradation leading to weakening and failure. Proper interpretation of accelerated test data requires models to link the accelerating variable to time acceleration. Time equivalence or time-transformation models assume a single-step degradation process that is rate-limiting [1]. Researchers proposed time-temperature, time-ageing time, time-stress, and time-water superposition principles, including their combination to obtain master curves by overlapping the plots for different environmental conditions, using horizontal shift factors, eventually associated with vertical shift factors [2-16]. Ultimately, these can be cast in a failure envelope recurring to parametric approaches, like Larson-Miller, allowing short-term failure extrapolation based on a single time parameter. Constant stress rate, creep, and fatigue tests (stress ratio, R=0) form the basis of the accelerated test methodology developed by Miyano and Nakada (Materials System Research Laboratory at Kanazawa Institute of Technology, Japan) over the last three decades combining different temperatures, ageing time, and humidity levels [17]. This methodology assumes the superposition principle holds to build up the master curves.

Above all, insufficient long-term experimental data under in-service conditions exist to assess the models' predictions. Recently Starkova et al. (Institute for Mechanics of Materials, University of Latvia) reported a 15 years-long moisture diffusion study of carbon, glass, and aramid fibre-reinforced plastic rebars [18]. These comprise different conditioning states, different humidity levels at room temperature, and their effect on the residual mechanical properties. Meanwhile, the conditioned specimens were stored unloaded, which does not correspond to expected in-service conditions.

Multiscale approaches provide a computational tool to examine the microscopic degradation of the matrix, the interface between the fibers and matrix, and its effect on macroscopic failure under different environmental and loading conditions [19, 20]. Although these approaches are computationally expensive, they allow in-depth comprehension of the synergistic effects of the involved degradation mechanisms. This promising path started the first steps into a virtual long-term testing approach.

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NUMERICAL MODEL FOR HOT FORMING OF A COMPLEX INDUSTRIAL PART

S.R.R. Mahendren[1], O. Pantale[1], M. Yves[2], O. Dalverny[1]

[1]*LGP, INP/ENIT, University of Toulouse, 47 Avenue d'Azereix, F-65016, Tarbes, France*

[2]*LAUAK AEROSTRUCTURES FRANCE, 2245 route de Minhotz, 64240, Hasparren, France*

ABSTRACT

Mostly driven by cost and performance, titanium alloys are one of the most widely used metallic materials for aeronautical applications and can make up to 15% of the total weight of an aircraft. Increasing environmental awareness and soaring energy prices have bolstered the need for lighter but high-performing materials, especially to accommodate the high temperatures of engines and exhausts. Keeping this in mind, high-temperature resistant alloys such as Ti6242 and TA6V could be considered as an interesting option over heavier Ni-based alloys. The availability of these alloys in sheet metal form makes them ideal for forming processes [1,2]. As such, this is why the industrial partner in this research (LAUAK group) has heavily invested in the Hot Forming (HF) and Superplastic Forming (SPF) of said alloys. With the requirements of deformations and elongations beyond cold forming capabilities (especially in high-strength alloys like TA6V), HF and SPF remain key assets to the company. Optimization of forming parameters to find the right balance between *high temperature for reducing spring back and metal toughness* and *not too high to maintain, handle and preserve tool life* is a necessity. When receiving a request for a quotation, the company has a limited time to respond and to find the right forming process (HF/SPF) and minimum forming temperature for the specific part, and all this determines the manufacturing cost. To eliminate any risks, they can use numerical methods such as Finite Element Analysis (FEA) to evaluate the adapted forming process for a complex shape. Having said all this, the goal of this collaborative project between LAUAK and LGP/ENIT is to develop new processes and methods in the HF family, by not only understating the physical phenomena and optimizing the forming parameters but also limiting the technical risks and shortening the cycles during the costing and industrialization of new parts.

In this project, our goal is to develop an uncoupled FE model to accurately predict the material behaviour during the isothermal HF process of a complex Titanium part used in the engine pylons of Airbus A320neo.

Authors have given numerical models for HF complex industrial [2] and simple parts [3]. The present work is the first step in importing the behaviour model from Abaqus to AutoForm a go-to software for LAUAK when it comes to the simulation of forming processes. Material properties are taken from existing literature [4] for now, but we have planned to perform tests to determine the material behaviour ourselves. All simulations are performed using Abaqus/Explicit. Although 6 parts are manufactured together every 20 minutes, for the purpose of the simulation we consider only one part and have considerably sped up the process to reduce the calculation time. The work includes a comparison of models using solid, classic and continuous shell elements, plasticity, strain rate and

temperature dependence, and with/without friction and mass scaling. The quantities used for comparisons are the Mises stress (SMISES, Figure 1), equivalent plastic strain (PEEQ), contact pressure (CPRESS) and section thickness (STH, Figure 2).

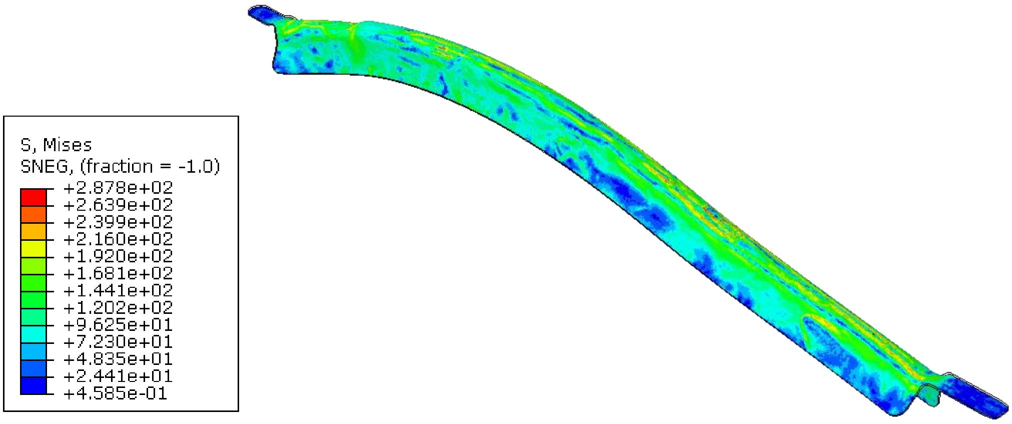

FIGURE 1 Stress distribution on the Blank

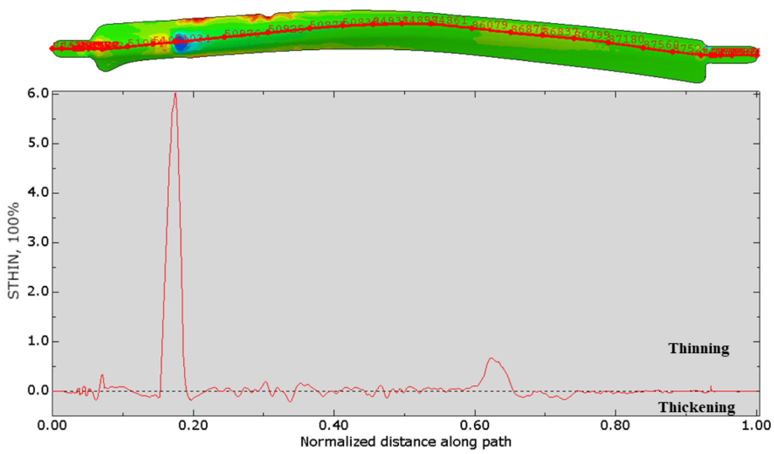

FIGURE 2 The change in thickness on the blank spine (STHIN)

Finally, the results are compared to the manufactured part based on the resulting geometry and sheet thickness.

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COMPARISON OF MECHANICAL PERFORMANCE OF MULTI-MODIFIED CEMENTITIOUS MORTARS AND PASTES SENSORS

A.K. Thomoglou, M.G. Falara, F.I. Gkountakou, A. Elenas, C.E. Chalioris

Department of Civil Engineering Democritus University of Thrace, Xanthi, Greece

ABSTRACT

In the current investigation, a comparison between the mechanical performance of nano-, micro-, and hybrid-reinforced cement mortars and pastes is achieved. The results in flexural strength, compressive strength, and flexural toughness of multi-modified cementitious composites strengthened with single-walled carbon nanotubes (SWCNTs), micro-scale carbon fibers (CFs), and their hybrid process are correlated and presented. The key parameter examined in this research, except the different scales of matrices (mortars and pastes) is the various amounts of the nano-modified 0.1, 0.2, and 0.3 wt.% of cement; the micro-modified specimens with 0.05, 0.1, and 1.0 wt.% of cement and the collaborative effect among the types of carbon fibers. The comparison of the cement mortars and pastes' mechanical strength and toughness was detected through 3-point bending and compressive tests on 4 cm × 4 cm ×16 cm and notched 2 cm × 2 cm × 8 cm prisms, respectively. The dispersion method of SWCNTs is made with 60 min ultrasonic energy, while the CFs incorporation followed a dry-mix method. The results expose that only a few amounts of nanotubes and CFs (0.1 wt.% SWCNTs and 0.5% CFs) are needed to enhance the mechanical properties, as well as the energy absorption, both in plain cement paste and in plain mortar. Subsequently, this research highlights the strong correlation of carbon multi-reinforcement of cementitious materials and provides new perceptions on the design of advanced multi-scale structural applications.

DEVELOPMENT OF A SMART-TRM COMPOSITE: TEXTILE-REINFORCED MORTAR EQUIPPED WITH DISTRIBUTED FIBRE OPTIC SENSORS

A. Gabor[1], M. Saidi[2]

[1]*Université de Lyon, University Lyon 1, Laboratory of Composite materials for Construction (LMC2),*

82 boulevard Niels Bohr, 69622 Villeurbanne, France

[2]*Université Savoie Mont Blanc, Laboratoire Procédés Energie Bâtiment, LOCIE,*

60 avenue du lac Léman, 73376 Le Bourget du La, France

ABSTRACT

Textile-reinforced mortar (TRM) composites are generally used to reinforce or repair civil engineering structures [1]. Their use has become widespread over the last two decades, especially for masonry substrates. The assessment of the mechanical and geometrical parameters that control the textile-matrix and TRM-substrate interactions has allowed the optimisation of the design of these composites. However, the monitoring of TRM-reinforced structures is generally limited to visual observations, or at best, to the use of traditional monitoring techniques.

The purpose of this work is to develop a smart-TRM, capable of both strengthening the structures and monitoring their structural health over time. For this purpose, distributed fibre optic sensors (DFOS) have been integrated into different TRM composites. These sensors, which have a diameter of 250 μm, allow to obtain the mechanical strain in the core of the composite with a spatial resolution of 2.6 mm. These sensors are based on the principle of Rayleigh backscattering [2].

The flexibility of the DFOS allowed the integration of several segments of optical fibres into the core of the TRM (Fig. 1), thereby enabling the behaviour of the textile reinforcement and the matrix to be assessed, as well as the interactions between these two components and between the TRM and the substrate [3]. The studied composites are composed of a self-compacting cementitious matrix, reinforced with one, two or three layers of textile. Two types of matrices and two types of textiles (AR glass and carbon) were used, which allowed the study of six different configurations.

The integration of DFOS into the TRM allowed the structural health monitoring of the TRM and the reinforced substrate as soon as the matrix was cast. These sensors were used to monitor the early age behaviour of the TRM, particularly the matrix hardening and the effect of the textile reinforcement presence [4]. This study allowed the identification of the matrix expansion, the quantification of the shrinkage value and the location of possible microcracks that could appear at this phase.

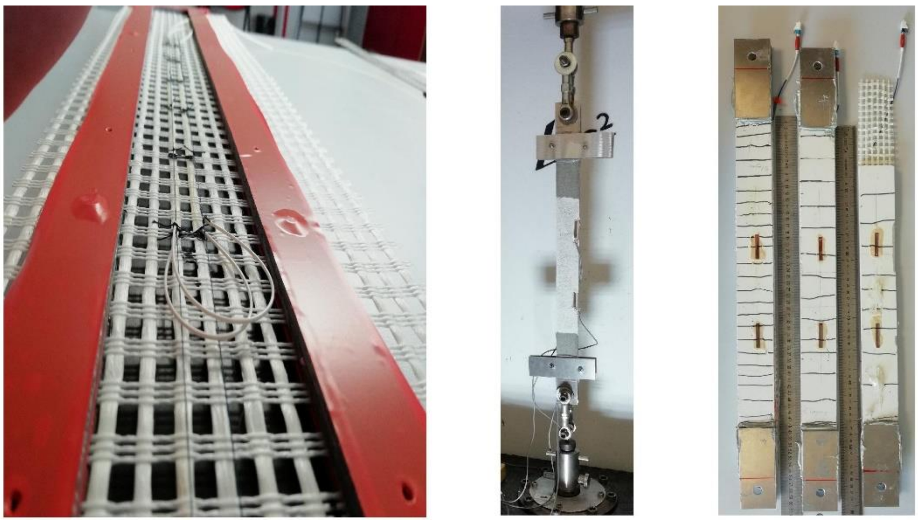
Then, these smart-TRMs were tested in direct tension. This study allowed a more precise assessment of the micromechanical parameters that control the cracking behaviour of the TRM, notably the shear

at the textile-matrix interface. This shear was quantified, as well as the load transfer length between the textile and the matrix, in addition to the influence of the cracks on the local behaviour and its impact on the global performance of the TRM.

These smart-composites were also tested under cyclic loading. These tests were used to monitor the variation of the textile-to-matrix shear and the degradation of the load transfer between the matrix and the textile as the cyclic loading progressed.

As a result of these studies, identical smart-TRMs to those previously studied were cast on masonry walls. These specimens were then pull-out tested to monitor the TRM-masonry bond. These tests allowed both the quantification and monitoring of the shear at the TRM-masonry interface, as well as the location of bond losses at this interface.

The study of the six different configurations allowed to assess the effects of mechanical (matrix, textile) and geometrical (reinforcement ratio) parameters on the local and global mechanical response of both the TRM and the reinforced support. The combination of these results led to the conclusion that the use of these smart-TRMs could be extended from reinforcement to also serve as an indicator of the structural performance of reinforced supports.



a b c

FIGURE 1 Smart-TRM: (a) preparation with DFOS; (b) TRM tensile test; (c) cracking pattern

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ABSTRACT: Session 4B

Monday 11 Sep. 2023	**SESSION 4B** Oral Presentations **Durability and Structural Health Monitoring-The AIOLOS project**
Session 4B Co-Chairmen:	**Alkis Paipetis,** Professor of Experimental Mechanical Behavior and Non-Destructive Testing of Composite Materials, Department of Materials Science & Engineering, University of Ioannina, Greece **D. Mouzakis,** Professor, Hellenic Army Academy, Department of Military Sciences Sector of Mathematics and Engineering Applications, Lab. of Applied Mechanics, Greece.

NOVEL CONCEPTS FOR AIR TURBINES FOR MULTIFUNCTIONAL DESIGN AND DURABILITY

Alkiviadis S. Paipetis[1], Georgios Foteinidis[1], Angelos Ntaflos[1], Maria Xenidou[1], Maria Vlacha[1], Angelos Itcharas[1], Konstantinos Karvanis[1], Maria Kosarli[1], Michaela Konstantinidou[1], Dimitrios Sioulas[1], Nektaria Marianthi Barkoula[1], Nicholas Tsouvalis[2], Dimitrios Lyridis[2], Konstantinos Anyfantis[2], Dora Liangou[2], Elias Bilalis[2], Panagiotis Sakkoulis[2], Nikolaos Silionis[2], Panos Evangelou[2], Evanthia Kostidi[2], Vasileios Tiriakidis[3], Thomai Tiriakidou[3], Kosmas Tiriakidis[3], Nikolaos Tiriakidis[3], Vasileios Papatsiros[4], Georgios Pechlivanoglou[4], Olivier Mauhuit[4]

[1] *Composite and Smart Materials Laboratory, Department of Materials Science and Engineering, University of Ioannina, Greece, E-mail: paipetis@uoi.gr*

[2] *Shipbuilding Technology Laboratory, Department of Naval Architecture & Marine Engineering, National Technical University of Athens, 15780 Zografos, Greece*

[3] *B&T Composites, Agrokthma Florina AA 1834, 53100 Florina, Greece*

[4] *EUNICE WIND AE, Chemaras 5, Marousi, 15125, Athens, Greece*

ABSTRACT

The scope of this work was the development of a new class of hybrid nanocomposite structures with enhanced mechanical strength, durability and SHM during operation capabilities towards the realization of sustainable air-turbines. The approach is a scale-up approach starting from the material at nano and micro level moving on to manufacturing strategies and finally the embedding of structural health monitoring functionalities.

The proposed approach forms the framework of the AIOLOS project and aims at wind turbine applications, wings and components of wind turbines for terrestrial or marine areas and will constitute alternative solutions with increased reliability and enhanced strength compared to the existing conventional composite materials. The methodology involves the production and optimization of manufacturing processes and materials characterization protocols both at matrix level and at laminated composite level. Hybrid nano reinforced materials are manufactured towards enhancing their durability, particularly in relation to operational efficiency in harsh environmental conditions. As it has been shown, the inclusion of 2D nanoparticles such as graphene is blocking water absorption via the creation of a strenuous path for the water molecule ingress in the structure.

At the same time the multi-functionality of the proposed hybrid structures is evaluated, specifically in relation to functionalities such as *i)* damage/strain sensing; *ii)* humidity sensing *iii)* advance functions such as de-icing functionality.

Finally, the inclusion of distributed sensing technologies based on optical fibers with particular emphasis in maintaining structural integrity will be evaluated.

Acknowledgements

This research has been co-financed by the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship, and Innovation, under the call RESEARCH – CREATE – INNOVATE (project code: AIOLOS T2EDK-02971).

USE OF MAGNETOELASTIC SENSORS FOR THE DETECTION OF SINGLE CRACKS IN CEMENT BEAMS

D. Kouzoudis, C.I. Tapeinos, M.D. Kamitsou, K. Varvatsoulis

Department of Chemical Engineering, University of Patras, Greece

ABSTRACT

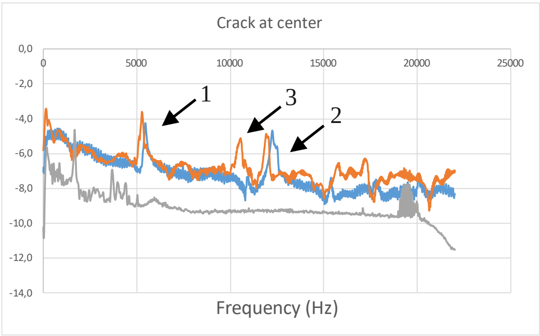
Among other sensing techniques for crack detection, strain sensors are of special importance as they are easy to install on the structures and relatively economic to operate. These sensors are typically made of a long conducting microwire deposited on a thin resin film. In the current work, a different class of materials is used as strain sensors, known as 'Metglas' which are metallic amorphous alloys. In these materials, a large conversion takes place between the elastic energy to the magnetic energy and vice versa. Typically, Metglas come in the form of metallic amorphous ribbons of ~25 μm thickness and have proven their potential in diverse sensing applications [1] in terms of *(a)* their low cost, *(b)* non-requirement of sophisticated expensive electronics (low operating frequencies in the kHz range) and *(c)* contactless nature, eliminating the need for electric connections, as their signal is purely magnetic. In previous work by our team [2, 3], these sensors have been used successfully to detect cracks in aluminum cantilever beams and this work is extended in the current presentation to simply supported cement beams. The transition to cement is not easy as it is a high dumping and brittle material which results in weakened signal and special care during excitation.

Magnetoelastic sensors were used as strain sensors for the detection of single crack formation in simply supported cement beams under bending vibrations. The sensors were attached on the surface of the beams and their signal was detected after a mechanical impulse excitation, in a contactless fashion by a detection coil. The received spectrum revealed three distinct bending modes which were shifting to lower frequencies under the introduction of a single crack at different locations along the beam. Thus, the current technique can be used for the detection of cracks on cement structures. The maximum detection sensitivity was 24% change in the sensing signal for every 1% decrease in beam volume due to the crack.

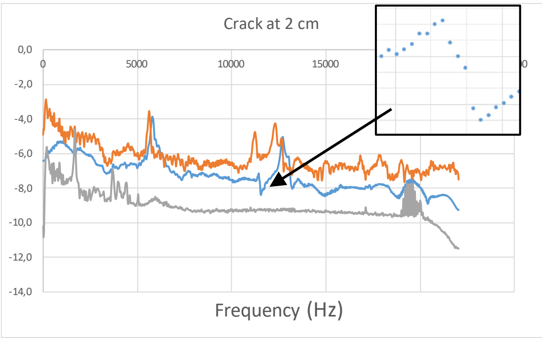
The beams with standard dimensions $4 \times 4 \times 16\, cm^3$ were prepared from raw materials and a cutting wheel was used to create a 4 mm wide and 2 mm deep crack. Two Metglas 2826 MB3 ribbons with an average composition of Fe – 45, Ni – 45, Mo – 5, B – 5 wt% were attached on them by double sticky tape and the beams were excited by an instant impulse by a falling point mass of 4.7 kg from a fixed height of 8 cm.

The capturing of the bending mode spectrum of each beam was based on the following procedure: Following the beam excitation, the magnetoelastic nature of the Metglas strips would result to a change of their magnetic state due to the mechanical deformation caused by bending oscillations. A near-by detection coil was capturing a corresponding changing magnetic flux which resulted by Faraday's law to a measurable emf voltage. A Fast Fourier Transform (FFT) on this signal, revealed the bending mode spectra of the beam (Figure 1 a-d) where a crack is introduced at different locations

along the beam's length. In the figure below, the gray spectrum corresponds to the baseline without Metglas sensors, the blue spectrum represents the crack-free case, and the red line corresponds to the presence of a single crack at the specified positions.



(a)



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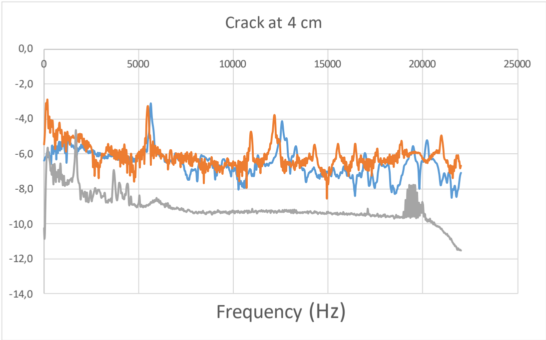

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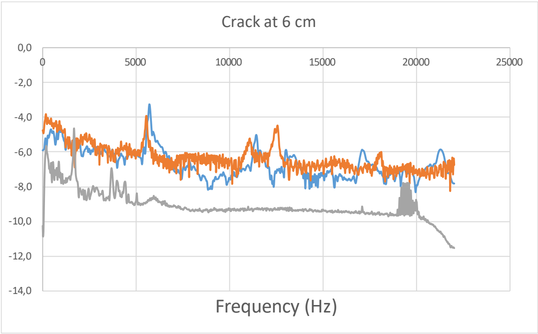

(d)

FIGURE 1 Bending mode spectra of the beam where a crack is introduced at different locations: (a) center, (b) 2 cm, (c) 4 cm and (d) 6 cm.

It is evident from these spectra that this new sensing method can be used for crack detection. The relative shifts of the frequencies are of the order of 2-4 % which are large enough to be used for Structural Health Monitoring of the beam as they can produce an early warning. These shifts are totally non-linear with respect to the crack location, but also quite independent of each other and thus they can be combined to provide quantitative information about the location of the crack.

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LOCALIZED SENSING OF DAMAGE INSIDE COMPOSITES VIA IMPEDANCE SPECTROSCOPY

G. Foteinidis[1], M. Kosarli[1], K. Anagnostou[1] and A.S. Paipetis[1]

[1]*Department of Materials Science and Engineering, University of Ioannina, Ioannina 45110, Greece*

ABSTRACT

Composite materials have been in increasing demand in the aeronautics industry as primary components of aircraft (Airbus A350, Boing 787) during the last few years. Due to their exceptional mechanical properties, such as strength-to-weight ratio, corrosion resistance, and the capability of manufacturing tailored structures, composite materials have applications on numerous aerospace components such as wings, fuselage aircraft, interiors, etc. Besides the advantages, a significant drawback of composite materials is that they are vulnerable to impacts. Impacts can cause various damage types, including matrix cracking, broken fibers, and delamination between the plies. These types of damage occur inside the composite material and expose it to danger as they cannot be detected by visual inspections on the surface. They are called barely visible impact damage (BVID) in aerospace applications, and they act as voids or crack initiators, while crack propagation is capable of leading to disastrous results due to aircraft structure's components failure [1]. To detect and localize BVID, a great effort in developing a variety of non-destructive evaluation (NDE) techniques has been made. The most prevalent NDE techniques in the aeronautic field are ultrasonics, IR thermography, vibration methods, radiographic inspection, Eddy currents, electrical methods, etc. [2]. Another approach to the detection of damage inside the composite materials is the incorporation of NDE sensors in the structure. These sensors are used for the Structural Health Monitoring (SHM). SHM strategies can provide useful information about the structural integrity of the material during flight, thus reducing the periodicity of the inspections [3]. On the other hand, the incorporation of external sensors may reduce the mechanical properties of the composite as they could act as defects [4].

In this research, the proposed structure is a novel smart composite that would have capabilities to identify, locate and heal impact damage and, finally, assess the quality of the repair based on impedance changes in an array of distributed sensing elements inside the composite. The sensing elements were formatted by exploiting the properties of the reinforcing phases of the composite. The layout of the smart composite is depicted in Figure 1. Another aspect studied in this work was the integration of the self-sensing system effect on the mechanical properties of the laminates, i.e., the knockdown effect. For this reason, low-velocity impact and compression after impact were performed on the laminates according to the relative ASTM. Three categories of laminates were manufactured in this chapter: *(i)* conventional, *(ii)* with CF electrodes, *(iii)* with CNT-ink electrodes.

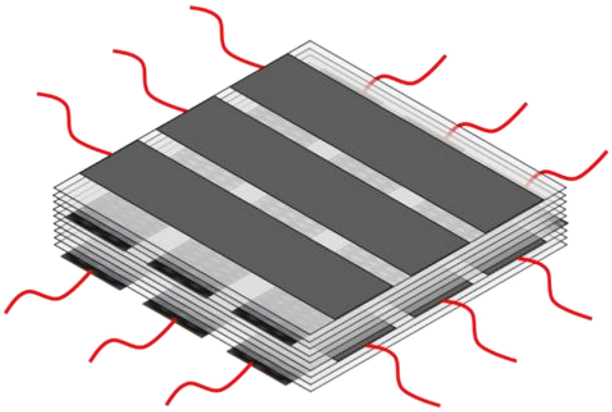

FIGURE 3 Smart composite layout with 3D SHM mapping topography capability.

Acknowledgements

Part of this research has been co-financed by the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship, and Innovation, under the call RESEARCH – CREATE – INNOVATE (project code: AIOLOS T2EDK-02971).

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DISTRIBUTED FIBER OPTIC SYSTEM INTEGRATION ON COMPOSITE MATERIALS FOR STRUCTURAL HEALTH MONITORING

M. Xenidou, K. Tsirka, A. Kalogirou, A.S. Paipetis

Composite and Smart Materials Laboratory, Department of Materials Science and Engineering, University of Ioannina, Greece

ABSTRACT

Low weight, high mechanical strength, high stiffness, and vibration damping ability are some of the many advantages of composite materials that have led to their increasing application to many industrial sectors. However, one of their drawbacks is the existence of imperfections inside the material which can reduce their mechanical properties and lead to unpredictable failure. Based on the above, the need arose for early damage detection and determination, which for several years was done exclusively by applying Non-Destructive Testing (NDT). Later, scientists focused on the development of Structural Health Monitoring (SHM) systems and methods. SHM systems provide continuous information of the integrity of a structure during operation. Detection of conditions that indicate damage at an early stage enables better exploitation of the materials. Several types of sensors can be used for this purpose. However, only those based on fiber optic technology offer the capability to perform quasi-distributed, and distributed measurements and can be embedded within the structure.

Optical fibers consist of a high–refractive index core, where broadband light travels. A low–refractive index cladding surrounds the core to reflect light back into the core. The total internal reflection guides the light inside the core. A coating (typically acrylate or polyimide) is applied for protection against environmental damage [1]. When a light wave enters an optical fiber, the Rayleigh, Raman, and Brillouin back scattering light are simultaneously obtained [2]. The Rayleigh scattering is caused by random changes in the refractive index of an optical fiber and belongs to the elastic scattering light, so its frequency will not drift during the scattering process.

Fiber optic distributed sensing measures strain and temperature by processing spectral shift in the Rayleigh backscatter of optical fibers integrated in a structure. When the strain in the fiber changes, the spectrum of back-scattering signals will drift in terms of frequency. The amount of drift is proportional to the strain generated by the optical fiber. Through relevant calculation of the measured and initial signals, the drift value can be obtained. Then, the strain value can be calculated from equation (1). The distributed strain information of the entire optical fiber can be obtained by scanning [3].

$$\Delta_{v} = C_{\varepsilon}\,\Delta_{\varepsilon} \quad (1)$$

In equation (1), Δ_{v} represents the value of the frequency drift of the Rayleigh spectrum, Δ_{ε} is the change of strain in the optical fiber relative to the initial value, and C_{ε} is the strain proportional coefficient of the optical fiber. The method described above is known as Optical Frequency Domain

Reflectometry (OFDR). The Rayleigh system working with OFDR is the only one to offer spatial resolution in the mm range.

It is important to recognize that strain measurement is different from damage detection. Damage is not a physical parameter, but simply a local change in material properties or structure boundaries (a crack is simply a new boundary) that degrades the performance of the structure. A crack may be the failure initiation point and may drop the strength of the structure by a large percentage, but before catastrophic failure, it produces negligible changes in most of the structure's parameters (natural frequencies, global

strain fields, and so on). Damage can only be detected by comparing the responses of the structure, acquired by sensors, before and after it occurs. Consequently, the only way to acquire information related to damage is by processing and comparing the raw signals received from the sensors before and after damage. Signal processing provides the feasibility to identify the "features", or parameters, that are sensitive to minor damage and can be distinguished from the response to natural and environmental disturbances [4].

The purpose of this study is to investigate the limitations of applying a DFOS system technology embedded in composite laminates for strain measurement before applying the system in a rotating part underwater. Parameters such as the mechanical degradation of the material, the capability of accurate strain measurement under loading conditions, and the signal losses due to connections are evaluated. Initially, the integration of the fiber optic sensor into the composite lamina is being studied. Afterwards, specimens with integrated sensors are being subjected to mechanical testing to evaluate the effect of an embedded sensor on the mechanical properties of a composite material and test the limitations of the sensing instrument by taking measurements under loading conditions.

Acknowledgements

Funded by the European Union Horizon-CL5-2021-D5-01 program under grant agreement No101056911 (CoPropel). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. The European cannot be held responsible for them.

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A NUMERICAL INVESTIGATION OF HAILSTONE IMPACT-INDUCED DAMAGE ON WIND TURBINE BLADE LEADING EDGE

G. Kalimeris, V. Kostopoulos

Department of Mechanical Engineering & Aeronautics, University of Patras, Patras University Campus, GR 26504 Patras, Greece

ABSTRACT

Wind turbines can be subject to a wide range of environmental conditions during their service life that could conceivably extend beyond 20 years. Hailstone impact is believed to be a key contributor in the leading-edge erosion and damage of the exposed composite laminates of wind turbine blades, especially close to the wing tip where high velocity impacts take place. This erosion on the surface of the blade accompanied by damage initiated in the structure of the composite laminates will eventually reduce the efficiency of the wind turbine and increase the cost of maintenance. In the present work, a finite element model is developed in LS-DYNA following validation against experimental data, to investigate the response and the key damage mechanisms associated with hailstone impact on the blade leading edge. To model the sandwich composite leading edge, conventional Lagrangian finite elements were used and the ply-based method with solid elements was adopted for the laminated skins. This technique can predict the separation of laminated plies with the use of cohesive elements and address the failure of each one of them on the grounds that each lamina is explicitly modelled. For the hailstone the Arbitrary Lagrangian-Eulerian Method (ALE) is utilized, accompanied by a strain-rate sensitive material model coupled to an equation of state. This is done to reproduce the flow characteristics of hail during high-speed impact. In addition to that, Fluid-structure interaction (FSI) methodology is employed to obtain the forces acting on the leading edge during the impact. The analyses are done for hailstone impact threats with single impact and multiple repeated impact. Apart from that, different impact scenarios such as single-point repeated impact and multi-point sequential impacts were carried out to investigate more complex damage interactions. After that, the same simulations were carried out again and re-examined with the use of a coating installed on the surface of the blade that is widely used in the industry to protect the leading edge from rain-droplet erosion. The outcome from this study provides insights on the significance of hail impact in the formation of leading-edge damage and on the effectiveness of a protective coating against hailstone impact. the impact damage threshold conditions were established, whereas a detail parametric study has been performed on the hailstone impact conditions and their relation to the developed damage. It was found that hailstone impact poses a significant surface erosive threat together with extensive delamination damage, based on individual impact damage formation, while a repetitive impact on an already impacted wing tip area significantly extends the pre-existing damage.

ABSTRACT: Session 5A

Tuesday 12 Sep. 2023	**SESSION 5A** Plenary Lectures **Nanocomposites**
Session 5A Co-Chairmen:	**V. Kostopoulos,** Professor, Applied Mechanics & Vibrations Laboratory, Department of Mechanical Engineering and Aeronautics, University of Patras, Greece. **Angelos Evangelou,** Research, and Innovation Manager at AmaDema, Cyprus.

TIMESCALES OF POLYMERS AND COMPOSITES: FROM VISCOELASTICITY TO FATIGUE

Alberto D'Amore

Università della Campania "Luigi Vanvitelli", Department of Engineering, Via Roma 19 81031 Aversa (CE) - Italy

ABSTRACT

This paper illustrates some subtle aspects of high-performance composites' mechanical reliability, including the unexpected and underestimated effects of polymers' viscoelasticity. From one side, it is calculated that the residual stresses arising within the matrix can be of the order of magnitude of the matrix tensile strength during the composite manufacturing processes. The residual stresses are a manifestation of the polymer viscoelasticity. They are unavoidable and act permanently even in the absence of mechanical loadings [1]. Conversely, the increase of static and dynamic strength with the loading rate is attributed to the sequence of damage modes that develop during repeated loading (fatigue). However, the fiber-matrix detachment, ply rupture, and delamination develop once the matrix reaches its critical damage state (CDS), which occurs when the matrix relaxes the applied stress by forming a network of cracks and crazes. Modeling the fatigue response of fiber composites shows that the CDS develops almost independently from the loading condition and that the time-dependent response of fiber-dominated composites depends on the time-dependency of the different damage mechanisms. The damages' development rate slows at high loading rates, which justifies why the composites' mechanical properties increase at higher loading rates [2, 3].

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SYNERGISTIC EFFECTS ON THE ELECTRICAL AND MECHANICAL PROPERTIES OF HYBRID POLYMER NANOCOMPOSITES. MODELING THE MAIN ASPECTS OF VISCOELASTICITY

Evagelia Kontou

National Technical University of Athens, Mechanics Department

School of Applied Mathematical and Physical Sciences

ABSTRACT

Synergistic effect of PLA/ hybrid nanocomposites

A series of hybrid nanocomposites based on Polylactic acid (PLA) matrix and mixtures of graphene oxide (GO) with carbon nanotubes (CNTs) or carbon nanofibers (CNFs), at various loadings, were prepared and experimentally studied [1]. Several experimental techniques were employed to analyze the morphology and the thermomechanical performance of the materials, as well as the dielectric properties. Apart from the mechanical enhancement (Table 1), the research findings lead the conclusion that a synergistic effect is demonstrated by the PLA/GO/CNT nanocomposites, by means of the higher crystallinity and the development of conductive paths into the bulk matrix.

TABLE 1 Stress strain results of PLA/ hybrids nanocomposites.

Material	E (MPa)	E increment (%)	Yield stress (MPa)	Tensile strength (MPa)	Failure strain (%)
PLA	3064 ± 150	-	34.4 ± 6.5	27.0 ± 5.5	7.39
PLA/GO/CNT/3.84%	3218 ± 160	5.0	40.2 ± 8.0	29.5 ± 7.1	4.21
PLA/GO/CNT/6.25%	4265 ± 230	39.2	40.4 ± 8.0	25.9 ± 6.3	7.18
PLA/GO/CNT/8%	5652 ± 300	84.5	47.4 ± 9.8	32.3 ± 7.9	6.19
PLA/GO/CNF/3.84%	3460 ± 190	12.9	38.5 ± 7.6	28.9 ± 7.2	6.01
PLA/GO/CNF/6.25%	3796 ± 208	23.9	-	43.9 ± 10.9	1.51
PLA/GO/CNF/8%	4000 ± 212	30.5	-	41.4 ± 10.2	0.01

More specifically, it was found that blending of GO with CNFs or with CNTs leads to a partially exfoliation of GO flakes and an improved dispersion between matrix and nanofillers, especially for

GO/CNT hybrids. The obtained shifting, in the RAMAN results, of the peak centers D, G and G΄ is associated with polymer-nanofiller and nanofiller-nanofiller interactions. It has been postulated that the CNTs have a higher degree of disorder. In addition, the important role of CNTs with the highest surface area, to the quality dispersion into the bulk matrix, has been detected and associated with the formation of nucleation sites for crystal growth. This was in accordance with the DSC results. Broadband dielectric spectroscopy revealed an interaction between GO and CNTs, which results in the development of conductive paths into the bulk matrix. This synergy is attributed to a better nanofiller dispersion and an effective linking of gaps between GO and CNTs (Figure 1). To this trend, the Young's modulus and yield stress of the PLA/GO/CNT hybrids appear the highest increment. Therefore, simple processing methods (like melt mixing) and low cost raw materials, provide us with the environment-friendly PLA/nanocomposites appropriate for targeted applications.

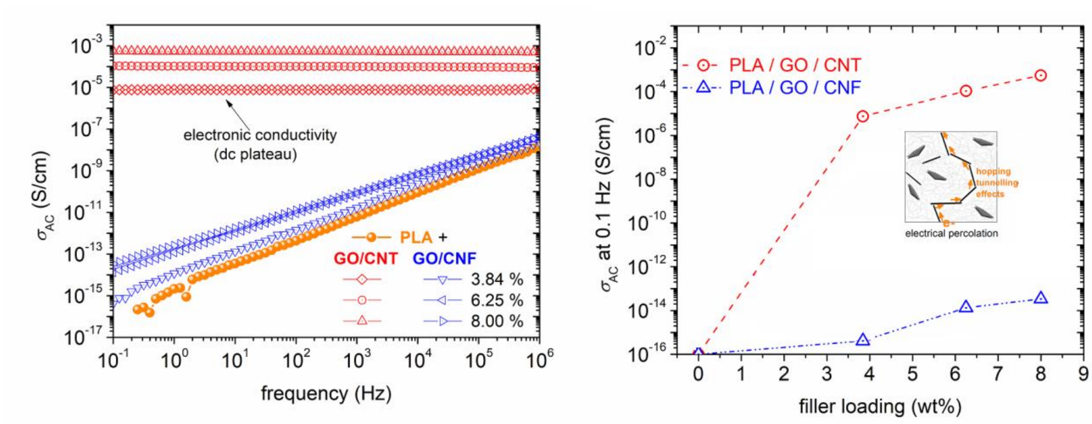

FIGURE 1 (Left) Comparative Broadband Dielectric Spectroscopy spectra of the real part of electrical conductivity (in AC), σ_{AC}, against frequency at 25^0 C (Right) σ_{AC} with varying nanofiller wt% loading.

Modeling the main aspects of viscoelasticity

The description of various loading types within the frame of viscoelasticity in a unified way, is always an interesting topic. A viscoelastic model analyzed in previous works [2], has been utilized to describe the main standard loading types of viscoelasticity, with the same set of model parameters. The analysis is based on a time-dependent integral constitutive equation (1):

$$\sigma(t)==\mu_0\,\varepsilon(t)+\mu\left[\varepsilon(t)-\int_0^t R(\text{t-}\tau)\varepsilon(\tau)\,\mathrm{d}\tau\right] \quad (1)$$

$$\text{Where } \mathrm{R}(t)=\int_0^\infty \Gamma(u)\,\mathrm{p}(u)\,exp(-\Gamma(u)\,\mathrm{t})\,\mathrm{du} \quad (2)$$

including a distribution function p(u), which is obeyed by the energy barriers that the molecular domains need to overcome upon the imposition of a stress/strain field. This function was determined by the loss modulus curve. Hereafter, creep-recovery, and relaxation and compliance master curves were evaluated with the same parameters (Figure 2).

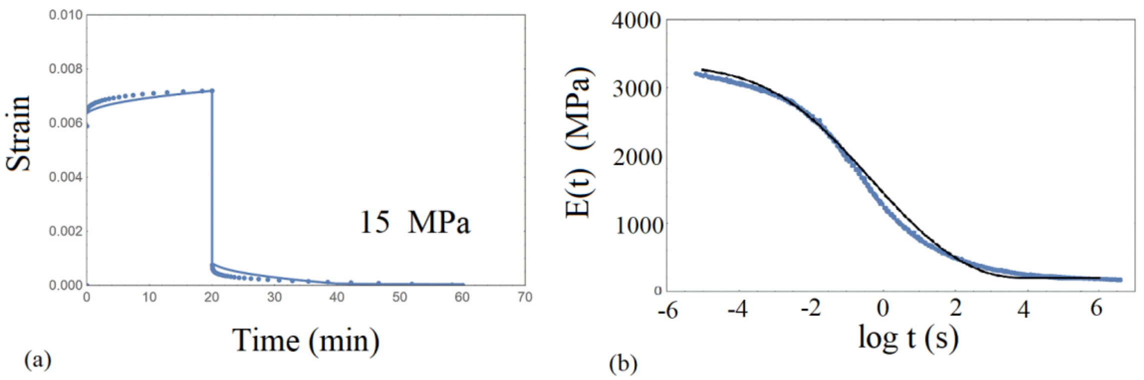

FIGURE 2 (a) Creep-recovery of PLA and (b) relaxation modulus master curve of PLA

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MULTIFUNCTIONAL COMPOSITES ENABLED BY NANOFIBERS: OPPORTUNITIES AND CHALLENGES

Vassilis Drakonakis

AmaDema (Advanced Materials Design & Manufacturing Ltd), Cyprus

ABSTRACT

Multifunctional composites, characterized by their ability to offer combined mechanical, electrical, thermal, and other functionalities, have garnered significant interest in diverse industries. Nanofibers have emerged as a promising solution for enhancing composite materials properties and enabling new functionalities. The present talk will try to summarize key insights from the literature, potential future research directions as well as AmaDema's findings in the field of nanofiber-enabled multifunctional composite materials. The talk will make an overview of various nanofiber manufacturing techniques, including electrospinning, template synthesis, and self-assembly, discuss the advantages as well as the limitations of each technique and their suitability for different applications. Furthermore, the integration methods used to incorporate nanofibers into composites will be explored, focusing on direct blending, layer-by-layer assembly, and nanofiber reinforcement. In addition, the Influence of nanofibers on the mechanical properties of composites will be extensively discussed, showcasing notable findings on enhanced tensile strength, young's modulus, and fracture toughness. Specifically, key findings on the additional functionalities enabled by nanofibers in composites, including electrical conductivity, thermal management, self-healing, energy storage, and sensing capabilities will be presented. Finally, the current challenges and limitations that hinder the widespread implementation of nanofiber-enabled multifunctional composites will be addressed.

MAGNESIUM-BASED NANOCOMPOSITES - PROCESSING, PROPERTIES AND POTENTIALS

Hajo Dieringa

Helmholtz-Zentrum Hereon, Institute of Material and Process Design, Max-Planck-Str. 1, 21502 Geesthacht, Germany, Email: hajo.dieringa@hereon.de

ABSTRACT

Magnesium alloys are the lightest structural metallic materials currently in use in industry. Despite their low density, high specific strength, and good machinability, however, there are also fields of application in which they hardly play a role. For reasons of sustainability, these areas must be addressed in the future, because lightweight construction with metals is one of the key technologies for reducing fuel consumption and CO_2 emissions, and thus a guarantee for sustainability and the circular economy. The properties of magnesium alloys can be significantly influenced by adding small amounts of ceramic nanoparticles. For example, the yield strength can be increased by Orowan strengthening or the creep resistance can be increased by influencing the grain boundary morphology. An improvement in ductility is also possible, which in turn could make it possible to extend the areas of application to formed components such as sheet metal, forged products or extruded profiles. Innovative magnesium-based nanocomposites are also an option in the field of additive manufacturing. This talk will therefore present examples of hybrid melt-metallurgical processes used to produce magnesium-based nanocomposites. This is followed by some examples of such nanocomposites and their properties, and finally their possible areas of application.

ABSTRACT: Session 6A

Tuesday 12 Sep. 2023	**SESSION 6A** Plenary Lectures **Hybrid and Multifunctional Materials**
Session 6A Co-Chairmen:	**N.-M Barkoula,** Professor, Department of Materials Science and Engineering, University of Ioannina, Greece. **V. Drakonakis,** Managing Director & Co-founder of AmaDema (Advanced Materials Design & Manufacturing Ltd), Cyprus.

INTEGRATING MULTI-FUNCTIONAL PERFORMANCE IN CERAMIC INCLUSIONS/POLYMER MATRIX NANOCOMPOSITES

Georgios. C. Psarras

Smart Materials & Nanodielectrics Laboratory, Department of Materials Science, University of Patras, Patras 26504, Hellas (Greece)

ABSTRACT

Ceramic nanoparticles/polymer matrix nanocomposites attract an increased scientific and technological attention because of their properties, the easiness of the fabrication, and their potential applications. This category of materials, also referred as nanodielectrics, appears to be very promising for current emerging technologies, which include stationary power systems, cellular phones, wireless personal digital assistants, and hybrid electric vehicles. The term nanodielectrics refers to: (a) polycrystalline semiconducting or insulating materials, with grain diameter at the nanoscale level and (b) polymer composites incorporating nano inclusions. Polymer matrix nanocomposites constitute a class of engineering materials with continuously increasing impact because of their tunable properties/adjustable performance and applications. Polar oxides/polymer nanodielectrics exhibit tunable polarization, related to the piezoelectric and/or ferroelectric behaviour of the filler [1-3]. In addition, nanoparticles could serve as an inherent network of nanocapacitors, where energy could be stored and retrieved [1-3].

Functional materials is a class of materials which has the ability to execute certain functions (operations) under the influence of an external (environmental) stimulus or a sign control. Until recently, engineering materials were selected for a specific application, only for the nominal values of their mechanical and physical properties (i.e. Young's modulus, tensile strength, refractive index, electrical conductivity etc.). All these values compose the material's behaviour at service. However, in our days the requirements/expectations of engineering materials are expanding to performances, and they should be able to respond in real time to a rapidly varying environment or control signals.

Multifunctionality is the combination of various desirable properties in a material or materials' system, targeting to develop a single material/system exhibiting all necessary responses under various loading conditions at service. Mechanical sustainability, suitable thermal response, tunable electric conductivity, variable electric polarization and dielectric permittivity, magnetic properties, thermally induced phase changes could be parts of the overall multifunctional behaviour, Figure 1.

In this set of studies ceramic piezo/ferro-electric polar oxides, ferromagnetic, and carbon allotropes nanoparticles are embedded in a polymer matrix (Figure 2). Morphology, thermal properties, static and dynamic mechanical behaviour, dielectric response, conductivity, magnetic properties, energy storing/retrieving capabilities, information storing and recovering, and induced multifunctionality are investigated by means of several experimental techniques. Considering the importance of interface in all nanocomposite systems, obtained data are also used targeting to the quantification of the inter-facial/phasial area and the investigation of its properties. Optimum type or types and amount

of reinforcing phase leading to the synergy of the occurring physical mechanisms in the under-test systems are analyzed and discussed.

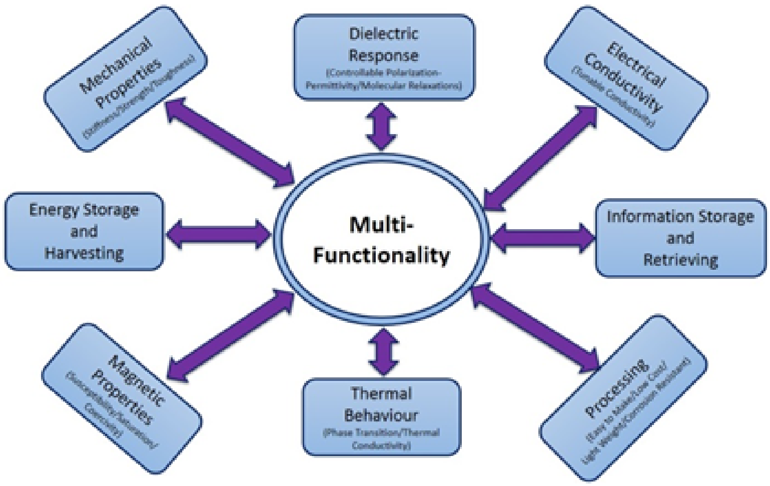

FIGURE 1 Schematic representation of materials' multifunctionality

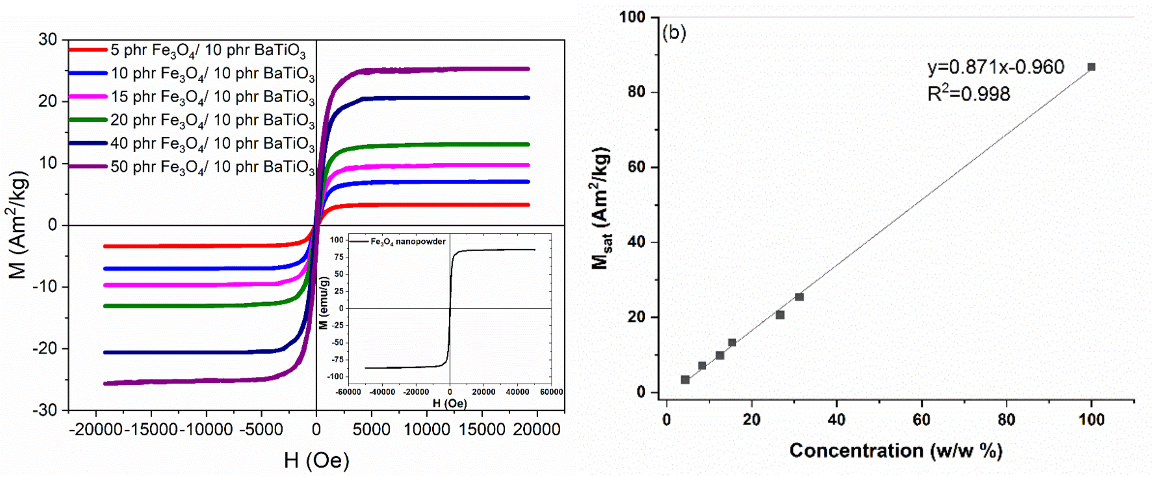

FIGURE 2 (a) Magnetic hysteresis loops for all hybrid composites, inset depicts the hysteresis loop of magnetite powder. (b) Magnetic saturation as a function of the Fe_3O_4 content [2]

Acknowledgements

The research work was supported by the Hellenic Foundation for Research and Innovation (H.F.R.I.) under the "First Call for H.F.R.I. Research Projects to support Faculty members and Researchers and the procurement of high-cost research equipment grant" (Project Number:2850).

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THE EFFECT OF EXTREME LOW TEMPERATURES ON THE DYNAMIC MECHANICAL PROPERTIES OF CARBON FIBER REINFORCED POLYMERS

Stephanos P. Zaoutsos

Laboratory of Advanced Materials and Constructions, Department of Energy Systems, University of Thessaly, Ring Road Larissas-Trikalon, Larissa, Greece.

ABSTRACT

Carbon fiber reinforced polymers (CFRP'S) can be used in supporting structural elements that operate at cryogenic temperatures and are connected to ambient temperature structures [1-4]. The advantage of light weight construction in combination with sufficient mechanical strength and enhanced specific properties make this type of polymeric composites ideal materials to maintain cryogenic systems in place and for long periods of time such as in applications of oil pipelines, liquid natural gas carriers and aircraft transportation. However due to the hostile environment of exposure to extreme low temperatures, cryogenic temperature conditions and moisture the mechanical behavior of these materials should be further studied to assure structural integrity and safe mechanical performance. Moreover, these materials exhibit a time dependent response due to the thermo-viscoelastic nature of the polymeric matrix. This mechanical behavior seems to be deteriorated under complex environmental thermomechanical loading subjected in the structure. Thus, time dependent mechanical behavior of CFRP' s at low temperature conditions should be also studied and possible mechanisms of failure due to the above-mentioned conditions must be verified [5-12].

In the current study the effect of extreme low temperatures on the mechanical properties of CFRP's is determined through extensive static and dynamic mechanical tests on specimens that have been exposed to extreme low temperature conditions. The overall testing program includes dynamic mechanical analysis on CFRP's that have been exposed either on certain periods of time at extreme low temperatures or subjected on thermal fatigue at a temperatures range not only above but also below zero temperature. Dynamic mechanical analysis (DMA) tests were conducted in CFRP specimens in three-point bending mode, both on frequency and thermal scans to determine the viscoelastic response of the material under extreme low temperatures conditions. All experimental tests were conducted both for aged and pristine materials for comparison purposes. Experimental findings occurring from static tests at three-point bending loading mode indicated that there is a decrease both on ultimate flexural strength and flexural modulus of the CFRP coupons implying a strong influence of the thermal fatigue on the mechanical behaviour of the tested composites.

Moreover, DMA tests revealed that there is deterioration both on T_g and storage modulus values while there is also a moderate increase in the damping ability of the tested material as expressed by the factor tanδ as the period of exposure at the given thermal fatigue profile increases.

The above mentioned overall mechanical behavior can be attributed to fiber-matrix local debonding, matrix cracking and increased brittleness that may occur due to repeated thermal expansion owing

to the thermal cycles that applied in the material and the existence of moisture transformed in frozen water that is present in cracks and voids leading in debonding and transverse microcrack growth thus resulting in material degradation.

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HYDROTHERMAL AGEING OF BASALT FIBRE-REINFORCED COMPOSITE WITH CARBON NANO-MODIFIED EPOXY MATRIX

T. Glaskova-Kuzmina[1], A. Aniskevich[1], J. Sevcenko[1], A. Zotti[2], A. Borriello[2], M. Zarrelli[2]

[1]*Institute for Mechanics of Materials, University of Latvia, 3-635, Jelgavas Str., LV-1004 Riga, Latvia*

[2]*Institute of Polymers, Composites and Biomaterials, National Research Council of Italy, 80055 Portici, Italy*

ABSTRACT

The aim of the work was to estimate the effect of hybrid carbon nanofiller over the flexural and electrical properties for an epoxy matrix and epoxy-based basalt fibre reinforced composite (BFRC) subjected to water absorption at 20, 50 and 70 °C.

A nanocomponent RTM6 (Hexcel Composites) epoxMmay resin was used as a matrix system. Multiwall carbon nanotubes (CNT) Nanocyl 7000 (Nanocyl) and carbon nanofibers (CNF) SA 719781 (Sigma-Aldrich) were used in the ratio 1:1 by mass at the content of 0.1 wt. For the preparation of BFRC/epoxy and BFRC/NC laminates the lay-up technology by using vacuum-assisted heating plate was used. For the unidirectional laminates, the test samples were cut in the direction parallel (par) and perpendicular (perp) to the fibers.

Water absorption tests were performed for all test samples in distilled water at 20, 50 and 70 °C until equilibrium to obtain full kinetics of moisture sorption. The duration for water absorption tests was 3.5 years, 8 and 5 months, accordingly. The mechanical properties were evaluated in a three-point bending mode before the environmental ageing and after the samples reached equilibrium moisture content at different temperatures. From the stress-strain curves, the elastic modulus and flexural strength were evaluated. The electrical resistance of the NC and BFRC/NC samples was measured by using a two-point methodology. Opposite facets of the samples were covered with conductive silver paint to reduce contact resistance effect. After the environmental ageing, the relative change of flexural strength and elastic modulus of the epoxy and the nanocomposite (NC) was within approx. 10% and 20%, accordingly. For nanomodified BFRC, a much higher effect (approx. by 20%) of absorbed moisture on flexural characteristics was found and likely attributed to higher defectiveness (e.g., porosity, the formation of agglomerates etc.). During flexural tests, the electrical resistance of the NC and BFRC/NC samples was evaluated. The electrical conductivity for UD BFRC/NC, before and after the hydrothermal ageing at different temperatures, was 2 and 3-3.5 times higher than for the NC, accordingly, revealing the orientation of electrically conductive nanoparticles and/or their agglomerates during lay-up manufacturing.

It can be concluded that though hydrothermal ageing significantly affected the flexural properties of both nanomodified epoxy and BFRC, the absorbed moisture (approx. 2 wt.% and 4 wt. %, respectively) improved the electrical conductivity of the materials by approx. 70-90% allowing better ability to monitor damages.

SMART NEW COMPOSITE MATERIALS BY ADDITIVE MANUFACTURING TECHNOLOGIES

Dionysios E. Mouzakis

Hellenic Army Academy, Leoforos Evelpidon (Varis - Koropiou) Avenue Vari P.O. 16673 - Greece

ABSTRACT

Additive manufacturing (AM), also known as 3D printing [1], is a process of creating three-dimensional objects from a digital file. The process works by adding material layer by layer until the object is complete. AM is a versatile technology that can be used to create a wide variety of objects, including prototypes, tools, and end-use parts. There are many different AM technologies available, each with its own advantages and disadvantages. Some of the most common AM technologies include:

- Vat photopolymerization: This technology uses a laser or UV light to cure liquid resin, one layer at a time. Vat photopolymerization is a good choice for creating objects with complex geometries or fine details.

- Material extrusion: This technology uses a heated nozzle to extrude melted material, such as plastic or metal, onto a build platform. Material extrusion is a good choice for creating objects with large or complex surfaces.

- Material jetting: This technology uses a print head to deposit droplets of liquid material, such as plastic or ceramic, onto a build platform. Material jetting is a good choice for creating objects with high-resolution details.

- Binder jetting: This technology uses a print head to deposit a binder onto a powder bed. The binder binds the powder together, one layer at a time. Binder jetting is a good choice for creating objects with complex geometries or hollow structures.

- Powder bed fusion: This technology uses a laser or electron beam to melt powder, one layer at a time. Powder bed fusion is a good choice for creating objects with high-strength properties.

AM is a rapidly growing technology with many potential applications. AM is already being used in a wide variety of industries, including aerospace, automotive, medical, and consumer products. As the technology continues to develop, AM is expected to become even more widely used in the future.

Some of the benefits of using additive manufacturing technologies include:

- Design freedom: AM allows for the creation of objects with complex geometries that would be difficult or impossible to create using traditional manufacturing methods.

- Reduced lead time: AM can significantly reduce the lead time for creating prototypes and end-use parts.

- Cost savings: AM can often be a more cost-effective way to produce parts than traditional manufacturing methods.

- Sustainability: AM can help to reduce waste and emissions by eliminating the need for tooling and machining.

Overall, additive manufacturing is a versatile and powerful technology with many potential benefits. As the technology continues to develop, AM is expected to become even more widely used in the future.

On the other hand, smart composite materials are materials that have embedded sensors, actuators [2], or other functional elements. These materials can be used to create objects that can sense their environment, respond to stimuli, or even self-heal.

The term "smart" in smart composite materials [3] refers to the ability of the material to interact with its environment in a way that is not possible with traditional materials. For example, a smart composite material might be able to detect the presence of a specific chemical or biological agent, or it might be able to change its shape in response to an applied force.

Smart composite materials are made up of two or more different materials that are combined to create a new material with unique properties. The most common type of smart composite material is a fiber-reinforced polymer (FRP). FRPs are made up of a polymer matrix, such as epoxy or polyester, and reinforcing fibers, such as glass, carbon, or aramid.

The sensors and actuators in smart composite materials are typically made from materials such as piezoelectrics, shape memory alloys, and electrochromic materials. These materials can be embedded in the polymer matrix, or they can be coated onto the surface of the fibers.

The introduction of additive manufacturing, however, has provided the researchers with new tools in manufacturing smart composite materials. In some cases, they are even referred to as 4D printed composites etc. [4].

In our work we present cases of 3D and 4D smart composite materials manufactured by simple additive manufacturing techniques such as FDM, combining with smart magnetoelastic elements which allow them to perform as smart damage detectors. These promising elements and materials along with the progress in the 3D printing technologies in the near future will allow the manufacturing of new generations of smart composites with inherent damage detection and possibly self-healing technologies [5, 6].

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ABSTRACT: Session 7A

Tuesday 12 Sep. 2023	**SESSION 7A** Oral Presentations **Design and Manufacturing**
Session 7A Co-Chairmen:	**Rui Miranda Guedes,** Professor in Mechanical Engineering, University of Porto, Portugal **D. Mouzakis,** Professor, Hellenic Army Academy, Department of Military Sciences Sector of Mathematics and Engineering Applications, Lab. of Applied Mechanics, Greece.

DEEP NEURAL NETWORK LEARNING IN STRUCTURAL DESIGN OF COMPOSITES

Constantinos Soutis

The University of Manchester, UK, E-mail: constantinos.soutis@manchester.ac.uk

ABSTRACT

The use of polymer composites reinforced with continuous fibres is increasing due to their high specific strength and stiffness, which make them comparable to metals, and their tunable properties that can be altered to produce lightweight materials with efficient structural configurations. The talk will be on artificial intelligence (AI) and, more specifically, deep learning, which is a subfield of machine learning (ML), applied to the design and behaviour of modern composite materials systems. The attractiveness of AI comes from its self-learning capability, the faster computer processing time of large datasets, and the potential to yield highly accurate results [1]. Recent studies will be discussed, wherein computational tools have been developed that mimic human brain activity to answer questions and solve challenging problems toward characterizing materials behaviour, real time structural health monitoring [2] and improving the performance of materials with less effort and cost.

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STRATEGIES TOWARDS SUSTAINABILITY – VITRIMER BASED COMPOSITES

Nektaria-Marianthi Barkoula

Department of Materials Science and Engineering, University of Ioannina, 45110, Ioannina, Greece

ABSTRACT

Thermoset-based composites find widespread application in various sectors including transportation (aerospace, automotive, marine), renewable energy, electronics, bio-medical devices, construction, etc. Compared to thermoplastic-based composites, thermoset-based ones show advanced mechanical performance, thermal stability, and environmental durability, due to the highly crosslinked structure that is developed during curing. However, their repair is not straight forward. Furthermore, once cured, thermoset composites cannot be reshaped. In addition, after the end of their working life, they are not easily recyclable since they cannot be re-melted or remolded. Thus, composite wastes usually end up in landfills, or they are processed through pyrolysis, with a large environmental impact (e.g., CO_2 emissions). For the reduction of energy consumption and waste materials, novel composites with life extension, repairability, reusability, and recyclability are needed. The design of such composites will offer enhanced sustainability through the reduction of waste material and energy.

One of the main strategies that has received great attention lately is based on the introduction of exchangeable chemical bonds into the polymer network of crosslinked systems, to create dynamic crosslinks. Resins with associative bonds have a characteristic temperature, namely the topology freezing transition temperature, T_v, above which the change of viscosity as a function of temperature is progressive, following Arrhenius law, as is observed in inorganic silica materials (glass) [1]. Due to their glass-like response at elevated temperatures, such systems are called vitrimers (latin: “vitrum”). As a result, vitrimers are insoluble and exhibit a rubbery plateau. Vitrimers can be repaired or reshaped by heating, while a new equilibrium state can be reached depending on the heating duration, the stress relaxation mechanisms, and the kinetics of the covalent bonds reshuffling.

Attempts have been made to realize reprocessing activated by functional nanoparticles - reconfiguring epoxy vitrimers by Joule heating, light, or by other stimuli. At composite level, the literature is quite limited regarding repairing and reshaping of such materials with dynamic bonds. The present study focuses on the development of functional vitrimer-based composites with the ability of reprocessing and reconfiguration through the application of electrical current. Emphasis is placed on the modification of the vitrimer matrix with carbon nanotubes [2], material with strong thermoelectric characteristics which aims to improve the external stimulus response of the vitrimer matrix and composite, for fast and innovative reshaping by Joule heating. The effect of CNT addition on the stress relaxation behavior of vitrimer matrix and respective composites is analyzed. The possibility to reshape the nano-modified vitrimer matrix and respective composites through electro triggering is assessed and the response time is compared with the one obtained after conventional reshaping (application of heat and pressure).

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MANUFACTURING AND TESTING OF THERMOPLASTIC BLENDS FOR VACUUM THERMOFORMING OF COVERS FOR UAVS PARTS

C.-E. Pelin[1], M. Sonmez[2], G. Pelin[1], A. Stefan[1], A. Dragomirescu[1], M.D. Stelescu[2], M. Nituica[2], M. Georgescu[2]

[1]*INCAS – National Institute for Aerospace Research "Elie Carafoli", Iuliu Maniu Blvd 220, Bucharest 061126, Romania, pelin.cristina@incas.ro, pelin.george@incas.ro, stefan.adriana@incas.ro, dragomirescu.alina@incas.ro*

[2]*National Research and Development Institute for Textile and Leather - Division Leather and Footwear Research Institute, Ion Minulescu St. 93, Bucharest, Romania, maria.sonmez@icpi.ro, maria.stelescu@icpi.ro, mihaela.nituica@icpi.ro, mihai.georgescu@icpi.ro*

ABSTRACT

Unmanned aerial vehicles (UAVs) have been used in particular in military applications, but the past years have shown that their use in commercial purposes is becoming more and more feasible. However, due to the limitations coming from safety, security, privacy and legal issues, current technologies require improvement in order to increase autonomy and safety operation standards in urban space [1]. Technological challenges are related to achieving lightweight durable UAV structure parts via cost and energy effective manufacturing routes using sustainable materials [2]. One of the necessities identified is the protection of the sensitive and expensive electronic elements in a UAV against environmental phenomena (rain, snow, wind, dust, extreme temperature values etc.) and unexpected incidents (crashes against obstacles, bird collision etc.), while keeping the weight gain added by additional covers to a minimum. Previous experimentations consisted of developing dedicated covers for UAVs that required the protection of electronic parts (Figure 1), by vacuum thermoforming of simple polypropylene (PP) films. However, for a durable use, more advanced materials formulations must be taken into consideration.

FIGURE 1 Preliminary demo PP cover mounted on INCAS UAV developed via vacuum thermoforming

The present investigation presents the experimental study regarding the manufacturing and testing of polymeric blend materials designed to be used as encapsulation of different elements in the structure of UAVs. The manufacturing stage involves the parameters establishment for obtaining of different thermoplastic polymeric blends through melt mixing followed by thermal pressing in order to obtain plates of 0.5 mm thickness. The plates were afterwards, processed into specimens with specific geometry for mechanical testing consisting of tensile, 3-point bending and impact tests (Figure 2).

The fracture cross section was analyzed using morpho structural techniques (SEM- Figure 3 and FTIR) and fractographic evaluation (optical microscopy). After the testing and investigation evaluation, the plates were subjected to vacuum thermoforming (Figure 4) in order to evaluate their behavior when processed via this technique.

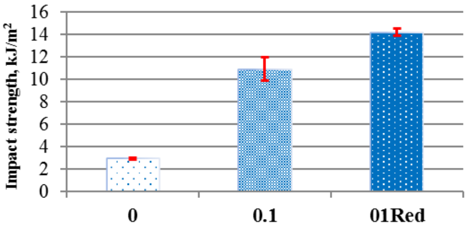

FIGURE 2 Impact strength of PP and PP/PE-g-AM blends: Sample 0 (100% polypropylene-PP), Sample 0.1 (50:50 PP:PE-g-AM), Sample 01Red (50:50 PP:PE-g-AM and 1% red pigment)

The materials presented good mechanical characteristics and more than satisfactory behavior during vacuum thermoforming processing.

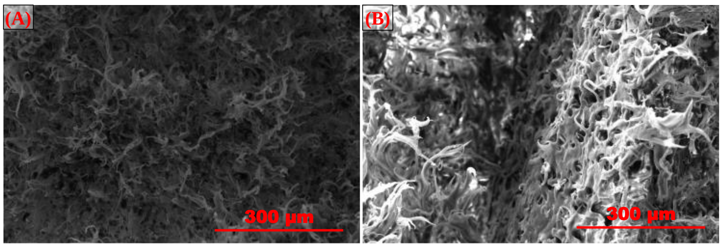

FIGURE 3 Scanning electron micrographs of (A) Sample 0.1 (50:50 PP:PE-g-AM), (B) Sample 01Red (50:50 PP:PE-g-AM and 1% red pigment)

All samples were successfully thermoformed in the chosen shape. Further experimental studies are undergoing within the research project that this study is part of, and they are focusing on adding surface modified aramid fibers as reinforcement into the above presented polymer blends formulations.

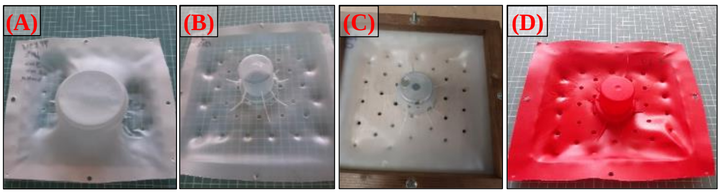

FIGURE 4 Polymer and polymer blends sheets after thermoforming: (A) Sample 0 (100% PP), (B) Sample 1 (100% PE-g-AM), (C) Sample 0.1 (50:50 PP:PE-g-AM), (D) Sample 01Red (50:50 PP:PE-g-AM and 1% red pigment)

Acknowledgements

This work was supported by a grant of the Ministry of Research, Innovation and Digitization, CNCS/CCCDI– UEFISCDI, Romania, project number 601PED/21.06.2022, within PNCDI III.

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THERMAL AND DYNAMIC-MECHANICAL BEHAVIOUR OF EPOXY RESIN CURED VIA JOULE EFFECT

L.C. Kontaxis[1], D. Hoxha[2], G.M. Chatziathanasiou[1], A.C. Patsidis[2], S.P. Zaoutsos[3], G.C. Papanicolaou[1]

[1]*Department of Mechanical Engineering and Aeronautics, University of Patras, Greece*

[2]*Department of Materials Science, University of Patras, Greece*

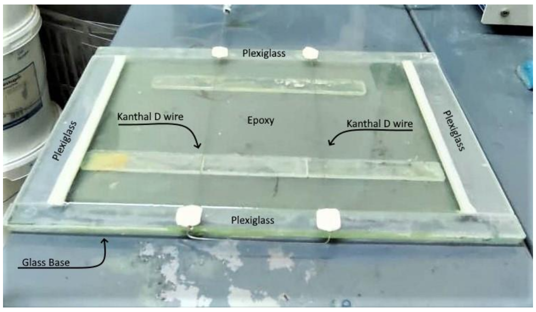
[3]*Department of Energy Systems, University of Thessaly*

ABSTRACT

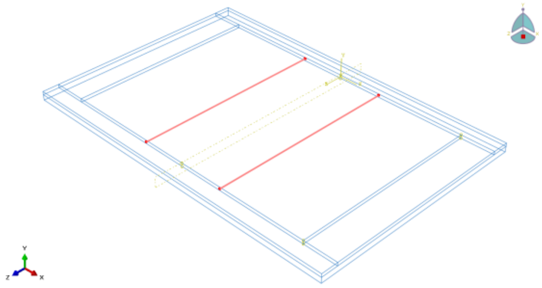
In the present study, epoxy resin sheets were cured by incorporating Kanthal D resistance wires in the epoxy matrix, while the epoxy sheets were cured by the heat produced by a direct electric current passing through the Kanthal wires, i.e., the Joule heating effect. Resistance heating, also known as Joule heating or the ohmic heating effect, is the process by which an electric current travel through resistance and transforms a part of its energy into heat. That heat is utilized for the curing of epoxy resins or epoxy resin composites and offers an out-of-autoclave, cost-effective alternative production method [1–5].

The temperature developed by the embedded Kanthal wires remained constant, at 50°C, for curing times of 4, 5, 6, 8, 9, 12, 14 and 24 hours. The degree of curing (DOC) and the dynamic viscoelastic behaviour of the epoxy resin were studied as a function of both the curing time and the point distance from the heating element. For the degree of curing, DSC experiments were carried out, while for the dynamic-mechanical behaviour of the epoxy resin, DMA experiments were carried out over a frequency sweep range. For the different hours mentioned, experiments were carried out over a range of different distances from the Kanthal heating element (10, 40 and 70 mm) to study the properties of the resin as a function of distance. From the DSC experiments, the curing time for a fully cured epoxy resin in relation to the distance from the heating element was determined, while from the DMA experiments, it was concluded that epoxy resin located at a significant distance from the Kanthal wire will never reach a fully cured condition, despite receiving heat from the heating element.

Furthermore, thermal images were captured during the Joule heating curing process, employing a thermal camera, to describe the temperature distribution variation with location and time, simultaneously. The experimentally obtained temperature distribution was next predicted and compared with respective numerical results. After the numerical model was validated the Kanthal wire separation distance was parametrized in order to obtain an optimal distance between Kanthal wires.



(**a**)



(**b**)

FIGURE 1 (a) Experimental setup and (b) simulate model in Abaqus

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CELL STRUCTURE ANALYSIS OF EXPANDED POLYPROPYLENE BEAD FOAMS UNDER COMPRESSION

I. Koch[1], G. Preiß[1], M. Müller-Pabel[1], B. Grüber[1], J. Meuchelböck[2], H. Ruckdäschel[2], M. Gude[1]

[1] Institute of Lightweight Engineering and Polymer Technology - ILK, TU Dresden, Germany

[2] Department of Polymer Engineering, University of Bayreuth, Germany

ABSTRACT

Closed-cell bead foams are excellent materials for lightweight applications with specific demands in energy dissipation during impact and crash events. Their use in numerous general engineering, automotive and safety equipment applications inevitably leads to loading scenarios with repeated loading and unloading [1]. Closed-cell bead foams are characterized by a hierarchical geometric structure that presents challenges for statistical reconstruction and finite element modeling. Understanding the complex interaction of micro-structure, and base material regarding stiffness, energy dissipation, damage, and failure under static and cyclic loading is in focus of ongoing research [2, 3]. To understand the macroscopic deformation behavior and to validate micro-scale numerical models, the local microscopic deformation behavior must be analyzed.

A versatile and powerful non-destructive method for digitizing, visualizing and analyzing the three-dimensional internal foam structure even under deformation is X-ray computed tomography (xCT). At TU Dresden ILK an in-situ x-ray computed tomography system is located, consisting of a screw-driven material test rig with a maximum capacity of 250 kN and 2000 Nm and a Finetec micro-focus xCT installed between the columns of the test rig. This setup allows mechanical tests on specimens and structures in tension, compression and torsion or processes (e.g., joining techniques, processing of materials) and tomographic imaging is performed in parallel.

In this work, three EPP bead foams with closed cells and different densities are investigated. Cylindrical specimens are extracted from steam-chest molded plates. Circular 3D-printed pads are bonded to both sides of the specimens to ensure parallel and repeatable load introduction. The specimens are loaded to selected deformation states and scanned with xCT while holding the stage. After reconstruction, the resulting image stacks are analyzed regarding the cell morphology using standard algorithms provided by the open-source package distribution FIJI. From the statistical analysis of the cell structure global and selected local deformation mechanisms are revealed. It is shown that morphological parameters such as cell volume, sphericity, mean axis orientation, etc. are influenced by compression deformation. Due to the structure-property-relationship, these results also suggest changes in anisotropy, stiffness, and damping behavior, supporting experimental results from mechanical tests.

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ABSTRACTS: Session 7B

Tuesday 12 Sep. 2023	**SESSION 7B** Oral Presentations **Sustainability and Thermoelectric Energy Harvesting-The HICOTEG project**
Session 7B Chairmen:	**Alkis Paipetis,** Professor of Experimental Mechanical Behavior and Non-Destructive Testing of Composite Materials, Department of Materials Science & Engineering, University of Ioannina, Greece. **Alberto Damore,** Professor, Università degli Studi della Campania "Luigi Vanvitelli", Aversa, Campania, Italy,

MULTIFUNCTIONAL THERMOELECTRIC CEMENT COMPOSITES: THE GREEN POTENTIAL OF CEMENT

I. Vareli, A. Gkaravela, N.-M. Barkoula, A.S. Paipetis

Composite and Smart Materials Laboratory, Department of Materials Science and Engineering, University of Ioannina, Greece

ABSTRACT

Thermoelectric materials convert thermal energy into electricity based on the Seebeck effect. In the presence of a temperature difference between the hot and cold ends of the thermoelectric materials, the charge carriers (holes, $h+$, in p-type materials and electrons, *e*–, in n-type materials) move from the hot side to the cold side, building an electrostatic potential in the material. Accordingly, a thermoelectric generator (TEG) is a transducer that converts the temperature differences on its sides/plates directly into electrical energy [1]. A TEG is internally composed of a doped semiconducting material, producing ***p***-type and ***n***-type legs. The effectiveness of thermoelectric material is described by a dimensionless thermoelectric figure of merit (*ZT*) which is defined as:

$$ZT = \frac{S^2\sigma}{\kappa}T = \frac{S^2\sigma}{\kappa_e + \kappa_l}T = \frac{PF}{\kappa_e + \kappa_l}T \qquad (1)$$

Where *S* represents the Seebeck coefficient, σ is the electrical conductivity, κ_e is the electronic contribution of thermal conductivity, κ_l is the lattice contribution of thermal conductivity, T is the absolute temperature at which the thermoelectric device is operating, and PF ($S^2\sigma$) is the power factor.

Thermoelectric cement-based composites, currently provide a new alternative to diminish the surface temperature of buildings through energy harvesting and decrease the large amount of heat emitted into the urban environment throughout summer [2]. Buildings can therefore be greener, and instead of being energy consumers, they will be transformed into energy harvesters. Cement, is a low-cost, mechanically durable, and electrically conducting material (conductivity values are far less than in metals). It reacts with water through hydration and forms the cement paste which is the matrix material in concrete (with fine and coarse aggregates). Cement-based composites can be rendered a *p*-type or an *n*-type semiconductor by the enhancement of appropriate materials (e.g., carbon nanotubes, carbon fibers), while cement paste could be characterized a highly weak *n*-type materials concerning ionic conduction [3].

The large variety of carbon allotropes is due to its capability of forming sp, sp^2, and sp^3 bonds. Particularly, graphite is the most well-known 3D allotrope of carbon while graphene, carbon nanotubes (CNT), and fullerene are the most widely studied and used 2D, 1D, and 0D allotropes. Also, other forms of carbon allotropes such as amorphous carbon (carbon black) are used for enhancing the cement matrix. Since cement is a fundamental material for buildings and construction and energy-saving policies are essential for a more sustainable future in construction, it is crucial that we take advantage of the thermoelectric behavior of cement by composite engineering. In the study

at hand, two types of carbon nanomaterials *(i)* single-wall carbon nanotubes (SWCNT) and *(ii)* nano carbon black (nCB) (Figure 1) were introduced into cement matrix, while the Seebeck coefficient (S), electrical conductivity (σ), and power factor (PF) for different contents were measured and calculated. The as developed cement-based nanocomposites (Table 1) were used as thermoelements for the fabrication of different cement-based TEGs and their thermoelectric performance were compared.

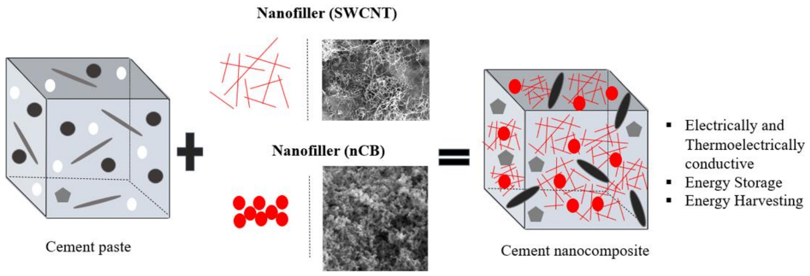

FIGURE 4 Thermoelectric cement-based nanocomposites enhanced with SWCNT and nCB.

TABLE 1 More details for the fabricated thermoelectric generators.

Number of TE	Type of TE	TE connection	TEG connection
10	Cement/ SWCNT	In series	-
10	Cement/SWCNT-nCB	In parallel	-
20	Cement/SWCNT-nCB & Cement/ SWCNT	-	In parallel

Acknowledgements

This research has been co-financed by the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship, and Innovation, under the call RESEARCH-CREATE-INNOVATE (HICOTEG-T1EDK-03482).

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DEVELOPMENT OF GRAPHENE NANOPLATELETS COATINGS WITH BARRIER PROPERTIES FOR DIFFERENT APPLICATIONS

M. Vlacha[1], A. Ntaflos[1], G. Foteinidis[1], K. Tsirka[1], A.S. Paipetis[1]

[1] *Composite and Smart Materials Laboratory, Department of Materials Science and Engineering, University of Ioannina, Greece*

ABSTRACT

Epoxy-based composites are structurally versatile materials with a wide range of challenging applications, associated with their enhanced mechanical properties. Glass fibers reinforced polymers (GFRPs) are mainly used for the construction of wind turbines, aerospace structural components, etc., so efforts are drawn on the research of the behavior of materials in response to external stimuli [1]. It has been proven that the efficiency of conventional composites can be improved by the nano-modification of the matrix [2]. Another approach for enhancing these properties is the deposition of the coating.

Environmental conditions such as high temperature and humidity can affect the durability of the composite materials thus reduce their lifetime. Therefore, it is critical to develop different approaches to eliminate the probability of the effect on overall mechanical properties and hydrothermal degradation [3]. Carbon-based materials like graphite, carbon nanotubes, and graphene are widely used inside the matrix as a barrier to moisture ingress since the introduction of a nanofiller with a large aspect ratio into the surface can improve barrier properties by creating a longer tortuous path for the penetrating molecules (4,5). Another functionality that the deposition of coatings could offer is the reduction of gas permeability. For example, the presence of the GNPs inside the resin has been proven that can decrease the permeability of CO_2 [6,7]. Using these nano-modified resins as coatings could offer the desired moisture and gas barrier properties to the composite structure.

In this study, dispersion-like inks of GNPs for the improvement of barrier properties as coatings were developed. The percolation threshold and the dispersion quality of the GNP inks were assessed via impedance spectroscopy. Morphological characterization was performed by scanning electron microscopy (SEM) analysis of the samples' surfaces that were prepared. The coatings were deposited on the surface of GFRPs, and moisture absorption properties measurements were applied according to ASTM 5229. Gas permeability of the coatings was measured by using an oxygen permeability tester.

Acknowledgements

Part of this research has been co-financed by the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship, and Innovation, under the call RESEARCH – CREATE – INNOVATE (project code: AIOLOS T2EDK-02971).

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MULTIFUNCTIONAL COMPOSITE STRUCTURES WITH SELF - POWERED SENSING CAPABILITIES

A. Voudouris Itskaras, L. Koutsotolis, A. Ntaflos G. Karalis, A.S. Paipetis

Department of Materials Science & Engineering, University of Ioannina, Ioannina, Greece

ABSTRACT

With the advancement of technology, fiber reinforced polymer matrix composites have replaced many conventional materials in numerous applications including aerospace, construction, automotive, etc [1]. An extension of these materials are the multifunctional composites that have attracted a great deal of attention in the last two decades, due to their ability to possess many functionalities simultaneously [2].

Global energy and environmental crisis have led the scientific community to research of energetically autonomous structures [3]. Thus, multifunctional materials are a significant candidate for many applications, as they can exploit alternative forms of energy from the environment and provide an additional nonstructural functionality as energy harvesting, sensing, self- healing etc. [4].

An alternative form of energy that can be utilized from those materials is the thermal energy as the largest amount of energy produced is released in the environment in the form of wasted heat. Therefore, the development of thermoelectric materials and devices are important for the utilization of unexploited thermal energy and the construction of self-powered sensors [5,6].

The scope of this work was to fabricate a polymer matrix composite with the ability to harvest unexploited thermal energy as well as the formation of a self-powered thermal sensor.

To achieve the above objectives, functional inks were developed from carbon-based nanostructured materials which were integrated into the composite through printing methods to compose a multifunctional composite structure.

The results obtained from the experiments performed, have demonstrated sufficient thermoelectric energy harvesting and immediate response to various thermal stimuli during their testing as thermal sensors.

Acknowledgements

This research has been co-financed by the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship, and Innovation, under the call RESEARCH – CREATE – INNOVATE (project code: AIOLOS T2EDK-02971).

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ABSTRACTS: Session 8A

Tuesday 12 Sep. 2023	**SESSION 8A** Oral Presentations **3D-Printed Scaffolds**
Session 8A Co-Chairmen:	**M. Dobreanou,** Professor, Dept. Laboratory Medicine, Univ Med Pharm Sc & Techn Tîrgu Mures, Romania **N. Athanasopoulos,** Foundation of Research and Technology, Hellas - Institute of Chemical Engineering Sciences, FORTH/ICEHT, Patras, Greece.

4D PRINTING WITH SHAPE-MEMORY COMPOSITE FILAMENTS

C.M. Fernandes[1], P. Esfandiaries[2], J.F. Silva[2], A.T. Marques[1,3*], A. Afonso[1,4]

[1] *FEUP - Faculty of Engineering of the University of Porto – R. Dr. Roberto Frias, s/n 4200-465 Porto, Portugal*

[2] *ISEP – Instituto Superior de Engenharia do Porto - R. Dr. António Bernardino de Almeida 431, 4249-015 Porto*

[3] *LAETA/INEGI – Associated Laboratory for Energy, Transports and Aerospace/Institute of Science and Innovation in Mechanical and Industrial Engineering*

[4] *Centro de Investigação de Fenómenos de Transporte*

** Corresponding author: marques@fe.up.pt*

ABSTRACT

The use of composites is growing. Consequently, the search for high performance and high rate of production process is increasing too. Advanced composite systems are already processed, in general, as in the case of Additive Manufacturing. Many structures with complex geometries can be made using 3D printing technologies. Composite structures with complex shape may be produced by laying up flat prepregs, without moulds. The application of the concept of folded composite structures or shape-memory polymers/composites is applicable too.

The present work aims to present a lightweight, structurally stable and self-deploying shelter using shape memory polymer composites (SMPC) and 4D printing technology. The key objective is to improve the structural properties of a shelter solution by using Shape Memory Polymer Composite (SMPC) filaments for 4D printing. To achieve this, a composite filament extrusion system is developed.

To understand the polymer material used in the study, thermal and mechanical characterization tests were conducted. The melt flow index (MFI) test provides insights into the PLA's flowability, while the thermogravimetric analysis (TGA) test evaluates its thermal degradation. The results align with existing literature on PLA materials, enhancing the overall understanding of the material's behavior and properties.

The initial extrusion installation consisted of a cylindrical liquefier barrel where the carbon fibers impregnated with the deposited PLA were mixed, and then extruded through a cylindrical die. However, this setup faces challenges such as inconsistent cross-sectional geometry and filament diameter. In response to these issues, modifications were introduced in the second iteration of the installation. A water-cooling system was incorporated to facilitate rapid filament consolidation at the extruder exit, ensuring the desired circular cross-sectional geometry within the die. Additionally, a motorized filament pulling system was integrated to achieve a more consistent filament diameter and explore different pulling speeds for fine-tuning filament properties. The implemented changes resulted in significant improvements in the quality of the filament samples compared to the original

setup, as the filaments exhibit enhanced consistency and quality. In the context of 3D printing, initial testing reveals extrusion problems when using the previously produced filaments. To address this, production resumed with a 3mm die diameter, ensuring an average filament diameter of 1.75mm, which ensures proper fitting within the printer's guiding roller elements. A brief approach to process simulation is also be presented.

ENHANCING THE THROUGH THICKNESS CONDUCTIVITY OF FIBER REINFORCED POLYMER COMPOSITES

M. Georgallas, K. Loizou, A. Evangelou, M. Karouzou, K. Sofocleous, V. Drakonakis

AmaDema (Advanced Materials Design & Manufacturing Limited), Cyprus

ABSTRACT

Carbon fibre reinforced polymer (CFRPs) composites have been established as the go to material in most applications that require superior strength to weight properties. Due to their unique combined properties, there is a continuous interest to harness the benefits of CFRPs in other high value and niche applications. In particular, efforts within the international literature indicate that there is a need to increase the through thickness electrical conductivity of CFRPs, to serve applications such as avionics and electronic casings, material damage sensing structures, sensitive robotics parts and space radio frequency applications. However, to the knowledge of the authors, no scalable solutions that combine cost effectiveness and substantial improvements at the multilayer composite level have been developed yet. Within the available literature for increasing through thickness electrical conductivity of CFRP multilayer structures, very limited works have used printing techniques to achieve toward this direction. Screen printing is a well-established technique which is traditionally used in the printed electronics industry and offers a lot of advantages in terms of processing and adjustability.

Considering the state-of-the-art research activity, this work aims to investigate and screen-print, through a custom-made configuration, a polymer solution reinforced with electrically conductive nano- reinforcements on predetermined patterns on both surfaces of a carbon technical fabric in order to increase the through thickness electrical conductivity of the resulting CFRP multilayer composite structure. Different polymer and nano/micro fillers have been investigated under the screen-printing processing technique.

Current results showed that the doping of polymer-based interlayers (incorporated into a CFRP) first with carbon nanotubes and second with copper nanowires increases the through thickness electrical conductivity of the CFRP from 0.1 S/m to between 8 and 10 S/m. Different combinations of polymer and nano fillers are examined here to achieve optimum processing characteristics for the screen-printing technique. A ‘four-probe’ configuration adjusted with the digital multimeter was utilized to measure electrical conductivity along several directions fabricated samples. Microstructural characterization of the polymer droplet/carbon fabric interfaces was performed in a SEM.

Therefore, screen printing is a scalable, promising and cost-effective solution to enhance technical fabrics in order to fabricate CFRPs with increased through thickness conductivity and unique multifunctionalities.

3D PRINTED BIODEGRADABLE SCAFFOLD FOR OPTIMAL RESTORATION OF KNEE FUNCTIONALITY AFTER AN ACL INJURY - A DEGRADATION AND STABILITY STUDY

J. Dulnik, D. Kolbuk – Konieczny, M. Moczulska - Hejlak

Institute of Fundamental Technological Research

Polish Academy of Sciences, Laboratory of Polymers and Biomaterials, Pawińskiego 5B St., 02-106 Warsaw, Poland

ABSTRACT

The Anterior Cruciate Ligament (ACL) is one of the major knee ligaments, one which is greatly exposed to injuries. Currently, in the case of significant damage to ligaments and tendons, the standard treatment approach is to use autografts [1]. The aim of this work is to develop a modern, innovative graft for reconstructing and regenerating the ACL after its injury. One of the major requirements that has to be met for this type of scaffold to promise a successful restoration of a knee functionality are its adequate mechanical properties. All medical devices, implants and grafts included, have to go through a sterilization process before use and because of that some of their properties can be altered, which is very often overlooked in published research, but may have severe consequences on material's performance.

Two types of biodegradable aliphatic polyesters are used in the process of 3D printing to obtain grafts of optimized architecture. Electron beam irradiation is used in two doses: 15 kGy and 25 kGy to assess how such sterilization technique impacts scaffolds properties. 3D printed samples sterilized with those doses as well as a non-sterilized control group are subjected to an experiment in two variations: a) a degradation study in phosphate buffer saline (pH 7.4, 37°C) that mimics the in-vitro environment, b) a stability study in 4°C (dry) that model normal refrigeration storage condition. Both experiments are conducted over 90 days with multiple control timepoints at which samples are weighed and their molecular mass is measured with gel permeation chromatography. The obtained data helps to optimize 3D printing scaffold prototyping method to design a graft used in the ACL reconstruction surgery that will facilitate full restoration of knee functionality with reduced occurrence of postoperative complications, pain, and patient's recovery time.

Acknowledgements

This work was founded by The National Centre for Research and Development through project Small Grant Scheme 2020 under The Norwegian Financial Mechanism 2014-2021. Grant number: NOR/SGS/BioLigaMed/0272/2020.

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THE COMBINED EFFECT OF 3D SCAFFOLD FEATURES AND BIOREACTOR STIMULATION ON HUMAN CELLS' FEEDBACK

F.K. Kozaniti[1], A.E. Manara[1], V. Kostopoulos[2], D.V. Portan[1]

[1]*Department of Mechanical Engineering and Aeronautics, Laboratory of Biomechanics and Biomedical Engineering, University of Patras, 265 04 Patras, Greece*

[2]*Applied Mechanics & Vibrations Laboratory, Department of Mechanical Engineering and Aeronautics, University of Patras, 265 04 Patras, Greece*

ABSTRACT

Biomimetic materials refer to those material which closely mimic the natural properties of the replaced tissue. This class of innovative materials are highly demanded nowadays. Recent studies have proved the importance of a tissue-like nature of the biomaterial in enabling the appropriate *in vitro* feedback of cell cultures [1]. Also, the reproduction of an *in vitro* environment capable to biomimic as much as possible the body one is necessary in order to perform the correct experimental assessment. Bioreactors are usually designed to meet the requirements of the cell-culture environment by addressing parameters such as temperature, oxygen, etc. [2] and partially reproduce the body-like environment.

In the present investigation we combined computational methods with experimental investigations to understand the response of human umbilical stem cells to a biomimetic environment. More precisely, the feedback of these cells when seeded in 3D printed scaffolds while dynamically stimulated in a home-made bioreactor was studied. The tested experimental parameters were the inlet velocity, the initial cell number involved in the experiment and the exposure time in the bioreactor. Experimentally, polyurethane and polylactic acid - 3D printed scaffolds were fabricated and fibronectin coated. Their mechanical processes were evaluated before and after sterilization. For their evaluation from biological viewpoint, human umbilical stem cells were used, and key processes and biomarkers were quantified (viability, total protein, Alizarin red, osteopontin, osteocalcin). SEM and confocal imaging have been performed. The mechanical testing of the scaffolds was performed by compression and has shown that the applied sterilization protocol has insignificantly affected their modulus (Fig.1).

Further on, MSCs were seeded in different numbers in the 3D porous scaffolds and exposed to the bioreactor (0.5 and 2 hrs. duration, 3 and 6 mm/s inlet velocity). Shorter exposure periods (0.5 hrs) and lower inlet velocity (3mm/s) were found more appropriate for an efficient adhesion and deposition of the cells to the scaffold fiber. Polyurethane enabled extremely rapid proliferation, followed by differentiation while PLA induced a moderate proliferation and parallel mineralization (Fig.2). Deeper analyses of the other biomarkers and of the micrographs demonstrated that the scaffold stiffness and the flow in the bioreactor play a synergetic role in the determination of cells response.

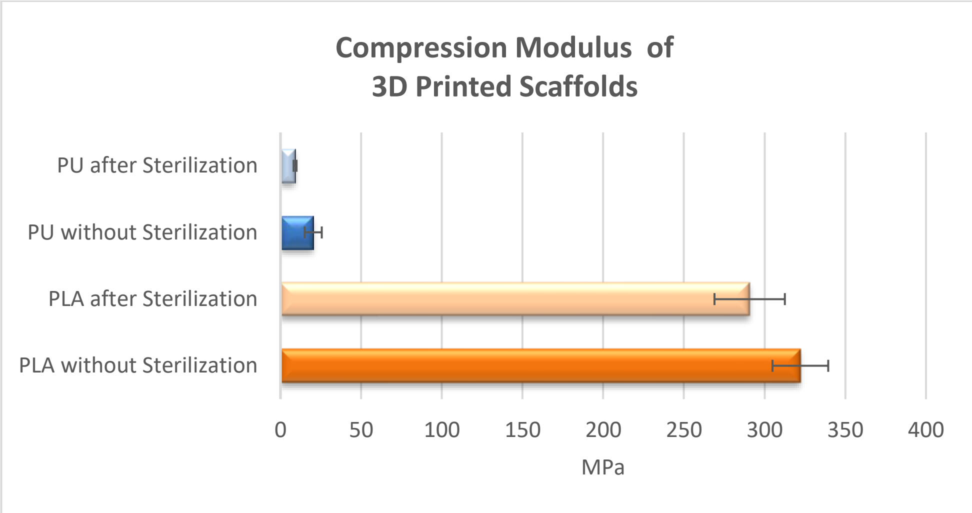

FIGURE 1 Compression Modulus od the polylactic acid (PLA) and polyurethane (PU) scaffolds before and after sterilization

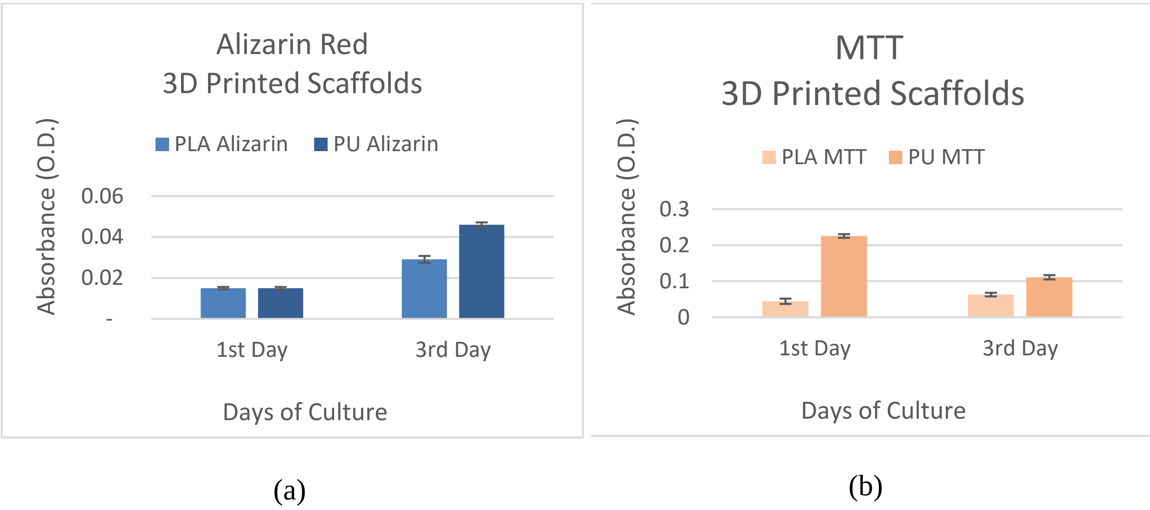

FIGURE 2 Cells feedback in scaffolds when exposed to bioreactor: (a) Viability evaluated by MTT test and (b) Mineralization evaluated by Alizarin red test

The optimum number of deposited cells depends very much on the material and the nature of the scaffold (overall properties including modulus, porosity, architecture), as well as on the duration of the experiment. Short experiments (0.5 to 2 hrs.) may involve $2.5x10^5$ cells if the surface area of the 3D structure is at least 1x1 cm^2. For longer incubation times (1 to 3 days), 10^5 cells in population is the optimum number.

Finally, the scaffolds stiffness has been found as the key enabling parameter decisive in cells feedback mechanism. Overall, it was concluded that the mechanical performance of the scaffold and more precisely its Young's modulus is the key biomimetic property that will program the cells life cycle and adaptation to the surrounding micro-environmental conditions.

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A COMPUTATIONAL APPROACH FOR THE INVESTIGATION OF THE COMBINED EFFECT OF 3D SCAFFOLD FEATURES AND BIOREACTOR STIMULATION ON HUMAN CELLS' FEEDBACK

A.E. Manara[1], F.K. Kozaniti[1], V. Kostopoulos[2], D.V. Portan[1]

[1]*Department of Mechanical Engineering and Aeronautics, Laboratory of Biomechanics and Biomedical Engineering, University of Patras, 265 04 Patras, Greece*

[2]*Applied Mechanics & Vibrations Laboratory, Department of Mechanical Engineering and Aeronautics, University of Patras, 265 04 Patras, Greece*

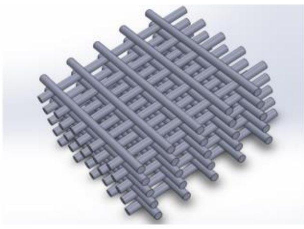
ABSTRACT

Computational fluid dynamics (CFD) is a widely used tool for investigating fluid flows in bioreactors. It has been used in the biopharmaceutical industry for years and has established itself as an important tool for process engineering characterization. As a result, CFD simulations are increasingly being used to complement classical process engineering investigations in the laboratory with spatially and temporally resolved results, or even replace them when laboratory investigations are not possible [1]. The use of digital twins in tissue engineering (TE) applications is of paramount importance to reduce the number of *in vitro* and *in vivo* tests. Combining 3D design with numerical stimulation facilitates the reproducibility between studies and the platforms optimization (physical and digital) to enhance tissue engineering processes [2].

In the present investigation, Comsol Multiphysics 5.2a, CFD Module, and Particle Tracing Module were used for the computational analysis of a bioreactor system that contained scaffolds loaded with cells (particles) flowing in a medium. The scaffold's geometry for the simulations was designed in Solidworks 2016 by Dassault Systems and the key varying parameters in the model were: inlet velocity, inlet particle number and stimulation time (Fig.1a). The scaffold was computationally designed to fit in a 6 mm diameter tube and its virtual dimensions were: pore size 1.5x1.5 mm^2, fiber diameter 0.5 mm and 5 mm thickness (Fig.1b).

		Inlet velocity (mm/s)					
		1		3		6	
Particles no.	5x10^4	30	120	30	120	30	120
	10^5	30	120	30	120	30	120
	2.5x10^5	30	120	30	120	30	120
		Stimulation duration (min)					

(a)



(b)

FIGURE 1 (a) Combinations of key parameters in the simulation: Inlet velocity (1/3/6 mm/s), No. of particles representing cells (5x10^4, 10^5 and 2.5x10^5) and Exposure time to bioreactor (30, 120 min) and (b) Structure of the virtual scaffold

Comsol software allowed the prediction of cells behavior in specific conditions, when loaded in a scaffold, and stimulated in a dynamic bioreactor. Between others, as observed in the diagram in Fig.2, Comsol modelling predicted that the number of attached cells to the scaffold considerably increases proportionally with the inlet velocity (Fig.2). After approximately 20 minutes of stimulation, for 1 mm/s velocity the prediction indicates an approximate number of 500 cells in the scaffold, for 3 mm/s there will be approximately 700 cells in the scaffold, and more than 850 cells are going to be developed in the scaffolds when the inlet velocity is 6 mm/s. The model indicates that the threshold for cells attachment is at 17 minutes exposure in the bioreactor. After that, the number of cells in the scaffold does not change drastically with time, being maintained constant in the case of all the applied inlet velocities.

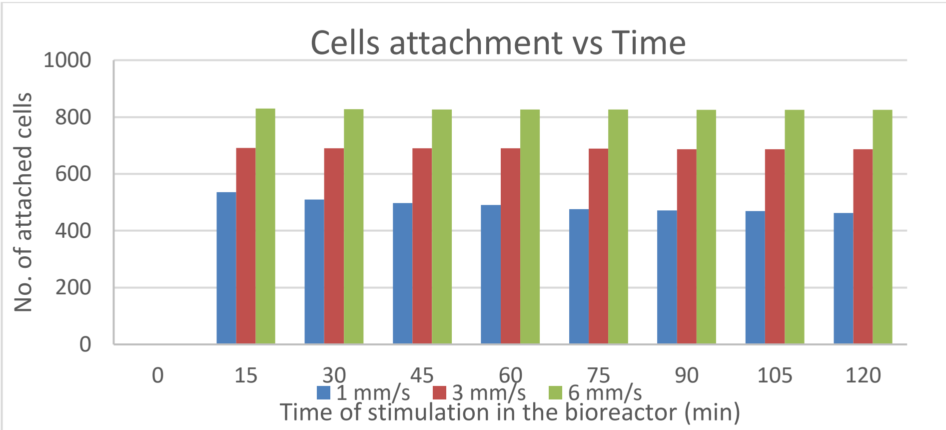


FIGURE 2 Predicted number of cells in the scaffold after several periods of exposure (from 20 to 140 minutes) and at different inlet velocities

Some important findings are extracted from the investigation: the Comsol software is recommended to predict cellular events in scaffolds, in a bioreactor, within the first half of an hour after contact between cells and substrate. According to the Comsol findings, the shear rate increases in the space of the scaffold pores, while the fluid velocity doubles inside the scaffold, which determines some changes in cells distribution, making it less uniform and efficient between layers 2 and 5 of a scaffold structure. Finally, it was computationally predicted that only 1.5% of the inserted particles attach to the scaffold. The physical explanation is that the shear stresses and the flow intensity carry the cells through the pores of the scaffolds leading to their loss with the fluid. From the huge particle number that are given as an input, only 1.5% stay on the fiber. This prediction fits the experimental reality, since it is well known that cells find it difficult to adhere to 3D scaffolds and that even for static conditions an adapted protocol involving coating with adhesion proteins is needed to obtain an efficient result. Experimentally, a solution to avoid cell loss from the scaffold due to physical events is the seeding of cells on the substrates in static conditions and their subsequent incubation for hours to days before the exposure to a bioreactor.

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COMPRESSIVE STRENGTH BEHAVIOR OF GYROID LATTICE STRUCTURE IN 3D-PRINTED CF-PEEK

V. Triminì [1,2], S. Varetti [3], G. Percoco[1], S. Corvaglia[2], I. Scavo[2], N. Gallo[2]

[1] *Department of Mechanics, Mathematics and Management Engineering, Politecnico di Bari, Italy.*
[2] *Leonardo Aerostrutture, Italy.*
[3] *Leonardo Labs, Materials, Italy.*

ABSTRACT

The aviation and aerospace industries require structures that are increasingly light and resistant to harsh environments. The lightening of aircrafts and spacecrafts is very important for reducing CO2 emissions and fuel consumption [1]. To achieve these purposes, one of the first steps is to replace the metal parts with composite materials that exhibit a high strength-to-weight ratio and high chemical, thermal and corrosion resistance [2]. Additive Manufacturing (AM) technologies allow the maximization of the use of materials while minimizing waste [3,4]. Fused Filament Fabrication (FFF) is the most widely AM technology used, initially for rapid tooling and rapid prototyping but also for the production of small volumes of end-use parts [5-7]. Through the slicing software, it is possible to establish the process parameters that will give certain properties to the printed part. It is well known that two of the most influential parameters are infill density and infill pattern [5,8]. The most common filling patterns are simple geometric structures, that allow durable construction combined with the high print speeds, such as grid, straight, honeycomb and cubic. A very interesting infill structure is a technically Triply Periodic Minimal Surface (TPMS) topology called ‘Gyroid’ (Fig.1). The Gyroid infill is a nature-inspired pattern whose most important feature is its almost isotropic structure, which, in contrast to all other patterns, means that it has the same resistance in all directions. The extruder follows a continuous curvilinear path that creates a sort of ‘maze’ with three-dimensional unit cells. It’s widely known that this infill pattern was inspired by a 2017 MIT study, where researchers designed one of the strongest and lightest materials available using graphene [9]. Today the gyroid infill is attracting a lot of interest in the biomedical field [10-12] but it could be very promising for several application fields such as aeronautics, aerospace, automotive, transportation and defense. The advantages of applying it to 3D printing for aerospace and aeronautical purposes are: i) a very good combination of high strength and low printing time, ii) isotropic strength in all directions (x,y,z), iii) excellent energy absorption capability and high fracture toughness, iv) high compressive and tensile strength despite less density and material usage (in comparison to other infill patterns) [13,14]. Thus, the final result is a 3D-printed part with high strength-to-weight ratio.

Among the materials used for metal replacement for aerospace and aeronautical additively manufactured parts, there are techno polymers such as polyariletherketones (PAEK) family, polyetherimide (PEI and ULTEM), polyphenylene sulfone (PPS) and their composites (techno-polymers filled with reinforcing materials). These polymers exhibit high mechanical strength, and excellent thermal and chemical resistance even in harsh conditions. The 3D printing of these materials needs the use of very advanced machines that must achieve nozzle temperatures higher

than those of common printers (at least 400 °C) due to the high melting point and viscosity of these thermoplastics. For the present study, it was chosen a commercial CF-PEEK, i.e. the Polyether(ether ketone) filled with chopped carbon fibers [15].

In this work, the effect of the gyroid infill pattern in CF-PEEK 3D-printed samples on compression strength was studied. A study on the process parameters (infill density and printing speed) was performed. Four printing speeds (17-20-23-30 mm/s) were tested for lower infill densities (from 5% to 25%) to evaluate the difference in 3D-printing quality. It has been found that the printing speed slightly affects the compressive strength of the parts, thus it was chosen the higher printing speed among the ones before mentioned for the evaluation of higher infill densities. The results showed that the compressive strength vs weight (or infill density) follows a power-law trend, indicating that the data are in agreement with the Gibson-Ashby prediction for bending-dominated lattices [16]. Therefore, the results of this work are very promising for the qualitative prediction of the strength-to-weight ratio of the gyroid lattice printed parts.

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ABSTRACTS: Session 8B

Tuesday 12 Sep. 2023	**SESSION 8B** Oral Presentations **Bioengineering**
Session 8B Co-Chairmen:	**Doina Ramona Manu,** Center for Advanced Medical and Pharmaceutical Research, "George Emil Palade" University of Medicine, Pharmacy, Science and Technology of Targu Mures, Romania **T. Katsila**, Head of the Laboratory of Biomarker Discovery & Translational Research Institute of Chemical Biology, National Hellenic Research Foundation, Greece

EXOSOMES: NEW STRATEGIES IN DIAGNOSIS, PROGNOSIS AND THERAPY OF BRAIN DISORDERS

D. Manu[1], M. Dobreanu[1,2,3], G. Şerban[4], R. Bălaşa[5,6], A. Bălaşa[7,8]

1 Centre for Advanced Medical and Pharmaceutical Research, "George Emil Palade" University of Medicine, Pharmacy, Science and Technology, Târgu Mureș, Romania

2 Clinical Laboratory, County Emergency Clinical Hospital, Târgu Mureș, Romania

3 Department of Laboratory Medicine, "George Emil Palade" University of Medicine, Pharmacy, Science and Technology, Târgu Mureș, Romania

4 Doctoral School, "George Emil Palade" University of Medicine, Pharmacy, Science and Technology of Târgu Mureş, Romania

5 1st Neurology Clinic, Emergency Clinical County Hospital of Târgu Mureş, Romania

6 Department of Neurology, "George Emil Palade" University of Medicine, Pharmacy, Science and Technology of Târgu Mureş, Romania

7 Neurosurgery Clinic, Emergency Clinical County Hospital of Târgu Mureş, Romania

8 Department of Neurosurgery, "George Emil Palade" University of Medicine, Pharmacy, Science and Technology of Târgu Mureş, Romania

ABSTRACT

Liquid biopsy is a non-invasive method for early diagnosis, prognosis, and monitoring of disease. Exosomes, nanosized (30–150 nm) endosome-derived vesicles, are released by all cell lineages in body fluids, with function in cell-to cell communication. Their use in the diagnosis of central nervous system (CNS) as liquid biopsies derived from blood or cerebrospinal fluid shows promising, especially in deep-seated lesions where use of tissue biopsies is limited by accessibility and spatial and temporal heterogeneity of lesions. Exosomes contribute to intercellular signaling in both physiological and pathological CNS states. The ability to cross the blood–brain barrier favors communication between CNS and cells from periphery. Their lipid bilayer allows them to safely travel within the bloodstream, to transport hydrophobic molecules and to join with their target cells. The aqueous core allows for the transport of various hydrophilic molecules and genetic material (messenger RNA, microRNA, and DNA) from their parent cells to adjacent or distant recipient cells through paracrine or autocrine mechanisms. This exosome cargo is diverse depending on the cells from which they are released [1, 2, 3].

Exosome isolation from body fluids is performed by ultracentrifugation, polymer-based precipitation, affinity-based capture, and filtration with a low exosome yield, interference with non-exosome contaminants and loss of exosome morphology and functional activity. To overcome these limitations, nanomaterials such as metal oxides or metal oxides functionalized hybrids- for example

hydrophilic bimetallic magnetic nanocomposites, are studied as capturers or as nanointerfaces to provide highly efficient isolation. Nanomaterials are also considered to improve the microfluidic devices interface for exosome isolation and downstream analysis of exosomes in one platform [4,5].

Liposomes and polymeric nanoparticles are synthetic drug delivery systems that can be used in brain disease therapy. Exosomes have the advantage to be biocompatible and non-immunogenic natural delivery systems, with long half-life in circulation. Exosomes are targeted drug delivery systems due to their surface proteins that promote interaction with target cells. Exosomes can be selectively loaded with therapeutic molecules, by *in vivo* pre-loading, during the exosome biosynthesis in donor cell, or *in vitro* post-loading, after exosome isolation. Exosome use as drug delivery systems shows disadvantages emerged from isolation and cryopreservation methods that often fail to maintain vesicle integrity and function. The presence of soluble substances in exosome suspensions, potentially lead to biological side effects [6]. The perspectives for therapeutic exosomes must be the development of nanomaterial-assisted exosome isolation techniques. For precise targeting of recipient cells, exosome surfaces can modify with hydrophilic polymers or ligands that specifically bind to receptors on target cells [7].

To reveal disease molecular signatures, to find prognostic and predictive biomarkers and to monitor therapy response, our team perform multiple methods for exosome isolation- differential gradient ultracentrifugation, polymer-based precipitation, and affinity-based capture. After isolation, the exosomes are analyzed by multiplexed flow cytometry and Western blotting to study exosome molecular signature in patients with glioblastoma or stroke and patient response to therapy.

As future perspective, nanoprobes built with nanomaterials integrated in various detector types for sensitive and multiplexed detection of exosome biomarkers are used, as these technologies will be validated and available.

Acknowledgements

This work was supported by the University of Medicine, Pharmacy, Science and Technology “George Emil Palade” of Targu Mures Research Grant number 10126/2/17.12.2020.

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EXTRACELLULAR VESICLES: TINY MESSENGERS WITH A BIG IMPACT ON ADVANCED MATERIALS

V. Bafiti, S. Ouzounis, T. Katsila

Institute of Chemical Biology, National Hellenic Research Foundation, 11635 Athens, Greece

ABSTRACT

Extracellular vesicles have emerged as key players in intercellular communication. These tiny membrane-bound structures, secreted by various cell types, are known to transport a diverse cargo of biomolecules, including proteins, nucleic acids, and metabolites. In addition to their biological roles, recent technological advances have unveiled their fascinating potential in the field of advanced materials.

Herein, we explore the significant impact of extracellular vesicles on advanced materials. Extracellular vesicles have been found to possess unique properties that make them promising tools for material scientists and engineers. Firstly, their nanoscale size and membrane composition enable efficient interactions with various advanced materials, including nanoparticles, nanocomposites, and biomaterials. This enables precise manipulation and modification of material properties at the nanoscale. Furthermore, the cargo carried by exosomes, such as signaling molecules, enzymes, and genetic material, can influence the behavior and performance of advanced materials. By harnessing the specific molecular content of exosomes, researchers can engineer material properties, enhance functionality, and induce desired responses, opening new possibilities for the design and development of advanced materials with tailored properties [1, 2].

We also perform structural analysis as it plays a vital role in understanding the interactions between extracellular vesicles and advanced materials. Techniques such as mass spectrometry, advanced imaging methods and image processing pipelines allow for the visualization and characterization of extracellular vesicles and provide valuable insights into the structural organization, surface properties, and interfacial interactions of extracellular vesicles with advanced materials, enabling a deeper understanding of their impact and potential applications.

We showcase recent advancements in the field and discuss key applications in areas such as drug delivery systems, tissue engineering, and sensors. Additionally, we highlight the challenges and future directions for utilizing extracellular vesicles as versatile messengers for advancing materials science.

Acknowledgements

This paper is co-funded by European Union’s Horizon 2020 research and innovation programme under grant agreement No 101112347, project NerveRepack (Intelligent neural system for bidirectional connection with exoprostheses and exoskeletons) and supported by the CHIPS Joint Undertaking and its members. We acknowledge PRACE for awarding access to the Fenix Infrastructure resources at CINECA and Jülich hosting sites, which are partially funded from the European Union’s Horizon 2020 research and innovation programme through the ICEI project under the grant agreement No. 800858.

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LDPE BIOACTIVE FILMS: FROM THE LAB TO THE PILOT PRODUCTION - CHALLENGES AND PERSPECTIVES

I. Giotopoulou[1], N.-M. Barkoula[1*], A. Porfyris[2], S. Vouyiouka[2], K. Safakas[3], G. Lainioti[3], A. Ladavos[3], R. Fotiadou[4], A.K. Polydera[4], H. Stamatis[4], A. Papageorgiou[5], I. Thanassoulia[5], I. Lambropoulos[6]

[1]*Department of Materials Science and Engineering, University of Ioannina, 45110, Ioannina, Greece,* [2]*Laboratory of Polymer Technology, School of Chemical Engineering, Zographou Campus, National Technical University of Athens, 15780, Athens, Greece,* [3]*Department of Food Science & Technology, University of Patras, 30100, Agrinio, Greece,* [4]*Department of Biological Applications and Technology, University of Ioannina, 45110, Ioannina, Greece,* [5]*Achaika Plastics S.A., 25100 Egion, Greece,* [6]*IPER, Laboratory of Chemical and Microbiological Analysis, 45221, Ioannina, Greece*

ABSTRACT

Since LDPE films find widespread use as flexible food packaging materials, the current study focuses on their transformation into active packaging, keeping the intervention in terms of material modification to a bare minimum. Essential oils have been in the spotlight during the last decades as natural preservatives for food products. The direct blending of these substances with the packaging material and their application in the form of coating has been two of the most convenient methods for the development of active packaging, however both methodologies have certain limitations that hinder their widespread application. Direct blending has been, however, linked with their extensive degradation and/or loss during high temperature processes [1]. At the same time the application of bioactive substances on the surface of packaging materials has been associated with inadequate adhesion of the coating with the polymer substrate, difficulties in drying using mild and industrially relevant conditions, and inability to control the bioactivity over time due to the direct release of the substances from the coating layer. A promising strategy is to entrap heat sensitive substances into the interlayer space of effective adsorbents such as clays [2, 3]. This strategy not only offers higher thermal stability, but also contributes to the delayed release of the bioactivity and thus its availability for prolonged periods. In the direction of effective coatings, the encapsulation/entrapment of the bioactive substances could also delay the migration rate of the substances.

Based on the above, the present work proposes the development of multi-layered films, each layer serving a different role. Thus, LDPE bioactive pellets are transformed into films, that are either used to develop, single-, bi- or tri-layered structures. In the bi- and tri-layered structures, the outer layer consists of neat LDPE, representing the core of the packaging material. This layer is in contact with the outer environment of the packaged food serving as a barrier to water or oxygen. The second layer is based on LDPE bioactive pellets, that serve as a reservoir of bioactivity, while the third layer, if applied, consists of the bioactive compounds in the form of coatings. In the tri-layered structure the coating layer is in contact with the food and supports the direct release of the bioactivity. The innovation in the current study, is that the two main layers of the proposed film are based on LDPE, which offers higher compatibility between layers and enhanced bioactivity. Furthermore, in the

proposed coating the volatile bioactive substances are entrapped into emulsion-based micelles and/or cellulose-based compounds, facilitating their stability over drying, adhesion with the polymer substrate and direct availability upon food contact.

For the preparation of the proposed films, bioactive nanocarriers are developed by the incorporation of thymol into clays. Nanocarriers are melt-mixed with LDPE to develop bioactive pellets. The effect of scaling-up on the thermal stability and release of the bioactivity from the pellets is thoroughly investigated. Coatings are prepared by the entrapment of the bioactive substances into emulsion-based micelles and/or cellulose-based compounds. Single-, bi-, and tri-layered bioactive LDPE-based films are developed using lab-scale and pilot scale methodologies (compounding and/or twin-screw extrusion, hot press or co-extrusion/film blowing, blade or flexographic coating), and their performance is assessed. The incorporation of thymol in organically modified montmorillonite is performed using a green method without organic solvents developed by members of the research team to develop bioactive nanocarriers [2]. For the lab-scale production of films, the bioactive nanocarriers are melt-mixed with LDPE matrix at 10 wt. % using a small-scale twin-screw extruder at 160 ^{o}C and 100 rpm to develop LDPE bioactive pellets. For the effective mixing of the nanocarrier with LDPE the extrudate passes through the lab-scale extruder 10 times [3]. Bi-layered films are developed through hot pressing together plain and bioactive LDPE-based films. Bioactive coatings are developed by the preparation of thymol-based solutions which are blade coated on the LDPE-based substrate. For the pilot production of the bioactive films, homogenization of the nanocarrier with LDPE is performed using an internal mixer followed by twin-screw extrusion using an intermediate scale extruder. The bioactive pellets are fed together with plain LDPE pellets in a pilot-scale co-extruder connected with a film blowing unit to produce a co-extruded LDPE bi-layered film. A flexography unit, that is conventionally used for the printing of the films is modified appropriately and used for the application of the bioactive coatings on the co-extruded bi-layered film.

The effect of processing conditions on the thermal stability, and amount of bioactivity of LDPE bioactive pellets and films is assessed. The bioactivity of the films is evaluated with respect to their antimicrobial and antioxidant properties. The release rate of the bioactive compounds into different food simulants is also examined. The obtained results reveal that the extrusion conditions have a significant effect on the bioactive substances' content that is maintained after processing. XRD results also suggest that processing has a great impact on the homogeneity and degree of intercalation of the bioactive nanocarriers in LDPE and in turn on the effective protection of the bioactivity. From the antimicrobial and antioxidant response of the bi- and tri-layered films, it can be concluded that all films present very high antioxidant activity, while the antimicrobial activity is very high in tri-layered films. TGA measurements reveal the beneficial role of clays in protecting the bioactive compounds during extrusion. The release rate experiments reveal that the inner layer presents a delayed release of the bioactive substances in relation to the almost direct release of the bioactivity provided by the coating. The overall performance of the developed films can be adjusted by changing the amount of the nanocarriers in the intermediate layer, the composition and content of the bioactive substance in the coating layer, as well as the relative thickness of each layer.

Acknowledgements

This research was co-financed by the European Regional Development Fund of the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call ‘Aquaculture’— ‘Industrial Materials’— ‘Open Innovation in Culture’ (project: AntiMicrOxiPac, project code: T6YBΠ-00232).

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DECODING EXTRACELLULAR VESICLE ENGINEERING; SEEING IS BELIEVING

S. Ouzounis, T. Katsila

Institute of Chemical Biology, National Hellenic Research Foundation, 11635 Athens, Greece

ABSTRACT

Extracellular vesicles (EVs) are nanoscale entities that are considered circulating translational biomarkers of choice when inter-individual variability, drug resistance, and adverse drug reactions are considered, while they are becoming key actors in bio-engineering and biomaterials science. Several microscopy approaches have been employed to study EVs, each with advantages and disadvantages, while a gold-standard method is still missing. To that end, standardization upon high-yield EV manufacturing remains a key challenge.

To enable the democratization of EV applications, herein, we introduce a multitask deep learning model for the optimal segmentation of EVs in publicly available transmission electron microscopy (TEM) images. We aim to overcome current limitations such as the error of the predicted masks, which affects all other measurements and provide a unified and robust solution for the automated detection, quantification, and characterization of EVs in TEM images.

The project is implemented in R language; the latest version of the language and web interface of RStudio server is needed for interactive computing. Same for the latest versions of Python and Anaconda. TensorFlow framework and Keras API are employed for the development of the deep learning model. Tensor Board serves as the visualization tool to monitor histograms of weights, biases, or other tensors as they change over hyperparameter tuning. The CUDA toolkit and cuDNN library are utilized to harness GPUs' acceleration and scale up to multiple GPUs. OpenMPI is required to enable a single-node multi-GPU application to scale across multiple nodes. NetCDF4 and HDF5 libraries are needed for parallel I/O, while the latest git version is also essential. For image visualization, the EBImage (toolbox for R) will be used. The R packages/libraries that are employed include: keras, tfdatasets, tidyverse, rsample, reticulate, caret, tfruns, tfestimators, and stringr. Overall, our methodology is based on instance segmentation and the Mask R-CNN model. The proposed end-to-end deep learning framework enables the fully automated annotation and analysis of EVs in TEM images.

Acknowledgements

This paper is co-funded by European Union's Horizon 2020 research and innovation programme under grant agreement No 101112347, project NerveRepack (Intelligent neural system for bidirectional connection with exoprostheses and exoskeletons) and supported by the CHIPS Joint Undertaking and its members. We acknowledge PRACE for awarding access to the Fenix Infrastructure resources at CINECA and Jülich hosting sites, which are partially funded from the European Union's Horizon 2020 research and innovation programme through the ICEI project under the grant agreement No. 800858.

IMMERSION OF 3D NON-CONDUCTIVE VS. CONDUCTIVE BIOMEDICAL SCAFFOLDS IN CELL CULTURE MEDIUM: FLUID ABSORPTION AND BIODEGRADATION

S. Mamali[1], G. Strnad[2], G.C. Papanicolaou[1], D.V. Portan[1]

[1]*Department of Mechanical Engineering and Aeronautics, University of Patras, Patras University Campus, 26504 Patras, Greece*

[2]*Faculty of Engineering and Information Technology, George Emil Palade University of Medicine, Pharmacy, Science, and Technology of Targu Mures, 540142 Targu Mures, Romania*

ABSTRACT

Biomimetic scaffolds offer cells a broad spectrum of biochemical and biophysical cues that mimic the *in vivo* extracellular matrix. Such materials have mechanical adaptability, microstructure interconnectivity, and inherent bioactivity, making them ideal for tissue engineering and regenerative medicine [1]. Multi-functionalization of the scaffolds refers to conferring them multiple purposes that will eventually enable a higher rate bio integration. Polylactic acid (PLA) has been used in fused deposition method (FDM) based 3D printing for many years [2]. Due to its biocompatibility and good mechanical properties comparing to other thermoplastics [3] it became the most popular thermoplastic for biomedical use. PLA can be manufactured and functionalized with several technologies.

The present investigation focused on the manufacturing of 3D printed biomimetic scaffolds for bone tissue engineering, followed by the observation of their weight loss after long and short-term immersion in solution. Two types of 3D printed scaffolds were prepared: *(i)* Non-conductive PLA scaffolds with 250 or 500 μm side-length of their square shaped pores (Fig.1a) and *(ii)* Conductive, carbon nanoparticles reinforced PLA scaffolds with 500 μm side-length of their square shaped pores (Fig.1b).

FIGURE 1 3D printed scaffolds made of (a) PLA, 500 μm square shaped pores and (b) PLA reinforced carbon nanoparticles, 500 μm square shaped pores

For the first experiment, scaffolds were immersed in fluid for 7 days and for the second experiment, for 24 hrs. The immersion solution was the cell culture medium that is normally used to maintain

stem cells, which contains mainly salts, proteins and antibiotics. A static and a dynamic experiment were performed; the setup partially mimicked the body-like environment. More precisely, for both experiments a hot plate magnetic stirrer has been used to heat the solution at 37^0 C, while for the dynamic one, samples were stirred with 500 rpm. For the 24 hrs. experiment, the weight loss of three extracted samples has been evaluated every 3 hrs.

The fluid absorption in the scaffolds was observed after 3 days of sample immersion. The second experiment was set up for 24 hrs. of immersion with the purpose to evaluate scaffolds potential as drug delivery carriers. On the other hand, since the absorption process is initiated in parallel with the degradation one and a competitive situation is developed, the two events were observed in parallel. An interplay of these two competitive processes which affect scaffolds' structure has been detected: *(i)* gain of weight with absorption of protein and *(ii)* loss of weight with degradation (Fig.2).

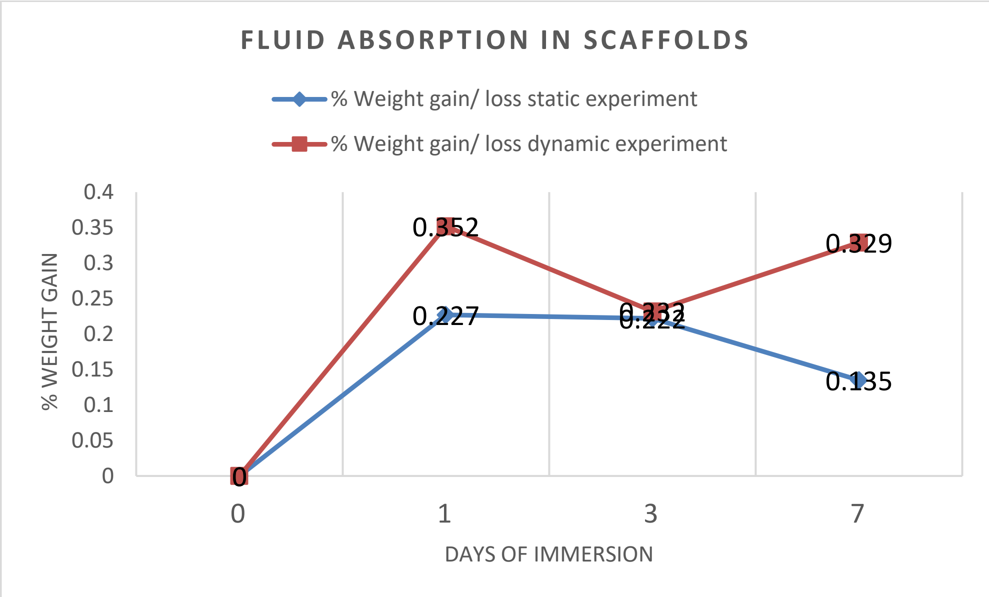

FIGURE 2 Absorption rate of fluid in the manufactured scaffolds after 1, 3 and 7 days of immersion

In between the pure PLA scaffolds, those with 250 μm pores were found more efficient than the 500 μm ones with respect to the fluid absorption, indicating that the amount of fiber is more important in this process than how large the pores are. Several thresholds were found were the interchange between absorption and degradation can be detected, for each type of scaffolds. One pronounced threshold has been found between hours 12 and 21 for the PLA non-conductive scaffolds. The conductive scaffolds (carbon nanoparticles reinforced PLA) have proved to be less efficient in fluid absorption; they enter in the degradation state from the very beginning, showing a fragile mechanical nature.

Overall, the absorption rate of fluid in the fibers vs. the biodegradation rate varies depending on the nature of the thermoplastic, as well as on the micro-environment. Further observation of these phenomena will solve different issues related to scaffold degradation in a body-like environment.

Acknowledgements

This paper is co-funded by European Union's Horizon 2020 research and innovation programme under grant agreement No 101112347, project NerveRepack (Intelligent neural system for bidirectional connection with exoprostheses and exoskeletons) and supported by the CHIPS Joint Undertaking and its members.

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Λ-FRACTIONAL DERIVATIVE AND ELASTICITY: THEORY AND APPLICATIONS

A.K. Lazopoulos

Mathematical Sciences Department, Hellenic Army Academy, Vari, Greece 16673

ABSTRACT

Λ-fractional derivative is defined and analyzed. It occurs that this fractional derivative satisfies all the prerequisites of differential topology for been a proper derivative in contrast to other fractional "derivatives" which are, in essence, operators. Therefore, the Λ-fractional derivative generates Differential geometry necessary for discussing applications. Therefore, it may be used in describing problems in physics, mechanics, etc. On the other hand, experiments in micromechanics and nano mechanics have shown that classical elasticity does not conform to those scales. In fact, Noll's axiom of local action is not valid anymore. A new approach is needed so that it may express the non-locality of these phenomena successfully. Therefore, Λ-fractional derivative, which is non-local by nature, is introduced and proposed to express successfully non- local phenomena in elasticity. Thus, outline of the Λ-fractional analysis will be presented. The initial space, along with the Λ-fractional space will be described. Further, the interrelation of those spaces will be described. Λ-fractional elasticity is presented and applications concerning the tension of a bar, plane stress, bending of a beam and others will be presented.

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ABSTRACTS: Session 9A

Wednesday 13 Sep. 2023	**SESSION 9A** Plenary Lectures **Smart Structural Composites**
Session 9A Co-Chairmen:	**John Botsis,** Professor Emeritus, Institute of Mechanical Engineering, School of Engineering, Ecole Polytechnique Federale de Lausanne, EPFL, Lausanne, Switzerland **Daniel Wagner,** Professor, Department of Molecular Chemistry and Materials Science, Weizmann Institute of Science, Rehovot, Israel.

SELF-HEALING OF FIBROUS COMPOSITES: ADVANCEMENTS IN STRUCTURAL MATERIALS

V. Kostopoulos[1,2*] and A. Kotrotsos[1]

[1] Department of Mechanical Engineering and Aeronautics, University of Patras, GR-26504 Patras, Greece; E-mail: kostopoulos@mech.upatras.gr; Tel.: +30-2610-969441

[2] Foundation of Research and Technology, Institute of Chemical Engineering Sciences (FORTH/ICE-HT), Stadiou Str., GR-26504 Patras, Greece

ABSTRACT

During the last few decades, Fiber-reinforced composites (FRPs) have been gradually replacing metals due to their high specific stiffness, strength, and resistance to fatigue and corrosion. However, these composites often experience matrix cracking and delamination between the layers due to their laminated structure.

A significant drawback of these composites is their poor interlaminar fracture toughness and strength. The mismatch in mechanical and thermal properties between the plies in different directions leads to out-of-plane stresses at the edges and in areas such as stringer run out, thickness variation, holes, and structural stiffeners joined to the composite skin, making them susceptible to delamination under in-plane and out-of-plane loads. Delamination is a common failure mode in laminated composites [1], resulting from fatigue loading or low-velocity impact events. Conventional repair techniques for composites are expensive, labour-intensive, and unable to address defects deep within the material.

Self-healing (SH) polymers [2] offer a potential solution to these challenges. This smart technology aims to repair matrix cracks and matrix/reinforcement debonding in-situ, extending the effective lifespan of composites, reducing maintenance requirements and costs, and improving the damage tolerance and reliability of composite structures. SH composites have previously been developed by embedding self-healing agents (SHA) into the matrix using microcapsules or vascular networks [3], which release the SHA upon crack damage. Another approach to self-healing composites involves matrices comprising reversible polymers [4], allowing multiple healing cycles at the same damaged site. Recently, researchers have focused on incorporating self-healing capabilities through the electrospinning process (EP) technique [5]. The main strategy behind this concept is to incorporate core-shell nanofibers filled with SHA, which react with an excess catalyst present in the matrix upon fracture [6]. Other investigations utilize bulk intrinsic electro spun fibers as the SHA within the composite matrix [7].

One of the most promising intrinsic systems for self-healing purposes is the Diels-Alder (DA) reaction mechanism, which exhibits resin-like behaviour at ambient conditions and thermoplastic behaviour at elevated temperatures [8]. In this study, novel self-healing concepts for laminated composites were developed by incorporating a DA-based mechanism polymer in electro spun form between the primary layers of the composite, specifically in targeted areas. The chosen SHA system was integrated into the composite architecture using two methods: solution electrospinning process

(SEP) and melt electro-writing process (MEP). After fabricating the composites, the samples were subjected to experimental and numerical investigations. The mechanical properties, healing capability, and healing mechanisms of these healable composites were examined through Mode I and Mode II interlaminar fracture toughness tests (quasi-static and fatigue), open hole tensile tests (quasi-static and fatigue), low-velocity impact tests, and compression after impact tests. Based on the obtained results, this novel approach can be considered a viable solution for the development of self-healing composites.

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ARE THERMOPLASTIC COMPOSITES THE FUTURE?

D. van Hemelrijck, J. Karami, R.H. Abadi, A.S. Kojouri, A. Katalagarianakis, Y. Zhu, A.S. Charkieh, L. Pyl, K.-A. Kalteremidou

Mechanics of Materials and Constructions, Vrije Universiteit Brussel, Belgium

ABSTRACT

For decades, thermoset carbon-fiber reinforced composites were the preferred material system for making structural parts for aircrafts. Wings, fuselages, and bulkheads are some indicative applications in aerospace. As composite materials are lightweight and strong, they are also widely employed in the automotive industry and in transportation for internal components of cars, buses, and trains as well as for the outer parts. Strength and durability are the main drivers for the use of thermoset composites also in infrastructure applications such as in buildings, bridges, and roads. In global is it expected that the composite market will have an expanding growth at a noteworthy Compound Annual Growth Rate (CAGR) of 6.1% from 2023 to 2032. In 2022, thermoset composite matrices like polyesters, vinyl esters, epoxies, bismaleimides, cyanate esters, polyimides and phenolics led the market with over 70% revenue share.

Although thermoplastic composite materials have been around for a long time, only recently manufacturers have begun to consider the use of thermoplastic based solutions for making primary structural components. Clearly, thermoplastic composites are earning a growing share of structural applications due to their many benefits. Their most notable advantage compared to thermoset materials is that the last ones have a limited self-life at room temperature and should be stored under cold conditions before being shaped. Once shaped, a thermoset part must undergo a curing process which requires a great deal of energy and time, consequently resulting in a high production cost. On the contrary, thermoplastic composites are characterized by certain advantages related to their processing methods and recycling properties. In an attempt to provide an answer to the question: “are thermoplastic composites the future?” other key advantages and remaining challenges will be critically analyzed in this study.

STRUCTURAL COMPOSITES ENABLED FOR THERMOELECTRICAL ENERGY HARVESTING: A ROUTE TO AUTONOMOUS FUNCTIONALITIES

Alkiviadis S. Paipetis

45500, Ioannina, Greece

Composite and Smart Materials Laboratory, Department of Materials Science and Engineering, University of Ioannina, Greece, E-mail: paipetis@uoi.gr

ABSTRACT

Lightweight advanced structural composites such as fiber reinforced polymers (FRPs) offer high specific strength, superior fatigue behavior and tailorable mechanical properties, thus making them attractive in specific industries such as aerospace. However, the aspect of CO_2 emissions reduction and a more sustainable life cycle cost analysis are key objectives leading to a positive environmental impact. Very recently it has been clearly established that composites suffer from the sustainability point of view, with this being their Achilles heel in their extensive use. This has been quantitively point out by experts in the field who analyze that composites are only marginally sustainable in high end applications such as in the Aerospace where leading manufacturers revert to aluminum and (very) large scale Wind turbine structures only if the relative stiffness to weight ratio is considered. A solid route towards sustainability is multifunctionality and particularly energy harvesting.

Smart or multifunctional materials and structures are defined as those that apart from fulfilling their primary load-bearing purpose, they simultaneously offer additional functionalities. FRP composites can be engineered at the nanoscale to achieve significant multifunctional macroscopic properties through versatile design approaches with enhanced specific mechanical, thermal and electrical properties.

Taking the above into consideration, two functionalities were architecturally integrated in composite structures, namely that of a thermoelectric generator (TEG) and of structural health monitoring (SHM). A composite, endowed with TE functionality, can directly produce an electric voltage when exposed to a temperature difference, via the Seebeck effect. Then, the produced energy may be utilized to power various types of sensors (e.g., SHM sensors), to establish self-powered autonomous SHM. Heat sources that create temperature differences are easily accessible and free even in the most remote places. Various designs for Thermoelectric Energy Generators (TEGs) devices exist to convert waste heat to useable electric power. which are commonly encountered in vehicles, aircrafts, and large-area power plants. To this end, a printed in-plane TEG was integrated within an CFRP part able to achieve adequate TE power and demonstrate the thermal energy-harvesting capabilities of advanced structural composites, with respect to scale-up and application pathways.

PROGRAMMABLE RESPONSIVE SMART SURFACES THROUGH ANISOTROPIC MULTILAYER MATERIALS†

N. Athanasopoulos[1], G.M. Chatziathanasiou[1,2], F. Paloukis[1]

[1]*Institute of Chemical Engineering Sciences (ICE/HT), Foundation of Research and Technology (FORTH) Stadiou Str, Platani Rion, Patras, GR- 26504, Greece, E-mail: n.athanasopoulos@iceht.forth.gr, nikos_athanasopoulos@protonmail.com*

[2]*University of Patras, Department of Mechanical Engineering & Aeronautics, Patras, 26500, Greece*

ABSTRACT

Stimuli responsive materials have attracted the interest of scientific community due to their unique capability to transform their shape according to our demands and implement various functionalities simultaneously. Anisotropic monolayer and multilayer materials, heterogeneous or homogeneous can be fabricated with the purpose to change the shape as a function of temperature, humidity or other stimuli.

In this study, we have developed hybrid, multilayer anisotropic materials that can be programmed to change their shape as a function of temperature. We design smart arrayed surfaces that consists of multiple unit-cells that change their shape, combining highly oriented polyethylene & metallic networks. The actuation is feasible using Joule-heating effect. Each unit-cell can be re-programmed to another initial shape different from the original, according to our demands. The material remains functional, following different initial and final shapes.

The programming and re-programming of the material is achievable because of the anisotropic behavior of the highly oriented PE, as well as the crystallinity ratio of the material. Both properties can be controlled during the fabrication or in-situ using low amounts of electrical power. Therefore, temperature responsive materials can be realized through low-cost multilayers, and be controlled externally by the user.

These smart surfaces could find application in various sectors, from soft robotics to thermal control.

Acknowledgements

This research is funded and implemented through the "H.F.R.I. Research Projects to Support Post-Doctoral Researchers, Greece", under the name INTEGRAL with project ID: 7401 and Reference Number 49597 - 24/05/2022.

ABSTRACTS: Session 10A

Wednesday 13 Sep. 2023	**SESSION 10A** Plenary Lectures **Biomimetics**
Session 10A Co-Chairmen:	**Costas Soutis,** Professor Emeritus of Aerospace and Materials Engineering, PhD (Cantab), FREng, Co-Founder and Director at Manchester Robotics Ltd, University of Manchester, U.K **Diana Portan,** Dept. of Mechanical Engineering. And Aeronautics, Section of Biomechanics, Univ.of Patras, Greece.

DURABLE COMPOSITES INSPIRED BY NATURE

C.M. Silva[1], V. Alves[1], A.T. Marques[1,2*], A. Arteiro[1,2], P. Nóvoa[1]

[1]*FEUP - Faculty of Engineering of the University of Porto – R. Dr. Roberto Frias, s/n 4200-465 Porto, Portugal*

[2]*LAETA/INEGI – Associated Laboratory for Energy, Transports and Aerospace/Institute of Science and Innovation in Mechanical and Industrial Engineering, Portugal*

* *Corresponding author: marques@fe.up.pt; ORCID: https://orcid.org/0000-0001-9388-2724*

ABSTRACT

Although there are Fiber Reinforced Composite - FRP structures in use for more than 50 years, their performance can be affected by several factors: loading conditions; environmental parameters (corrosion, temperature etc.); fire. Particularly, the mechanical properties are influenced by time, temperature and environment, being durability (long-term properties, life prediction accelerated testing) an issue of practical and crucial interest. The continuous use of composite systems, especially in structural applications, require high reliability for long durations causing some concerns regarding the stiffness and strength of the material through time. There are several standards and theories related to this issue, being the two approaches much different.

Nature gives several solutions, from which we can learn and try to apply to composite systems. Biomimicry is an industrial product philosophy that plays an important role in complex human and does that by using inspiration found in nature and can be achieved at three different levels, where the first one is considered to be the most common approach [1]:

1. Imitating the form or function of nature
2. Imitating natural processes
3. Imitating natural systems

The purpose of this paper is to analyze the durability issues of polymeric matrix composite structures, including accelerated and pragmatic life predictions approaches [2, 3]. and to suggest for more reliable life performance, Moreover, it will present some solutions applicable to composite systems, particularly when more flexible advanced processes are used, in order to enhance durability.

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BIOMIMETIC BIOMATERIALS: FUNCTIONING PRINCIPLES, KEY PROPERTIES AND PERSPECTIVES

Diana V. Portan

Department of Mechanical Engineering and Aeronautics, Laboratory of Biomechanics and Biomedical Engineering, University of Patras, 265 04 Patras, Greece

ABSTRACT

By delivering biomimetic biomaterials it is expected to considerably accelerate implant biointegration, as a result of an increased biorecognition. Biomimetic biomaterials match the natural properties of the tissue and provide multi-functionality, which in turn reduces the gap between the natural material and the synthetic product, thus promoting an optimum ‘symbioses’ between them. Functioning principles of biomimetic materials refer to their overall properties and performance, but can be classified in some main categories: *(a)* Chemical compatibility through bioactivity; *(b)* Structural and mechanical performance similar to the natural tissue to be replaced; *(c)* Texture that will allow the transport of bioactive principles or an incorporated drug-delivery system and *(d)* Gradient properties or surface functionalization to assure smooth interphases variation of properties from tissue to biomaterial and vice versa. In each of these categories, the key properties are dependent on the replaced tissue. For instance, replacing bone tissue requires a material with appropriate compression modulus - the focus is on the mechanical performance. Synthetic skin also requires appropriate mechanical adjustment, but the key property is the elasticity modulus. Biomaterials for synthetic vessels demand appropriate surface to eliminate the risk of thrombosis. Further on, the biomaterials that replace damaged brain parts must be accordingly built to perform in a humid environment of electrolytes. Generally, body microenvironment consist in: *(1)* humidity due to the existence of the body fluids, which influence the radical processes taking place in a biomaterial, changing pathways and reaction kinetics [1], *(2)* a physiological condition with comparable ranges of load or pressure, viscosity and sliding speed produces friction and complex tribological phenomena, depending on the tissue location, [2], *(3)* low intensity electricity generated by the human body through biological electric field and current electrical potentials ranging between 10 and 60 mV at various locations [3], *(4)* vibrations produced by cyclic loading of the tissues that have elastic properties [4], and *(5)* complex mechanical loading especially in the case of the musculoskeletal system.

To function in such a complex environment, biomimetic biomaterials must be personalized with respect to the implant type and situs. They are usually produced by bottom-up techniques encompassing the desired properties and functions. An accurate design of what is targeted and good multidisciplinary knowledge combining biology, medicine, materials science, and engineering are demanded. There are several challenges, for example in the case of natural derma, which is an extremely complex tissue. A representative scheme may be seen in Fig.1. The natural skin is made of five up to seven layers that could be synthetically reproduced through a multi-layered composite material. Each layer has a different structure, biochemistry, and function. Its most well-known functions are the self-healing, the thermoregulation and the protection. While the self-healing has

been already copied and applied in polymers engineering and the protection mechanism has also been applied in synthetic systems, the thermoregulation process is much too complicated to be reproduced in the lab. This is not the only limitation; in the process of construction of a biomimetic synthetic tissue that could mimic the natural derma, the most challenging issue is related to how to join the many layers together without introducing discontinuities between them [5]. The perspectives in this direction are associated to spraying technologies of biocompatible adhesive that could ensure appropriate adhesion and almost zero thickness of the interphase. However, it must be also considered that the multi-layered composite has to perform in a humid, salty environment at 37^0 C.

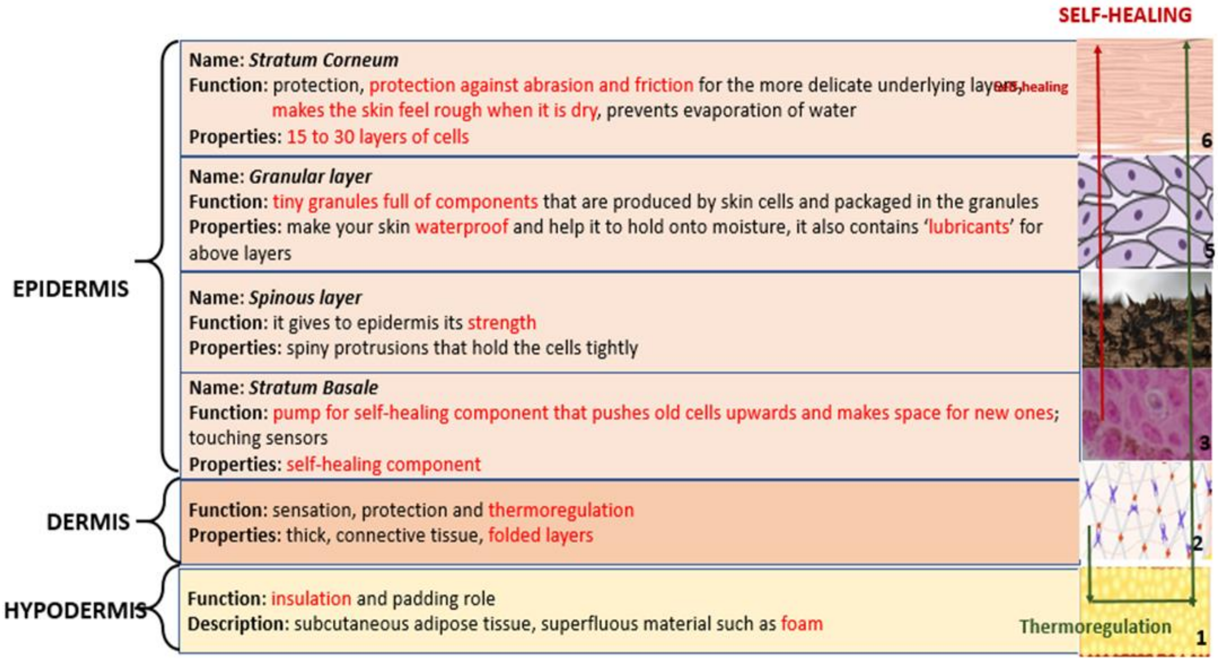

FIGURE 1 Schematic representation of the composition of the natural derma

Finally, some main steps are proposed for an effective process of design, manufacturing and testing of a biomimetic biomaterial: *(1)* Selection of the application; *(2)* Market investigation; (3) Scientific investigation – selection of advanced technologies and materials; *(4)* Preliminary theoretical and experimental studies to select the materials and technologies with higher perspectives; *(5)* Preparation of experimental protocols; *(6)* Preparation of experimental setup; *(7)* Running experimental cycle and *(8)* Final evaluation and assessment. Comparing to the elaboration process of classic biomaterials, the one related to biomimetic materials presents multiple challenges, new solutions, a highly multidisciplinary approach, and unpredicted risks.

Acknowledgements

This paper is co-funded by European Union's Horizon 2020 research and innovation programme under grant agreement No 101112347, project NerveRepack (Intelligent neural system for bidirectional connection with exoprostheses and exoskeletons) and supported by the CHIPS Joint Undertaking and its members.

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BIOMIMETIC PRINCIPLES OF PROGRAMMABLE SHAPE CHANGE MATERIALS AND THERMAL MANAGEMENT

Nikolaos Athanasopoulos

1Institute of Chemical Engineering Sciences (ICE/HT), Foundation of Research and Technology (FORTH), Stadiou Str, Platani Rion, Patras, GR- 26504, Greece, E-mail: n.athanasopoulos@iceht.forth.gr, nikos_athanasopoulos@protonmail.com

ABSTRACT

Extremely complex movements can be performed through the materials' self-shaping & self-folding capabilities in response to a stimulus. Anisotropic and heterogeneous monolayered or multilayered structures have been observed in Nature, playing a critical role of plants and dead tissues' movements. Moreover, unstable structures and differential mechanistic strategies are used extensively in order to reproduce or survive from extreme light or temperature changes. These mechanistic movements are crucial for survival reasons, and thermoregulation is one of the most critical functions. Leaves/petals perform thermonastic movements (folding caused by a temperature stimulus) and adapt their geometrical characteristics and the exposed material to prevent overheating. While a few ectotherms use simple patterned structures to control the temperature of their body. All the above stimuli responsive materials and structures have been realized using various engineered materials. The shape-change of these responsive materials can be programmed through the control of their structure using combinations of manufacturing methods. Furthermore, in temperature control, the effective thermo-optical properties as a function of temperature, can be controlled and programmed accurately.

Acknowledgements

This research is funded and implemented through the "H.F.R.I. Research Projects to Support Post-Doctoral Researchers, Greece", under the name INTEGRAL with project ID: 7401 and Reference Number 49597 - 24/05/2022.

ABSTRACTS: Session 11A

Wednesday 13 Sep. 2023	**SESSION 11A** Oral Presentations **Design – Manufacturing and Testing**
Session 11A Co-Chairmen:	**Kalliopi Artemi Kalteremidou,** Department of Mechanics of Materials and Constructions (MeMC), Vrije Universiteit Brussel (VUB), Brussels, Belgium. **Olesja Starkova,** Institute for Mechanics of Materials, University of Latvia, Riga, Latvia.

LASER PROCESSING OF MATERIALS AND FUNCTIONALITIES

D. Alexandropoulos[1], S. Mazuccato[2] and G. C. Papanicolaou[3]

[1]*Department of Materials Science, University of Patras, Patras 26504, Greece*

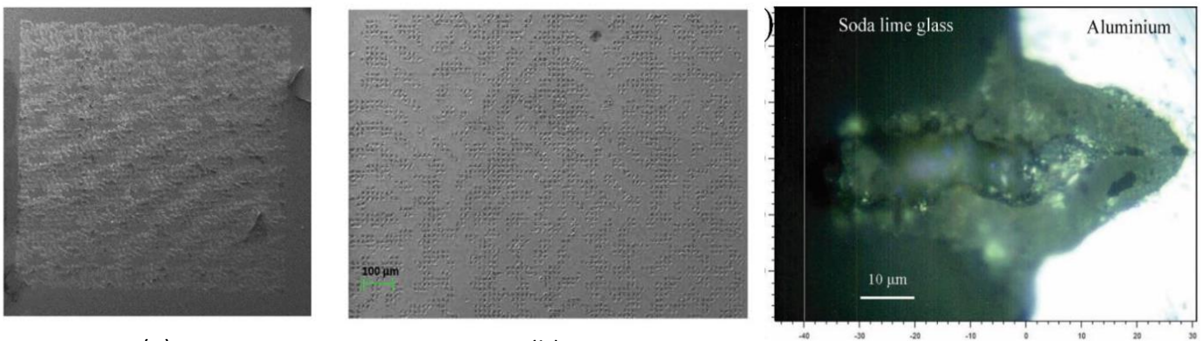
[2]*SISMA S.p.A.,via dell'Industria, 1 - 36013 Piovene Rocchette VI, Italy*

[3]*Department of Mechanical Engineering and Aeronautics, University of Patras, Patras 26504, Greece*

ABSTRACT

Laser processing is mostly identified with machining of materials, that is cutting, drilling and sanding [1]. Certainly, the potential of lasers far exceeds mainstream machining and opens new ambitious prospects for diverse yet practical functionalities that include (but not restricted to) laser joining of dissimilar material [2], fabrication of physical unclonable functions [3] for security and traceability applications and engraving of holographic optical structures [4]. Indicative results for these are shown in Fig 1.

The aforementioned application scenarios can be realized with ultrashort pulsed lasers (picosecond and femtosecond) as well as nanosecond lasers. Fs pulsed lasers offer precise control of the laser matter interaction with minimal heat affected zone (HAZ). However, the emphatic disadvantage of using fs pulses for laser processing of materials is that these lasers are not suitable for upscaled industrial production due to long term stability issues and maintenance. From the viewpoint of industrial compatibility, the prospects are better for PS lasers, as these are already used in industrial environments, but on the downside, they are expensive. On the other hand, the industrial production line is the natural environment of ns lasers. Additionally, ns laser sources are an order of magnitude cheaper than ultrashort pulsed laser sources.



(a) (b) (c)

FIGURE 1 (a) Laser engraving of holographic mask on metal (b) laser engraving of PUF (c) microscopy of cross-sectional area of laser welded glass to aluminum

In this talk we will present recent research activity in the field of laser processing of materials with emphasis on industrial applications.

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NDT OF COMPOSITE COMPONENTS FOR AUTOMOTIVE APPLICATIONS

K.-A. Kalteremidou, L.Pyl, D. Van Hemelrijck

Department of Mechanics of Materials and Constructions, Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussels, Belgium

ABSTRACT

Non-Destructive Testing (NDT) of composite materials has been a topic of great interest for the global scientific community. The final aim of engineers is the Structural Health Monitoring (SHM) of composite components in real applications. Building block approaches are necessary for this target, starting with NDT studies on coupon specimens and moving towards the testing of larger scale components. In this study, NDT of carbon/epoxy sub-components has been undertaken in order to assess the occurring damage mechanisms. V-shape components were initially tested under static and fatigue, tensile and compressive loads to examine the mechanical response of the corner section of a square beam component with a potential usage in a vehicle frame for a suspension mount (Figure 1) [1]. The square beam component was then tested in a progressive manner under static and fatigue compressive loads [2]. Conventional strain gauge measurements were compared in all cases with the more innovative Digital Image Correlation (DIC) and Acoustic Emission (AE) methods, in order to explore the benefits and limitations of all of them. The last two techniques were proven to provide, in all cases, a more sensitive and conservative estimation of the onset of damage. DIC, when applied through the thickness of the V-shape components, could provide specific strain profiles leading to failure, whereas it could indicate the location of the occurring damage when applied to the external surface of the square beam components. AE was proven to provide the exact location of damage as well as the migration of the locus of damage during testing through advanced localization algorithms (Figure 2). All results were compared with the AE findings of tests on coupon specimens to explore the potential of acoustic methods for damage identification and classification in composite structures.

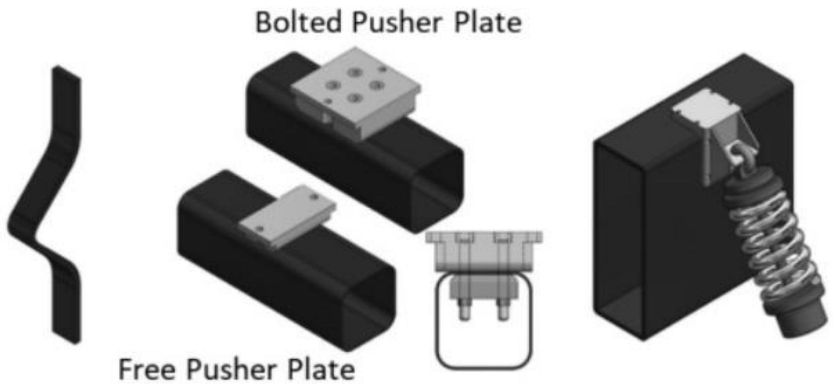

FIGURE 1 Outline of the iterative test nature of the test program [2]

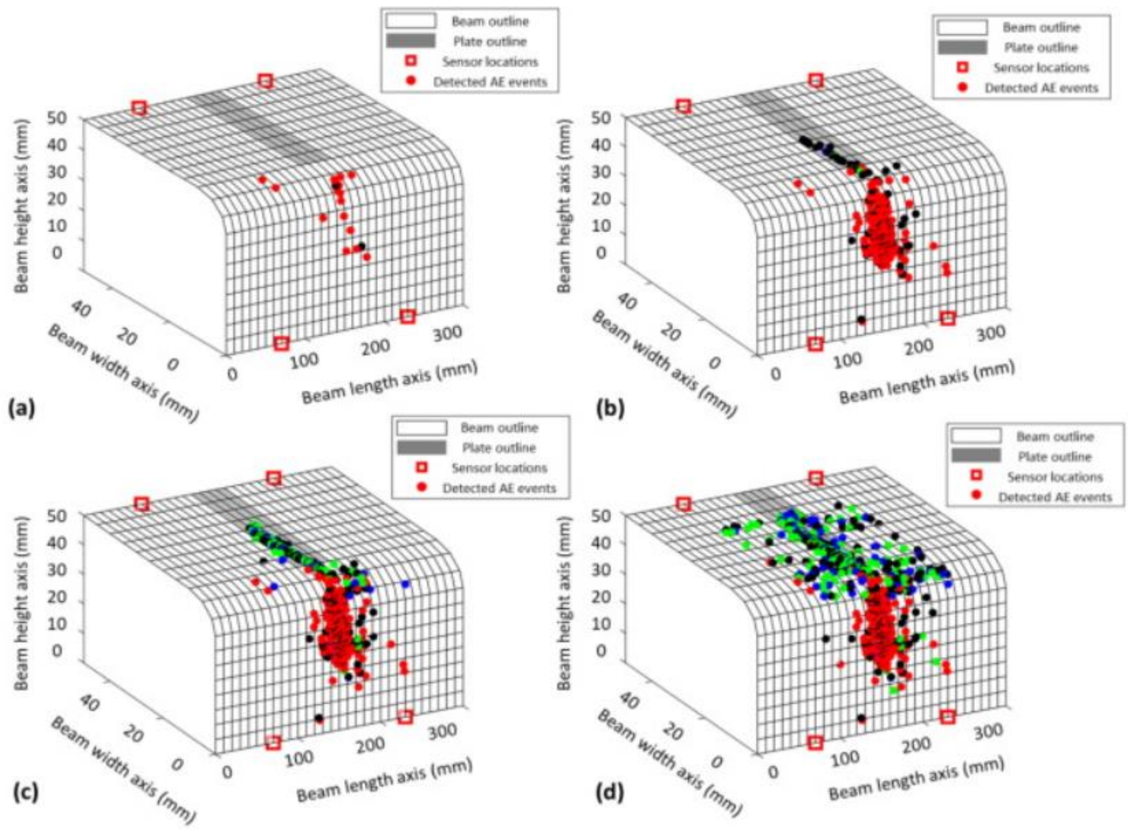

FIGURE 2 AE event location build-up on a beam component for different fatigue cycle steps [2]

Acknowledgements

The work leading to this publication has been partially funded by the SBO project "M3Strength", which fits in the MacroModelMat (M3) research program, coordinated by Siemens (Siemens Digital Industries Software, Belgium) and funded by SIM (Strategic Initiative Materials in Flanders) and VLAIO (Flanders Innovation & Entrepreneurship Agency). The authors gratefully acknowledge the material suppliers Mitsubishi Chemical Corporation and Honda R&D Co., Ltd. and would like to thank the financial support of the Fonds Wetenschappelijk Onderzoek (FWO) research program "Multi-scale modelling and characterization of fatigue damage in unidirectionally reinforced polymer composites under multiaxial and variable-amplitude loading" (G.0090.15).

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PROBABILISTIC AND EXPERIMENTAL INVESTIGATION OF FATIGUE CRACK GROWTH IN ALUMINUM PANELS REPAIRED WITH BONDED SINGLE-SIDED ALUMINUM PATCHES

D. Karagiannis[1], V. Kostopoulos[2], G. Sotiriadis[2]

[1]*The Composite Materials Group, Department of Mechanical and Aeronautics Engineering, University of Patras, Patras, GR-26500, Greece*

[2]*Applied Mechanics & Vibrations Laboratory, Department of Mechanical Engineering and Aeronautics, University of Patras, Greece*

ABSTRACT

Fatigue cracking in fastener holes represents one of the most important problems in the design of airframe structures, such as lower wing skins. Even under well controlled laboratory test conditions, experimental test results for coupon specimens and full-scale articles indicate a significant statistical variability in fatigue crack growth damage accumulation. Therefore, the application of statistical approaches to fatigue crack propagation has received considerable attention [1].

The present study concerns the development of a simple crack growth -based statistical model for fatigue crack propagation in fastener holes under constant amplitude fatigue loading. The methodology is based on the Equivalent Initial Flaw Size (EIFS) concept and includes plain as well as adhesively repaired fastener hole coupons. The statistical distributions of both the crack size at any time instant and the crack propagation life to reach any specific crack size are derived analytically. Two cases have been considered: straight-bore clearance-fit fastener holes in 2024-T3 aluminum and adhesively repaired coupons of the former configuration.

The equivalent initial flaw size (EIFS) concept was developed in the ‘80s in an attempt to determine the initial crack size for fracture mechanics-based life prediction. The EIFS accounts for the initial quality, both from manufacturing and bulk material properties of structural details. The calculation of EIFS is usually performed using a back-extrapolation method. This approach uses fatigue crack growth analysis with an assumed initial crack geometry and size to match the material failure data in different aeronautic applications [2]. In practice, the EIFS Distribution (EIFSD) is used to predict a distribution of crack growth lives for a given structure and loading conditions similar to that from which the EIFS distribution was derived. Most commonly, a probabilistic approach, is coupled with EIFS to assess structural integrity [3].

The EIFSD is derived from fractographic data in the small crack size region (e.g 0.254mm to 1.27mm) and “data pooling” and statistical scaling techniques. Once appropriate EIFSD is established the determination of a suitable service crack growth master curve follows. The two-segment deterministic - stochastic crack growth approach (DCGA-SCGA) [4] will be used in the current study to predict the probability of crack exceedance $p(i, \tau)$, at a given service time, and/or the cumulative distribution of service time to reach a specific crack size x_1. The concept of the two-

segment deterministic - stochastic crack growth approach (DCGA-SCGA) is schematically shown in FIGURE 5. In the small crack region where crack size $a(t) < a_0$, we consider a Deterministic Crack Growth Approach (DCGA) in which the Crack growth parameters are treated as deterministic values resulting in a single value prediction for crack length/size. For cracks larger than α_0 i.e. $(a(t) > a_0)$, a Stochastic Crack Growth Approach (SCGA) is considered which accounts for the crack growth rate dispersion in the durability analysis.

For the experimental investigations flat aluminium 2024-T3 specimens have been prepared with thickness of 1.6mm. The plate dimensions were (LxW) 240x80mm and a 5mm diameter hole as drilled in the middle of the middle of the coupon using conventional machine tools. For the repaired specimens, the same aluminium grade was used as doubler patch, with 1.2mm thickness. The patch dimensions were (LxW) 60x80mm and was centrally bonded using FM-73M adhesive. The crack length was measured optically and the fractographic data was used to determine the crack growth rate parameters Q_1 and Q_2, which depend on the load spectrum.

The specimens were subjected to tension-tension loading at a frequency of 10 Hz, with R=0.1, where R is the ratio between the minimum and maximum load exerted by the machine. Various stress levels were applied and FIGURE 6 depicts the crack growth curves for S_{max} 75Mpa. It should be noted that crack lengths are reported as a single value corresponding to the sum of the crack lengths developed on each side of the hole perpendicular to the loading axis.

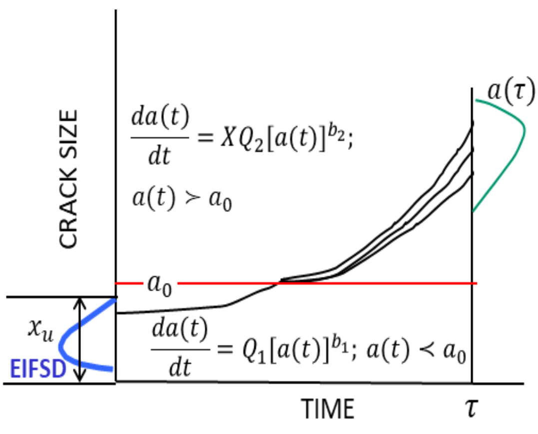

FIGURE 5 Two segment deterministic stochastic crack growth approach.

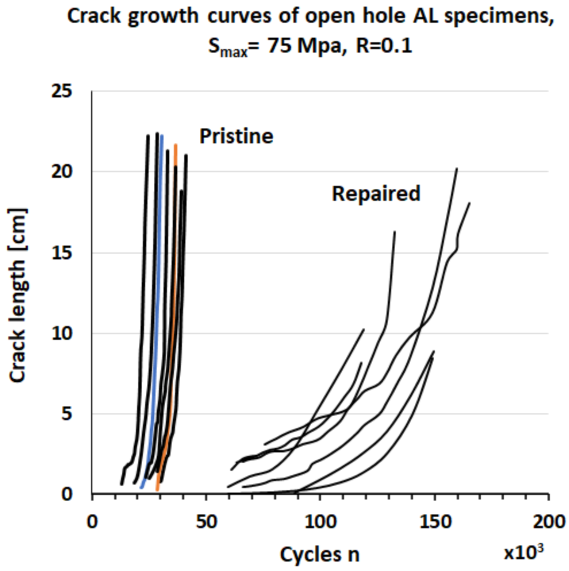

FIGURE 6 Tension - tension fatigue of open hole AL specimens, with and without repair, S_{max}= 75 Mpa, R=0.1.

Following the developed analysis, it is possible to estimate the "extend of damage" defined as the number of structural details i.e. straight bore holes, expected to develop cracks that exceed a specified crack size limit at a given service time. TABLE 1, gives an example of the estimation of the extent of damage for the repaired specimens and the comparison with experimental findings.

TABLE 1 Extend of damage estimated for 10^5 loading cycles and 1.5mm and 3.5mm crack lengths for repaired AL specimens

			Computed		Test Results	Computed		Test Results
Stress Region	Max Stress [Mpa]	N. of details in region	Probability of containing a crack >= 1.5mm at 100.000 cycles	Average no. of details containing a crack >= 1.5mm at 100.000 cycles	Experimental results of details containing a crack >= 1.5mm at 100.000 cycles	Probability of containing a crack >= 3.5mm at 100.000 cycles	Average no. of details containing a crack >= 3.5mm at 100.000 cycles	Experimental results of details containing a crack >= 3.5mm at 100.000 cycles
1	90	7	1,22E-10	8,54E-10	0	1,27E-10	8,86E-10	0
2	100	7	1,22E-10	8,54E-10	1	1,22E-10	8,86E-10	0
3	125	7	0,421	2,947	5	4,00E-02	0,28	2
4	150	7	1	7	7	1	7	7
5	200	7	1	7	7	1	7	7
			SUM:	**16,9**	**20,0**		**14,3**	**16,0**

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FABRICATION AND CHARACTERIZATION OF ELECTROSPUN SWCNTs DOPED THERMOPLASTIC POLYURETHANE STRUCTURES INTENDED TO STRAIN-SENSING APPLICATIONS

A. Kotrotsos[1], N. Syrmpopoulos[1], A. Lemonias[1], V. Kostopoulos[1,2,*]

[1] *Department of Mechanical Engineering and Aeronautics, University of Patras, GR-26504 Patras, Greece*

[2] *Foundation of Research and Technology, Institute of Chemical Engineering Sciences (FORTH/ICE-HT), Stadiou Str., GR-26504 Patras, Greece*

***** *Correspondence: kostopoulos@mech.upatras.gr; Tel.: +30-2610-969441*

ABSTRACT

Responsive materials are a class of smart materials that exhibit controllable properties when subjected to an external stimulus [1]. The stimuli can vary, including temperature, pressure, moisture, electric fields, chemical compounds, and light [2]. When the response property of the material can be accessed by electronics, the material structure can function as a sensor [3]. For instance, when the response property is force or length, the material structure can act as an artificial muscle [4]. Sensors typically require a large specific area, which can be achieved by reducing their dimensions. Additionally, sensors need to be assembled into a measuring instrument to form a stable continuous circuit, enabling current flow.

Based on these requirements, the electrospinning process (either solution electrospinning (SEP) or melt-electro-writing process (MEP)) is the most effective and suitable technique for preparing one- or two-dimensional material structures. Electrospun nanofibers are lightweight, continuous, possess a large specific surface area, and can be easily nano modified to enhance electrical conductivity [5].

In this study, highly sensitive and flexible strain sensors based on thermoplastic polyurethane (TPU) doped with single-walled carbon nanotubes (SWCNTs) were fabricated using SEP and MEP techniques, respectively. Specifically, pure electrospun TPU as well as modified TPU samples containing 0.5 wt% and 1 wt% of SWCNTs were prepared, and the doped samples were utilized for strain sensing applications. After fabrication, optical analysis was conducted to determine the fiber size and arrangement of the sensors. Scanning electron microscopy (SEM) and optical microscopy (OM) images of the samples produced by SEP and MEP techniques showed a significant reduction in fiber diameter due to nanomodification. This behavior can be attributed to the increase in electrical conductivity of the polymer solution and polymer melt. Micro-tensile tests demonstrated that nanomodification enhanced both the Young's modulus and tensile strength in both cases, while the electrical resistance of the nanomodified samples increased with the applied tensile strain during the tests. A direct correlation between strain and resistance increase was observed during loading. Based on these findings, electrospun structures of this type hold great promise for strain sensing applications.

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NUMERICAL FINITE ELEMENT ANALYSIS OF THE CHASSIS OF A ROBOTIC EQUIPMENT FOR HANDLING DRILLING PIPES

M. Ciolcă, T. E. Brănescu, D. Vlăsceanu

Politehnica University of Bucharest, Romania

ABSTRACT

Currently, in the drilling equipment development market, several problems are encountered regarding the optimization of the way of working in practical projects. To ensure an optimized, short-term, and useful process for operators, some of the companies specialized in this field propose a series of fixed equipment, whose purpose is to store the pipes used in the drilling process. The problems encountered in these proposals relate to the fact that there is a limit on the capacity of storing and transporting pipes, so if it is necessary to increase the pipes quantity, it will be done manually by the operators. This can affect the operator's health because the drilling process requires heavy drilling pipes [1].

The proposed solution consists of the implementation of a mobile system for drill pipes storage, capable of moving to different places, independent of the drilling machine and which also contains a robotic system necessary to handle the pipes (Fig. 1).

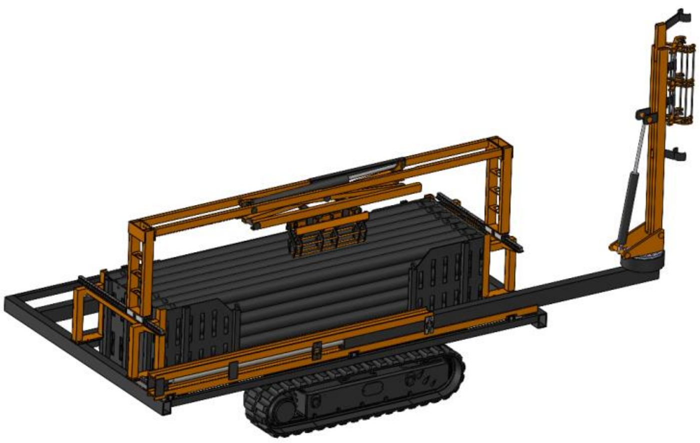

FIGURE 1 Proposed equipment for handling drill pipes.

This system can move the drill pipes from one location to another and with the help of a robotic arm can manipulate them to be retrieved from the storage area and then positioned in the drill head of the well. From a mechanical point of view, the assembly consists of a series of systems: the chassis, the support for the drill pipes, the rolling bridge that lifts one pipe from the support and brings it above the robotic arm, the robotic arm, sequentially connected to the rolling bridge so that it receives the pipe and then slides and positions it in the drill head.

Such a system requires complex finite element numerical analyzes to determine if the structures that make it up are safe, stable and provide integrity. Starting constructively from the base of the assembly, a very important part of the system is the chassis because the entire system is based on it.

Thus, the paper aims to analyze using finite element method the structure of the chassis to establish if it presents stability and integrity. Using ANSYS Workbench the chassis meshing was made with Patch Conforming Method module, since errors related to the size of the elements may appear on certain crossbars [2]. The elements used are of the tetrahedral type (Fig. 2).

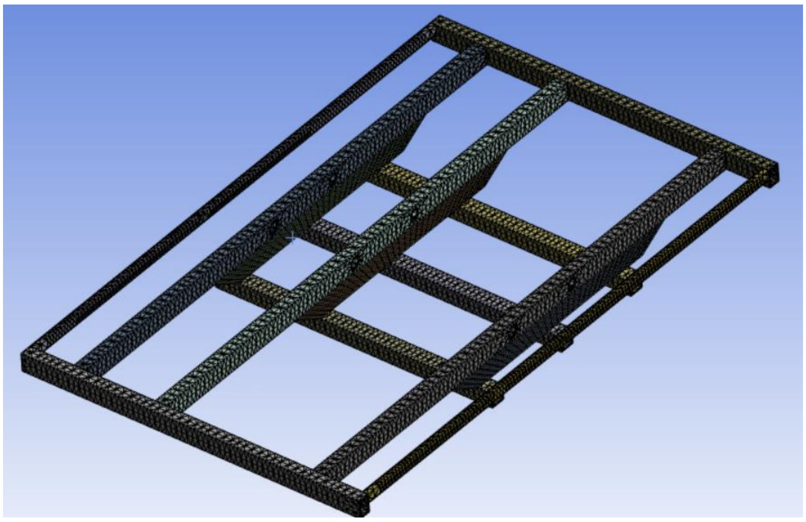

FIGURE 2 Analyzed model meshing with ANSYS Workbench.

The equivalent stress reaches maximum values of 282 MPa in assembly areas between the base crossbars and the tracks and respectively the outer crossbars and the ends of the chassis. (Fig. 3).

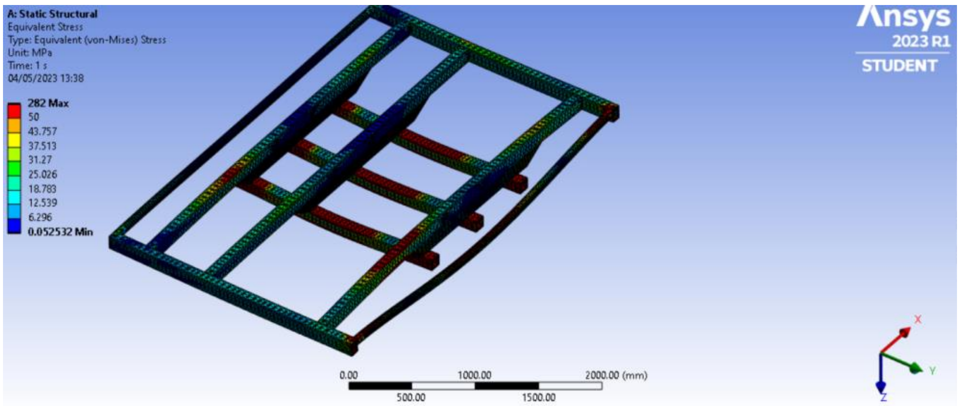

FIGURE 3 Equivalent stress for the analyzed model.

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ABSTRACTS: Session 12A

Wednesday 13 Sep. 2023	**SESSION 12A** Oral Presentations **Interfaces and Interphases**
Session 12A Co-Chairmen:	**Tatjana Glaskova-Kuzmina,** Institute for Mechanics of Materials, University of Latvia, Riga, Latvia **Diana Portan,** Department of Mechanical Engineering and Aeronautics, Laboratory of Biomechanics and Biomedical Engineering, University of Patras, Greece.

INTERLAYER TOUGHENING MECHANISMS IN COMPOSITE MATERIALS: THE ROLE OF NANOFIBERS

A. Evangelou, K. Loizou, M. Georgallas, M. Karouzou, K. Sofocleous, V. Drakonakis

AmaDema (Advanced Materials Design & Manufacturing Ltd), Cyprus

ABSTRACT

Fiber reinforced composites (FRPs) have gained significant prominence in a wide range of applications due to their high specific strength, making them a viable alternative to conventional materials in sports, transportation, and aerospace industries. This study proposes a novel approach to reinforce the interlayer region of FRPs through the thermal consolidation of a polymer nanofiber system on the surfaces of dry technical fabrics, such as carbon glass and aramid. The enhanced functionality of this approach stems from the incorporation of three different scales, mimicking the architecture of natural structures like feathers.

The research presented in this work focuses on evaluating the suitability of polymer-based electrospun nano fabrics as interlayer reinforcements for multilayer FRPs. A scalable and high throughput process is developed to consolidate the nano fabric layers. Various polymer materials, including polyamide 6, polyacrylonitrile, and polyvinylidene fluoride, both plain and doped with multiwall carbon nanotubes, are investigated. The effect of nanotube concentration on the properties of nano fabrics is thoroughly examined. Stress-strain behavior and morphology of the nano fabric systems are analyzed using techniques such as Scanning Electron Microscopy. Additionally, Differential Scanning Calorimetry is employed to investigate the thermal behavior of the nano fabrics, including glass transition temperature, crystallinity, and melting point, with respect to processing parameters at the composite level. Furthermore, the mechanical performance of the nanofabrics is assessed through heat treatment to simulate typical processing parameters encountered during composite manufacturing.

The study aims to unravel the underlying mechanisms responsible for the observed mechanical performance improvements. These mechanisms include enhanced load transfer, improved interfacial bonding, and increased resistance to crack propagation. The incorporation of nanofibers at the interlayer level leads to improved toughness, stiffness, and strength properties of the resulting composites. The findings from this research contribute to the understanding of how nanofiber reinforcement at the interlayer level can significantly enhance the overall mechanical performance of FRPs.

MODELLING THE FIBER-MATRIX INTERPHASE IN POLYMER MATRIX/LONG NATURAL FIBERS UNIDIRECTIONAL COMPOSITES

E. Psarra, G.C. Papanicolaou

Department of Mechanical Engineering and Aeronautics, University of Patras, GR-26500, Patras, Greece, Corresponding Author: Erato Psarra, erato.psarra@gmail.com

ABSTRACT

Natural fiber composites (NFC) have emerged as a potential option for sustainable industrialization, because of their renewable, abundant, and environmentally friendly natural reinforcements. A challenge currently associated with NFCs is the engineering of their interface to prevent macroscopic failures when used in long-term structural applications. To help assessing the load-bearing capacity of polymer-based NFCs, the Hybrid Viscoelastic Interphase Model considers the time-dependent contribution of fibers to polymer matrices. The model is applied to Luffa Cylindrica (LC), a natural fibrous material with a multi-porous architecture of high anisotropy and low density, impregnated with an epoxy resin (ER) system. The results of tensile creep tests on the LC/ER composite material are used to validate the model applied to unidirectional long-fiber composites. To this end, the model provides new insights into the viscoelastic response of this intriguing NFC.

Natural fiber composites (NFC) are increasingly recognized as a compelling solution for promoting sustainable industrial practices. Growing concerns about global warming have intensified interest in NFCs, due to their ability to biodegrade and burn without producing harmful gases or solid residues, while recovering energy. In addition to their environmental benefits, NFCs stand out for their low density and cost, making them a potential alternative in the composites industry. Certain NFCs offer superior technical performance, meeting the structural requirements of diverse applications such as decking, interior panels, railings and automotive components.

A challenge in the deployment of NFCs lies in the effective engineering of their interface to avoid macroscopic failures when used in structural applications [1,2,3]. The fiber/matrix interface plays an active role in determining the mechanical properties of a composite material. It is the mechanism responsible for transferring loads between the fibers and the matrix, thus influencing adhesion, with an impact on the durability of the composite and its resistance to environmental factors [1,2]. Consequently, interface design and optimization are important for the development of high-performance NFCs.

To fill research gaps in durability data for polymer-based NFCs, a hybrid viscoelastic interphase model is proposed. The hybrid interphase can be defined as the zone of material around the fiber, strongly influencing the matrix properties in a non-trivial manner. The interphase has a time-dependent spatial and property response and can initiate failure [1,3,4,5]. Here, the developed model considers the temporal contribution of fibers to polymer composites. The assumptions of a time-dependent adhesion coefficient and modulus provide a better description of the micro-structural phenomena occurring in the interphase regime. Adhesive bonds are stochastically distributed along the longitudinal direction of the fiber, transforming the representative volume element (RVE) into 2D, while representing a more realistic condition of the interphase (Figure 1) formed during the manufacturing process.

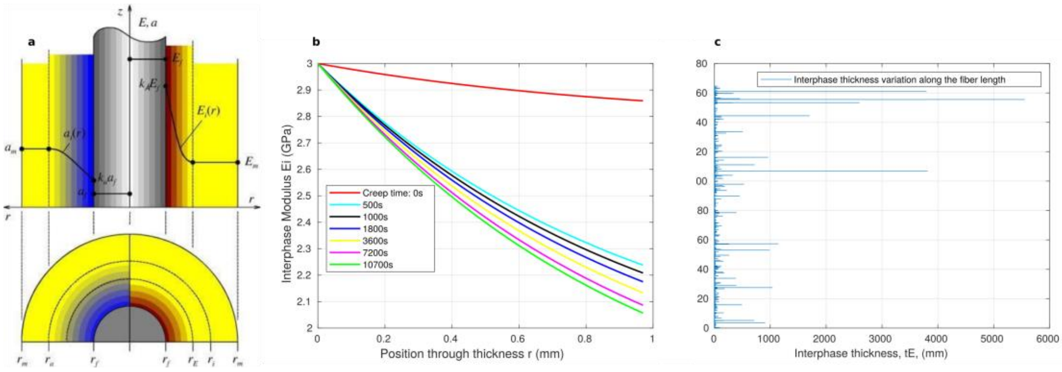

FIGURE 1 (a) Hybrid Viscoelastic Interphase RVE representation; (b) Local elastic modulus as a function of interphasial thickness and creep time; (c) Local thickness of interphase along the fiber's longitudinal direction

To find a first application, a natural fiber reinforcement is selected. Luffa Cylindrica (LC) is the dried fruit of a sponge-like plant belonging to the Cucurbitaceae family. The fruit has a cylindrical shape of continuous fibers linked together in a complex polypore lattice architecture. It comprises an interwoven vascular system of random micro-lattice networks of extremely high porosity (79-93%), with fibers growing longitudinally on the inner surface, circumferentially on the outer surface, and radially in the core region (Figure 2). To this end, LC long fiber plies are impregnated with epoxy resin and subjected to creep tension. This NFC features improved mechanical properties compared with pure polymer, as shown by a 30% increase in creep modulus [6].

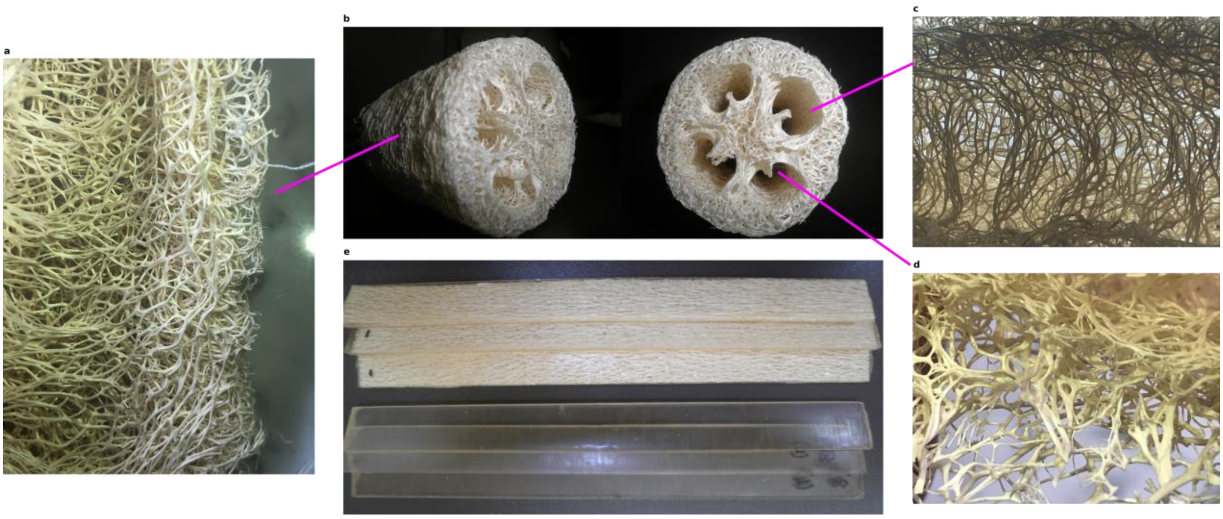

FIGURE 2 LC column fiber polyporous network morphology and structure: Left - An inner layer with interlaced fibers; Up center - Glocal view; Up right - The radial core layer; Down right - Network from the middle of the column wall; Down center - Creep tensile specimens of LC/ER and pure epoxy resin (ER)

The model is applied to the creep response of Luffa Cylindrica/Epoxy Resin (LC/ER) samples and their effective response is calculated. Poisson's ratio is taken into account in the analysis, as it affects the variation of interphasial thickness as a function of time. Local and global deformations are defined by experiments and homogenization schemes.

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THEORETICAL AND EXPERIMENTAL INVESTIGATION OF FLEXURAL BEHAVIOR OF SINGLE-LAP JOINTS OF SIMILAR AND DISSIMILAR ADHERENDS

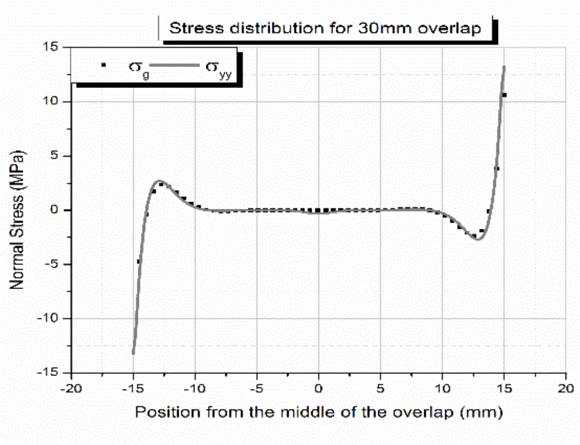
D. Karagiannis, Ch. Kousiatza, L.C. Kontaxis, D.V. Portan, G.C. Papanicolaou

The Composite Materials Group, Department of Mechanical and Aeronautics Engineering, University of Patras, Patras, GR-26500, Greece

ABSTRACT

Adhesively bonded joints have been intensively studied because of their extensive use from the simplest to the most complex constructions. The lap joint has become a standard test specimen with a view to assessing the strength and the structural properties of joints and for that reason numerous analytical relations have been proposed in order to predict the distribution of stresses within the joint as well as its strength. The present study concerns the experimental and analytical investigation of adhesively bonded single-lap joints between similar and dissimilar adherends in a three-point bending (3PB) arrangement. Indeed, with very few exceptions concerning transverse impact and out of plane bending [1-3], most of the theoretical and experimental work in literature concerns in plane loading of the joint configuration. In practice however nothing precludes that out of plane loads will have to be taken into account.

Although the closed-form solutions have their limitations, they are easy to use, especially for parametric studies. In the present study, an analytical model has been developed for calculating the shear and normal stresses in the adhesive layer of symmetric single lap joints, assuming linear elasticicy and neglecting the variation of stresses along the width of the joint. The adhesive layer thickness is assumed to be very small compared to the other dimensions of the joint. The interfacial stress distribution within the adhesive, was computed and compared with 2D Finite Element Analysis (FEA) results for the symmetric lap joints with very good correlation. Moreover, the analytical model was used in order to assess the effect of different geometric and material parameters on joint stiffness and maximum normal and shear adhesive stresses developed at the ends of the overlap.



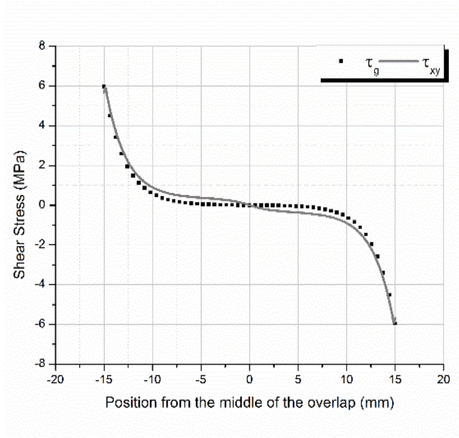
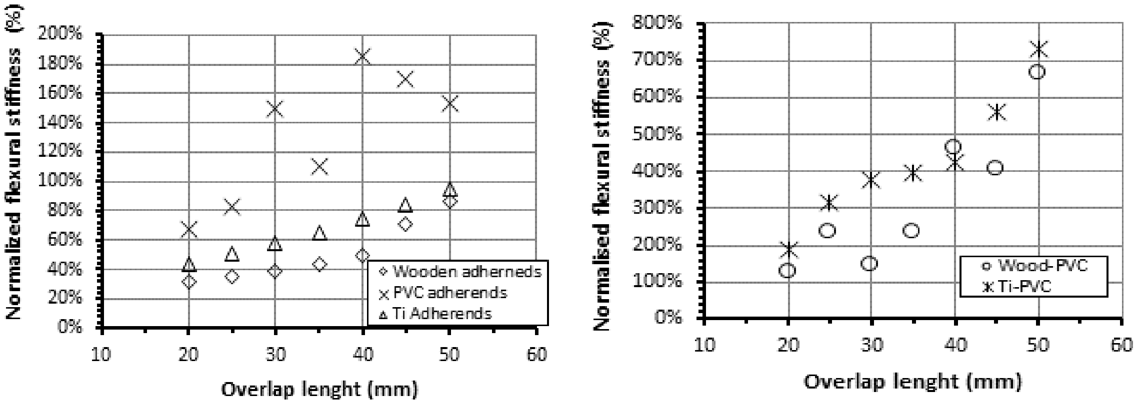


FIGURE 7 Distribution of shear (right) and peel (left) stresses in the adhesive for a symmetric lap joint with Ti adherend. Symbols indicate the analytical solution while lines correspond to FEA predictions

The comparison between the analytical and numerical predictions is shown in **Error! Reference source not found.** for a symmetric joint with Ti adherends in three-point bending configuration under a concentrated force P =30Nt at the center of the joint. The FEA predicted adhesive shear stresses τ_{xy} and the corresponding normal-peel stresses σ_{yy} are plotted as continuous lines whereas the respective analytical predictions, τ_g and σ_g , as symbols in the graphs. The analytical model is quite accurate and offers the possibility to perform parametric studies. In the present study the effect of different geometric and material parameters on joint stiffness and maximum normal and shear adhesive stresses at the ends of the overlap have been investigated.

The experimental investigations include the effect of overlap length on the mechanical response and the strength of the joint. Single-lap joint coupons were manufactured from wood, Poly Vinyl Chloride (PVC) and titanium sheets and the corresponding joints were tested up to failure. The experiments were executed at room temperature 25 °C. The outside stationary supports were 100 mm apart while the inner loading point, at mid-span, was always at the middle of the overlap. In all tests the crosshead speed was constant and equal to 1 mm/min.

Error! Reference source not found. shows the normalized flexural stiffness of the different lap joint configurations with respect to the flexural modulus of the individual adherends that was obtained from the bending tests. In **Error! Reference source not found.**a, the ratio for the symmetric joints is shown and in **Error! Reference source not found.**b for the non-symmetric ones. In the latter case the reference is the PVC adherend. It can be noted that flexural stiffness of the joint is smaller than that of the adherends for small overlaps. For all groups of the symmetric lap joints the flexural stiffness ratio is increasing together with the overlap, converging to that of the respective adherend for 50mm overlap.



(a) **(b)**

FIGURE 8 (a) Normalized flexural stiffness of symmetric joints with respect to single adherend and (b) normalised flexural stiffness of non-symmetric joints with respect to PVC adherend.

For the symmetric joints made of wood the joint is increasingly loaded up to a point where failure occurs in the adherend at the edge of the overlap. The PVC symmetric joints fail due to excessive plastic straining of the adherend at the edge of the overlap at the same location as the wooden symmetric joints. The same behavior is seen in the non-symmetric joints with PVC adherends (wood-PVC, Ti-PVC). The joint always fails at the PVC due to excessive plastic straining.

The Ti symmetric joints fail at the adhesive layer. The initial debond occurring at around 0.2mm deflection is not catastrophic as the joint is able to carry more load before it fails. The joint can withstand higher loads as the overlap increases. For all joint configurations the flexural stiffness increases with increasing overlap length. The flexural stiffness ratio of the symmetric joints with respect to that of the adherends is shown to be in the range of 30 to 40% for 20mm overlap and increasing to 90% for longer overlaps. The same trend in flexural stiffness ratio is observed for the non-symmetric joints for which the PVC-Ti joint shows a sevenfold increase in its flexural stiffness compared to PVC.

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NUMERICAL AND EXPERIMENTAL STUDY OF TWO DIFFERENT SANDWICH BEAMS SUBJECTED TO THREE POINT BENDING

A.-M. Tălîngă, G. Jiga, F. Baciu, M. Ciolcă

[1] *University POLITEHNICA of Bucharest, Faculty of Industrial Engineering and Robotics, Department of Strength of materials, ROMANIA, E-mail: ana_maria.talinga@upb.ro*

ABSTRACT

Sandwich beams are used to strengthen a structure. Some models can also be used in aircraft due to their low weight. As they are strength elements, it is very important to know their behavior when subjected to bending.

Once the materials were selected, the geometry was performed in CATIA V5 and later, imported into Ansys Workbench.

Generally, a sandwich beam is characterized by a multi-layer surface structure, usually consisting of three layers:

- Two covering layers also called "skins", which form the load-bearing structure (disc, plate or membrane), made of a stiff and strong material.
- An intermediate layer called "core", much thicker than the two skins, of reduced weight, having the role of separating the two faces and ensuring the transmission of efforts from one skin to the other. Usually, this core can be honeycomb (made of aluminum, paper, plastic), foam (polyurethane, polystyrene) or profiles (metal, plastic) [1].

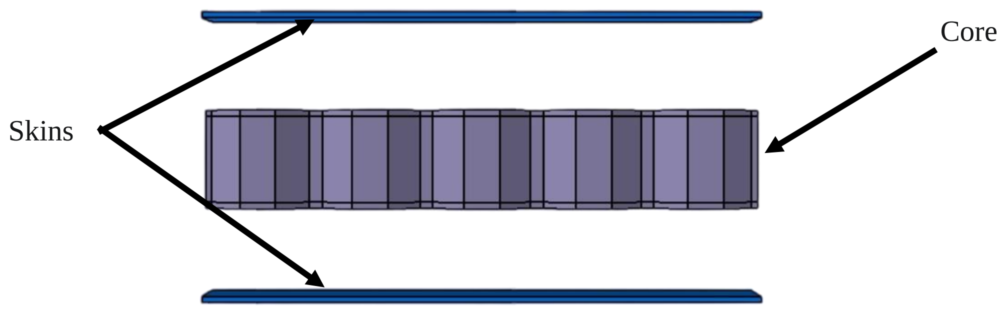

FIGURE 1 The components of a Sandwich structure

In this paper the authors analyzed numerically and experimentally the behavior of two different types of sandwich panels subjected to three points bending. For comparison, for an imposed deformation the efforts for two different models of core were determined. The two models have a honeycomb configuration with cells wall angle inclination α of 30^o and 60^o and are depicted in Fig. 2.

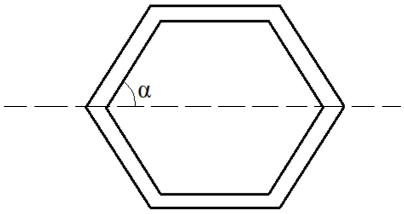

FIGURE 2 Angle variation

These cores have been noted with:

F1- For the honeycomb with a cell wall inclination of 30^o;

F2- For the honeycomb with a cell wall inclination of 60^o.

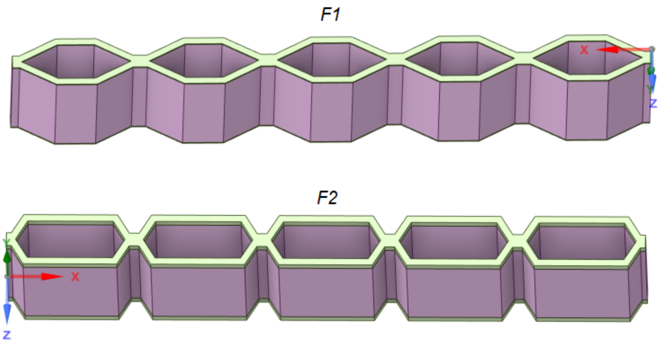

FIGURE 3 The two different core models

The core was made from PLA (Polylactic acid), an othotropic material. As compared to other biopolymers, PLA exhibits several benefits such as:

1. Eco-friendly – it is renewably-sourced, biodegradable, recyclable and compostable.
2. Biocompatible – it is non-toxic;
3. Processability – it has better thermal processability compared to poly (hydroxyl alkenoate) (PHA), poly (ethylene glycol) (PEG) and poly (γ-caprolactone) (PCL).

Polylactides break down into nontoxic products during degradation and, being biodegradable and biocompatible, they reduce the amount of plastic waste. [2]

In accordance with the numerical simulations in Ansys Workbench, in order to check the validity of the results, a set of five specimens with two different core configurations have been tested on a universal INSTRON testing machine according to ASTM C393.

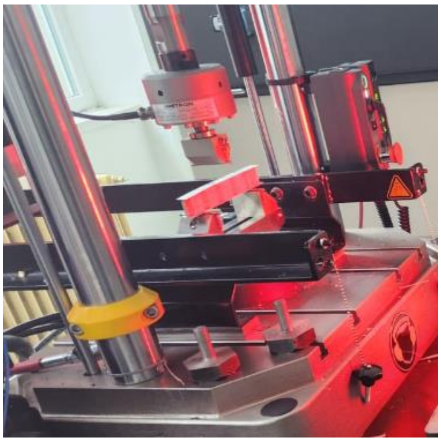

FIGURE 4 Three points bending test equipment

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AGEING AND DEGRADATION OF STRUCTURAL BONDED ASSEMBLIES

H. Welemane[1], S. Marguet[2], H. Obeid[1,2], B. Hassoune-Rhabbour[1], A. Abadie[1], J.-F. Ferrero[2], A. Léonardi[3], T. Mérian[1]

[1] *Laboratoire Génie de Production, INP-ENIT, 65016 Tarbes, France.* Helene.Welemane@enit.fr

[2] *Institut Clément Ader (ICA), Université de Toulouse, CNRS UMR 5312, UPS, INSA, ISAE-SUPAERO, IMT Mines Albi, 31400 Toulouse, France*

[3] *CLIX Industries, 31850 Montrabé, France.*

ABSTRACT

A joint is a mechanical connection that binds several parts together to prevent their relative displacement on a macroscopic scale. This connection can be temporary or permanent, and must meet a number of requirements, including transmitting the forces applied between the assembled parts. If the connection between elements is not mastered, this will reduce the mechanical strength of the structure as a whole. There are a number of different assembly techniques, including welding, where the parts or a filler material - usually metal - are fused together; fastening, where additional elements (screws, bolts, rivets) are used; and bonding, where the assembly is achieved using a substance called an adhesive. Among them, structural bonding can significantly help reduce the weight of mechanical systems. The ability to combine materials of different types (metals, polymers, composites...) and properties (mechanical, thermal, electrical...), the preservation of the assembled parts (no thermal degradation or drilling of assembled parts), and the almost continuous diffusion of forces between the elements, are just some of the advantages of this process, which explains its rapid expansion in a number of engineering fields [1,2]. Such combination of mechanical performance with reduced weight, and sometimes even improved aerodynamic profile, leads for instance to new design solutions for many structural components in the aerospace industry. The success of structural bonding depends not only on the performance of the adhesive itself, but also on its suitability for the parts to be bonded. Validation of this process therefore requires studies both on the scale of the adhesive material and on the structural scale of the assembly. Epoxy resin-based thermosetting adhesives are the most used in the aerospace and automotive industries [3]. These adhesives adhere well to steels, can be used at high temperatures and have high shear strength, while exhibiting low shrinkage after cross-linking. For optimization purposes, many industrial contexts today impose particularly severe service conditions on mechanical structures. The development of impact adhesives, reinforced either by rubber-like or mineral particles, is typically the result of growing demand from the automotive industry to ensure passenger safety [4].

Despite these strong performances, the sensitivity of these adhesives to environmental conditions is still an obstacle to the development of bonding for some structural applications. Indeed, environmental exposure can have adverse effects that seriously affect the durability of bonded structural assemblies (see review by [5, 6]. In practice, the penetration of moisture into bonded joints

is the main cause of a significant reduction in their mechanical properties. The majority of factors influencing moisture absorption and the mechanical properties of polymers have been extensively studied. One can cite for instance internal factors such as the physical and chemical nature of the material and external factors such as temperature relative humidity and ambient pressure. Ageing studies typically consider static thermo-hydric conditions, i.e. a constant level of humidity and temperature applied for a given period. The glass transition temperature generally falls because of interactions between the water and the resin [7]. These changes in the physico-chemical properties of epoxy systems under hygrothermal environmental conditions are naturally reflected in their mechanical cohesion, with a deterioration in their mechanical properties and increase of their ductility [8]. Such damage behaviour of adhesive materials obviously has repercussions on the scale of assemblies, where a significant drop in strength can be observed under water ageing, with an even greater intensity if high temperature is associated [9].

Unlike static ageing, the effects of hygrothermal cycling on the durability of epoxy adhesives and assemblies has received very little attention in the literature. In this work, we look at the durability of epoxy adhesives dedicated to transport applications, Permabond Loctite® ESP 110 and DOW Betamate 1496V. The load considered is cyclic hygrothermal ageing (12-hours cycle comprising 5 hours at 70°C and 90% relative humidity followed by 5 hours at -40°C, in accordance with ISO standard 9142). This cycling is in line with the conditions to which bonded assemblies are really exposed during their life cycle and also accelerates the ageing process of adhesives. An experimental campaign on mass specimens (material scale) and bonded assemblies (macroscopic scale) was carried out over 6 months of ageing. In the case of the adhesive material, water absorption was monitored by gravimetric analysis, while changes in the glass transition temperature were determined by DSC analysis. The evolution of mechanical stiffness, strength and elongation at break is characterized on single-lap assemblies and on mass specimens, under quasi-static conditions. Particular attention is paid to the manufacturing procedure and the loading of materials and structures to guarantee the reliability of the tests. Correlations between micro and macroscopic behaviours are highlighted and discussed. This combined analysis at different scales provides an in-depth understanding of the physicochemical phenomena induced by hygrothermal ageing and provides important information for the subsequent modelling of bonded joint assemblies.

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ABSTRACTS: Rapid-Fire Poster Session

Monday 11 Sep. 2023	**Rapid-Fire Poster Session** **(HALL A)**
Session RFPS Co-Chairmen:	**Gabriel Jiga,** University POLITEHNICA of Bucharest, Romania. **Stephanos Zaoutsos,** Professor, Department of Energy Systems, University of Thessaly, Greece.

SMART ENGINEERED NANOSIO$_2$-RGO-POLYMER COMPOSITES FOR TISSUE ENGINEERING

I. Botiz[1,2], M. Muresan-Pop[1], I. Rusu[1], A. Vulpoi[1]

[1]Interdisciplinary Research Institute on Bio-Nano-Sciences, Babes-Bolyai University, Cluj-Napoca, Romania;

[2]Faculty of Physics, Babes-Bolyai University, Cluj-Napoca, Romania

ABSTRACT

There are more and more reports in the literature discussing the fabrication of various composites to be used in tissue engineering. Most recent of such reports are based on injectable composites generated by combining the bioactive glass (BAG) with polymers such as poly(caprolactone) [1] or various pluronic and/or poloxamer copolymers [2]. Often the resulting composites are strengthened from the mechanical and biological point of view either through the utilization of physical processes like self-assembly and 3D printing [3] or by employing additional carbonic materials such as graphene oxide. The latter variant is generally feasible by interconnecting the graphene oxide sheets with the BAG through a hybridization process that requires the presence of dopamine [4].

In thin work, the fabrication of smart injectable nanocomposites displaying potential in tissue engineering is reported. Initially, by combining the gelation properties of pluronic F127 with the thermo-responsive attributes of nanoSiO2-based glass, a less complex pluronic/BGA composite was obtained. Then, the latter was further strengthened with the addition of small percentage of reduced graphene oxide (RGO) in the presence of dopamine. At the end, all resulting composites were characterized using optical and scanning electron microscopy (combined with energy-dispersive X-ray spectroscopy), X-ray diffraction (XRD), thermogravimetry/ differential thermal analysis and underwent preliminary antibacterial tests.

Acknowledgements

The authors acknowledge the financial support of the Romanian National Authority for Scientific Research and Innovation, CNCS-UEFISCDI, project no. PN-III-P1-1.1-TE-2021-0388.

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FINITE ELEMENT ANALYSIS OF HALLUX VALGUS SURGICAL CORRECTION USING CORTICAL SUSPENSION SYSTEMS

M. Nica[1], E. Nuțu[2], C. Cîrstoiu[1], G.G. Jiga[2]

[1]*Carol Davila University of Medicine and Pharmacy, Bucharest, Romania*

[2]*University Politehnica of Bucharest, Romania*

ABSTRACT

Hallux valgus is one of the most common chronic conditions affecting the human foot. It is characterized by the development of a progressive and irreversible deformation of the foot, through the lateral deviation of the hallux and the medial displacement of the distal extremity of the first metatarsal leading to the disruption of the normal, alignment of the first metatarsophalangeal joint (Figure 1, a).

The treatment of hallux valgus has seen an evolution marked by numerous changes and controversies. One of the currently applied surgical techniques for hallux valgus correction relies on using cortical suspension systems (Figure 1, b). Basically, the procedure enforces the first metatarsal bone to the normal position by connecting it to the second metatarsal bone via traction wires which pass through cylindrical holes drilled in the two bones and supported by metallic small plates, as one can notice in Figure 1b. Although the procedure is effective, there are cases which report the second metatarsal fracture, during normal walking. In this respect, it is of interest to identify the best approach for fixing the wires, so that the stresses into the second metatarsal bone are minimized. For this purpose, numerical simulations are most suited, because they can easily provide information on the biomechanics of the analyzed system without affecting the patients. Also, the influence of different parameters on the stress level induced in bones, such as hole diameter, the distance between holes or their positions can be investigated.

(a) (b)

FIGURE 1 (a) Radiography showing hallux valgus deformity and (b) correction using cortical suspension systems

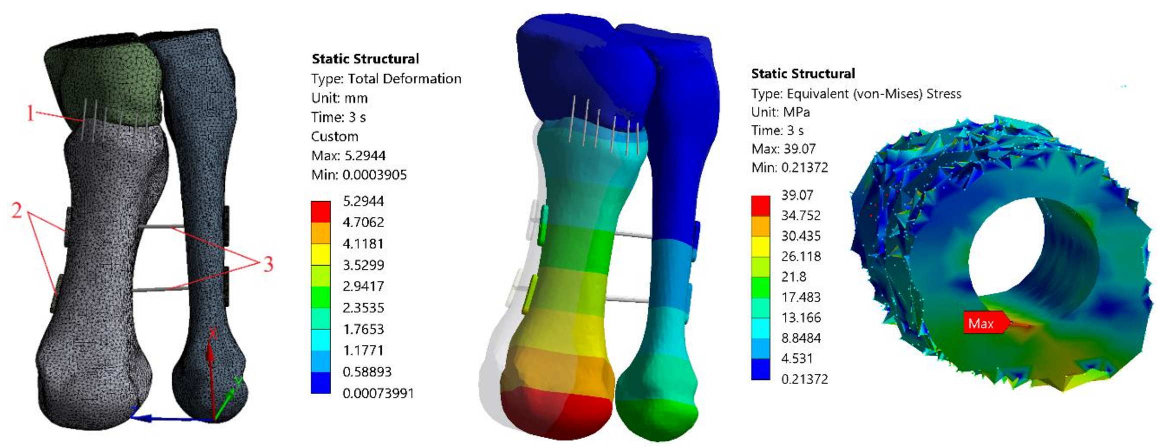
Under the mentioned arguments, this paper deals with finite element simulation of the hallux valgus correction effect on the stresses induced into the second metatarsal bone during the push-off phase of the gait cycle.

A 3D model is created starting from CT scans of a 36-year-old female, having studied pathology. The geometry was virtually reconstructed using 3DSLICER v5.2.2 open-source software, while the finite element modeling and analysis are done using ANSYS software, version 2023 R1. Higher order tetrahedrons are used for meshing the biomechanical assembly, as shown in Figure 2a.

The model comprises four bones: the first two metatarsals and their corresponding cuneiforms. The bone material is defined as linear elastic with an average Young modulus of 7 GPa [1]. Between the first metatarsal and the first cuneiform, frictionless contact is imposed, to allow relative movement, according to the reality of the surgical intervention. The second metatarsal and the second cuneiform are modeled as a single bone, to accommodate the reduced mobility corresponding to their anatomy. Besides bones, the following elements are included in the model (Figure 1a): 1-beam elements emulating the ligaments, by equating their stiffness, 2- titanium plates, and 3-beams emulating the traction wires.

The analysis is done in three load steps. The first step consists in pretension of beams that model the ligaments, to assure contact nonseparation between the first metatarsal and the first cuneiform. In the second step, the traction wires are preloaded to enforce the first metatarsal to move towards the second one (see Figure 2b for overall displacements). The last step corresponds to application of forces on the two metatarsals, according to Jacob [2].

For the analyzed case, the results in terms of von Mises stresses indicate no risk of failure for the second metatarsal, as the maximum stress is 39.07 MPa (Figure 2c). According to Frost [3], this stress value is under excessive damage accumulation limit (60 MPa). However, the quantitative stress value is rather formal, due to several reality simplifications, such as material properties. Nevertheless, the model presented in this paper, is created to allow for qualitative comparisons of different surgical parameters, and it is shown that can reproduce the hallux valgus correction coupled with normal walking.



(a) (b) (c)

FIGURE 2 Finite element model of the Talus valgus surgical correction: mesh and model details (a), overall displacements after the application of push-of forces of the gate cycle, and von Mises stresses around one hole into the second metatarsal bone

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MESOPOROUS NANOPARTICLE BIOACTIVE GLASSES FOR APPLICATION IN DENTISTRY

M. Muresan-Pop[1], C. Frent[1], A. Vulpoi-Lazar[1]

[1]Interdisciplinary Research Institute on Bio-Nano-Sciences, Nanostructured Materials and Bio-Nano Interfaces centre, Babes-Bolyai University 400271, Cluj-Napoca, Romania

ABSTRACT

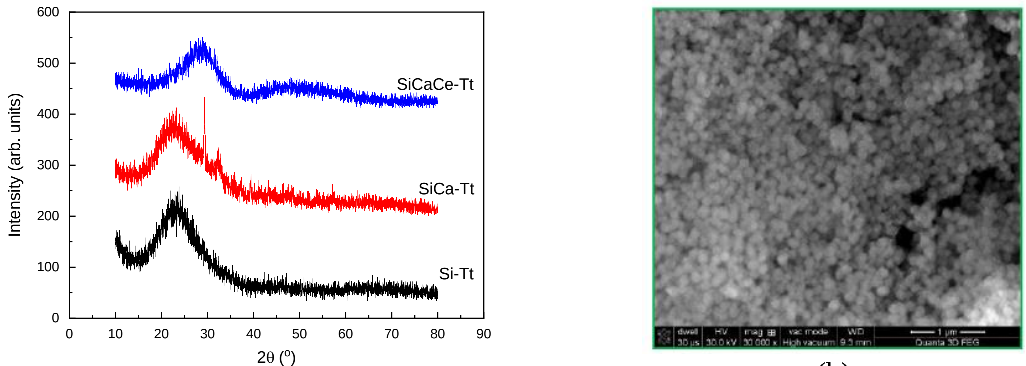
The main goal of the present study was obtaining mesoporous bioactive glass nanoparticles (nMBG) in an optimized formula, prepared with the composition SiO_2-CaO-CeO, by using a structure directing agent. The presence of Cerium in the composition of these systems can reduce inflammatory response, mainly due to the antioxidant activity of the ions [1-3] promoting osteogenesis and angiogenesis effects.

The optimum concentration of bioactive precursors in this nMBG was established through structural and morphological analysis of the samples prepared. To characterize the newly obtained materials (nMBG) and to highlight the compositional, structural, and morphological improvements, the systems obtained were investigated through X-ray powder Diffraction (XRD), Differential Thermal Analyses (DTA/TG), Fourier Transform Infrared Spectroscopy (FTIR), Morphological Analysis by Scanning Electron Microscopy (SEM),

The X-ray powder patterns showed an amorphous structure in the case of the Si system, and a semi-crystalline structure in the case of the Si-Ca and Si-Ca-Ce systems. (Fig.1a)

From the analysis of the FTIR spectra obtained on the samples were highlighted the vibrational modes characteristic of the silicate structure of the calcined samples.

From the electron microscopy, SEM images of the samples, the change in the morphology of the particles was highlighted, after calcination they have a spherical shape (Fig.1b).



(a) (b)

FIGURE 1 (a) XRD powder patterns and (b) SEM image of the calcined samples

Acknowledgements

The authors acknowledge the financial support of the Romanian National Authority for Scientific Research and Innovation, CNCS-UEFISCDI, project no. PN-III-P1-1.1-TE-2021-0388.

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INFILL PERCENTAGE INFLUENCE OF THE 3D PRINTED PLASTIC PARTS ON DIMENSIONAL AND SHAPE TOLERANCES

F. Chiscop[1], G. Jiga[2], T.G. Dobrescu[3], M.C. Dijmărescu[4], P.I. Brăileanu[5]

[1]*Department of Robots and Production Systems, University Politehnica of Bucharest*

[2]*Department of Strength of Materials, University Politehnica of Bucharest*

[3]*Department of Robots and Production Systems, University Politehnica of Bucharest*

[4]*Materials Technology and Welding, University Politehnica of Bucharest*

[5]*Department of Machine Elements and Tribology, University Politehnica of Bucharest*

ABSTRACT

3D printing is an innovative and versatile technology that allows the manufacturing of three-dimensional objects by adding successive layers of material until the final shape is achieved. The use of this manufacturing method has advantages and disadvantages in terms of dimensional and shape tolerances of the parts. Regarding the dimensional tolerances of 3D printed parts made of plastic materials (such as nylon, ABS, PLA, PC, etc.), they can have variable precision depending on the 3D printer's accuracy. The dimensional tolerances of parts obtained through 3D printing are larger than those obtained through traditional manufacturing methods. The layering process introduces variations in the final dimensions of the parts. These variations can be compensated through post-processing operations or by optimizing the printing parameters. One adjustable printing parameter is the fill percentage of the part.

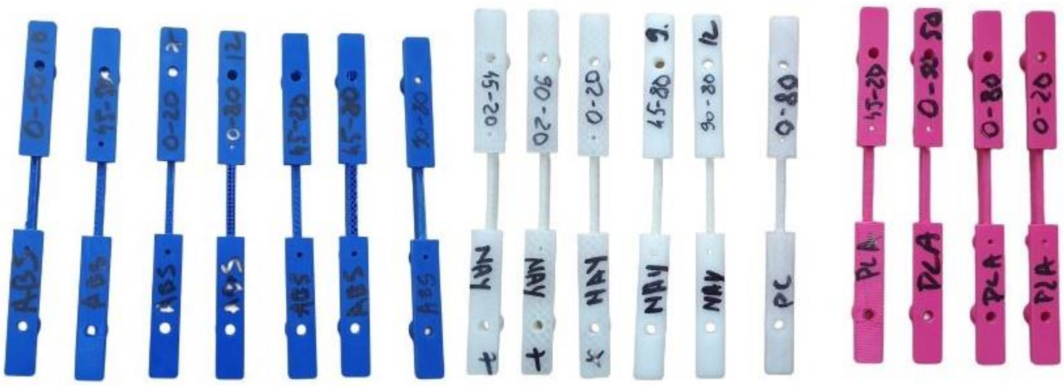

FIGURE 1 Printed samples

This article establishes a relationship between the fill percentage of the parts and their final shape by transitioning from the 3D virtual models to the finished piece, measuring the dimensional and shape tolerances for plastic parts (Fig.1). For the correct construction of the part, the model requires support structures.

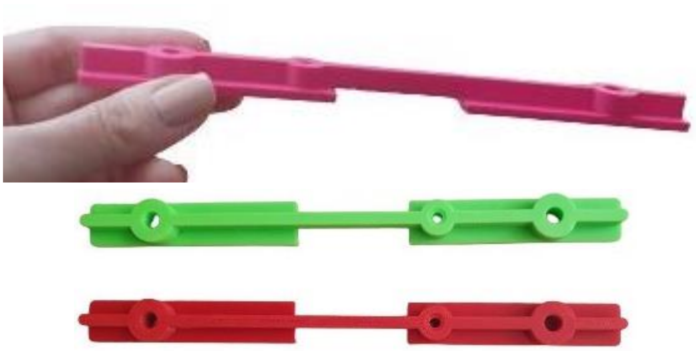

FIGURE 2 The support structures

The support structures can affect the shape tolerances of the part (Fig.2). In conclusion, 3D printing can be used to manufacture parts with adequate dimensional and shape tolerances, but with certain limitations that need to be considered based on the part's specifications.

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DESIGNING AN EXTRACELLULAR VESICLE FOR BIOENGINEERING APPLICATIONS

V. Bafiti, T. Katsila

Institute of Chemical Biology, National Hellenic Research Foundation, 11635 Athens, Greece

ABSTRACT

Extracellular vesicles (EVs) facilitate cell-to-cell communication from short to long distances in health and disease, carrying a series of biomolecules including nucleic acids, proteins, and metabolites. Thus, they exhibit a wide range of bioengineering applications. The latter are well-supported by key advantages that EVs share as a. they are devoid of cell-related complications, while exerting similar functions, b. their size allow sterilization by filter membranes in large quantities during production, c. EVs remain active following repeated freeze-thaw and freeze-drying processes lowering their threshold for large-scale production, d. they have stable lipid bilayers protecting their contents when in blood circulation and e. EVs represent an evolutionary conserved cellular communication mode with readily available carrier characteristics and mechanisms.

Herein, we first provide a critical overview of the current methods for the isolation and identification of EVs. Next, we showcase various designs and modification strategies of EVs per bioengineering application, alone or in combination with selected biomaterials. Emphasis is put on the surface modification of EVs and their cargo of interest, listing their advantages and limitations as they are essential for tailoring their content and enhancing their targeting abilities. For this, a step-wise comparison of loading strategies is performed along with a thorough description of self-assembly, punching, co-culturing with precursor cells as well as pre- and post-isolation modification. Exosomes and exosome-mimetics in regenerative medicine serve as a paradigm, following the synergy of our wet- and dry-lab pipelines that enrich each other for optimum performance.

The proposed roadmap addresses the full potential of current strategies and technologies utilized in the design and engineering of EVs, and discusses the future prospects and hurdles in the translation of engineered EVs into practical solutions. By harnessing the natural capabilities of EVs and refining their properties through innovative design approaches, these vesicles hold great promise for revolutionizing the field of bioengineering and transforming the landscape of modern medicine.

Acknowledgements

This paper is co-funded by European Union’s Horizon 2020 research and innovation programme under grant agreement No 101112347, project NerveRepack (Intelligent neural system for bidirectional connection with exoprostheses and exoskeletons) and supported by the CHIPS Joint Undertaking and its members.

BIODEGRADATION PROFILE OF 3D PRINTED PLA SCAFFOLDS AFTER LONG-TERM IMMERSION IN CELL CULTURE MEDIUM

A. Angelopoulou[1], D.V. Portan[1], L.C. Kontaxis[1], D. Kouzoudis[2], G.C. Papanicolaou[1]

[1]Department of Mechanical Engineering and Aeronautics, University of Patras, Patras University Campus, 26504 Patras, Greece
[2] Dept. of Chemical Eng., Section of Materials Science and Technology, University of Patras, 265 04 Patras, Greece

ABSTRACT

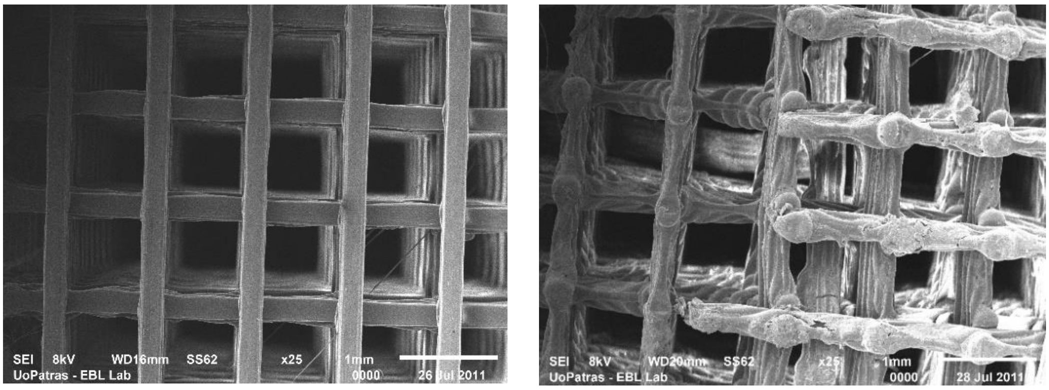
Understanding a scaffold's biodegradation mode and rate is crucial for its successful application in implantology. The culture of cells in 3D dimensions reproduce the anatomy or physiology of a tissue for informative or useful study and therefore 3D scaffolds have been intensively used *in vitro* as innovative and convenient platforms for the growth and long-term maintenance of human cell cultures with the purpose to clarify aspects related to basic biology [1, 2]. However, observing the properties degradation of the scaffolds with time is highly demand to appropriately predict important biointegration events. The mechanical characterization of the scaffolds upon long-term immersion in simulated body fluids can offer information on their feedback when exposed to micro-environments that closely mimic the physiologic one and this crucial to later understand perspectives and limitations related to the tissue ingrowth process into the biomaterial.

In the present investigation, 3D printed biomedical PLA scaffolds were manufactured and their biodegradation upon long-term immersion in cell culture medium was studied. The immersion setup allowed to run a dynamic experiment, which partially mimicked the body-like environment. The cell culture medium is normally used to maintain stem cells *in vitro*, and contains mainly salts, proteins and antibiotics. A double wall glass recipient was use to heat the solution by war water transfer, at 37^0 C; the glass recipient was kept on a magnetic plate and samples were stirred at 500 rpm (Fig.1).

FIGURE 1 Experimental setup for the immersion of the PLA 3D printed scaffolds in cell culture medium

The experiment was initially planned for 3 months, but several specimens were almost completely dissolved after 2,5 months. Measurements were performed for days 1, 3, 7, 14, 21, 28 etc. of immersion. Five specimens were extracted from the solution for each measurement day. One of the specimens was used for SEM analysis and 4 of them were weighed and further tested in compression.

The SEM images in Fig.2 show a control, non-immersed scaffolds (Fig.2a) and a scaffold after 42 days of immersion (Fig.2b). It may be clearly seen the difference between the structure of the PLA fiber. The control, non-immersed scaffold presents a smooth fiber with continuous aspect. On the opposite, the fiber of the scaffold that was immersed for 42 days presents several imperfections as a result of visco-plastic deformation. Each stage of the biodegradation provides a clearer view on the response of the scaffold structure to a body-like micro-environment.



(a) (b)

FIGURE 2 SEM images of 3D printed PLA scaffolds: (a) control specimen and (b) specimen after 42 days of immersion

The analysis of the weight loss indicates a that fluid uptake took place until the 10th day, when the degradation process became really pronounced (Fig.3). After the 10th day, the absorption process was not measurable anymore, indicating that the fiber was saturated.

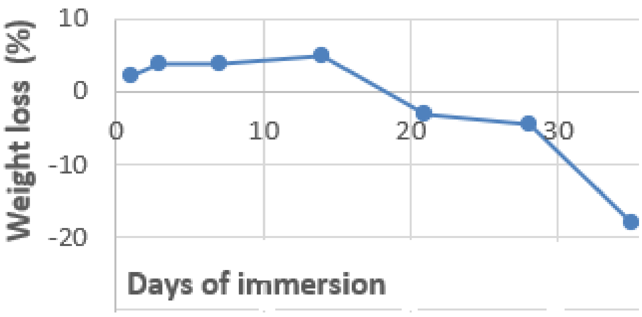


FIGURE 3 Weight loss percentage with immersion days

The compression modulus was reduced to less than half after 40 days of immersion and the degradation of the specimens did not allow to evaluate their modulus after day 40.

Acknowledgements

This paper is co-funded by European Union's Horizon 2020 research and innovation programme under grant agreement No 101112347, project NerveRepack (Intelligent neural system for bidirectional connection with exoprostheses and exoskeletons) and supported by the CHIPS Joint Undertaking and its members.

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NOVEL MULTIMATERIAL HYBRID JOINING PROCESS FOR CFRP-METAL STRUCTURES IN AVIATION INDUSTRY

A. De Zanet[1*], S. Varetti[1], E. Pappa[1], C. Annicchiarico[2], A. Ricciardi[2], M. Pagone[2], N. Gallo[2], A. Kumar[1] and G. De Pasquale[3]

[1] Leonardo s.p.a., Leonardo Labs, Italy, Corresponding Author: alessandro.dezanet.ext@leonardo.com

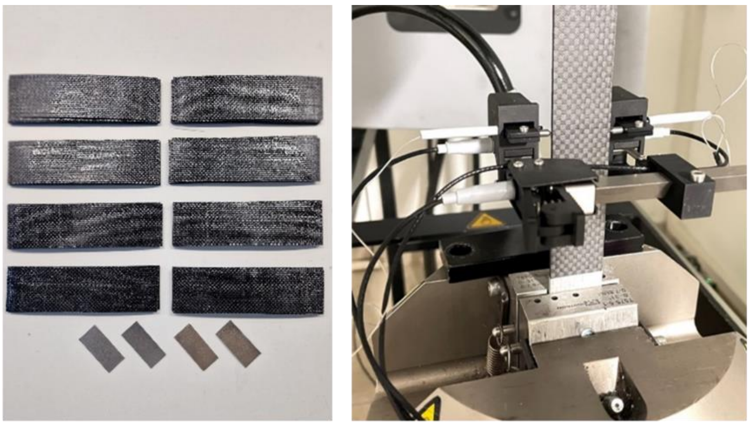
[2] Leonardo s.p.a., Leonardo Aerostructures Division, Italy

[3] Politecnico di Torino, Smart Structures and Systems Lab, Italy

ABSTRACT

Joining is a critical step in the manufacturing process of aerostructures. Thus, the aviation industry is engaged in a continuous effort to improve economic and technological performances of joints, by promoting sustainability through design and recycling. Traditional strategies for joining metal and CFRP rely on riveting. However, rivets have many drawbacks. Indeed, they introduce additional weight to the structure, the assembly process is time-consuming and CFRP fibers are exposed to damage during operations, and inspection and maintenance are difficult. Furthermore, corrosion and rivet failure are additional issues. For this reason, many researchers are working to identify new solutions for metal-CFRP coupling that do not require using rivets [1].

To overcome these limitations, while increasing the quality and sustainability of joints, new concepts based on digital and hybrid processes are under investigation. This is the objective of MIMOSA that proposes a new innovative process for multi-material joining of Additive Manufactured AlSi10Mg and carbon fiber-reinforced polymer (CFRP) (*Figure 1a and 1b*), thus replacing riveting.



a) b)

FIGURE 1 (a) Set of CFRP coupons and (b) test setup.

This novel joining solution exploits the reinforcement given by the mechanical interlocking between the CFRP and 3D anchors built on the metal surface to avoid rivets and increase reliability. In addition, a lattice layer is introduced to compensate the thermal expansion mismatch between metal and CFRP. Such design and the associated manufacturing process were patented by Politecnico di Torino [2, 3].

Moving from this concept, MIMOSA consortium aims to demonstrate the feasibility of the entire fabrication process for industrial application, advancing the TRL. Specifically, a vertical stabilizer will be manufactured and validated as business case. The joints proposed in the project have the potential to reduce the weight by 51%, while increasing the mechanical performances and shortening the lead time. Furthermore, the proposed joint design can increase materials recycling, enabling to recover up to 50% of the metal and 90% of CFRP. The MIMOSA project is presented by introducing the design and the rationale behind the proposed joining solution, the manufacturing processes, project's goals and its roadmap.

Acknowledgements

MIMOSA project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 101091826.

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AN INNOVATIVE METHOD FOR ENVIRONMENTALLY FRIENDLY RECYCLING OF GFRPS

G. Petropoulos[1], A. Kotrotsos[1], V. Kostopoulos[1,2,*]

[1] *Department of Mechanical Engineering and Aeronautics, University of Patras, GR-26504 Patras, Greece*

[2] *Foundation of Research and Technology, Institute of Chemical Engineering Sciences (FORTH/ICE-HT), Stadiou Str., GR-26504 Patras, Greece*

***** *Corresponding Author: kostopoulos@upatras.gr; Tel.: +30-2610-969441*

ABSTRACT

Fiber reinforced plastics (FRPs) are nowadays widely used in many industrial domains such as automotive, wind turbines, aerospace and civil infrastructure, thanks to their high specific stiffness and strength and their fatigue and corrosion resistance. Based on market reports the global FRP composites market is expected to grow at a steady pace, as these types of materials find varied end-use applications [1]. Taking into consideration these aspects, it is highly necessary introduce new design concepts based on circular economy principles and the life cycle assessment (LCA). In parallel, for the already existed assets it is necessary to establish an FRP waste management system to avoid landfilling or incineration at the end-of-life stage. This system will be responsible for reinforcement and matrix recovery while in parallel this process will be beneficial for the economy and the environment. Thermoset materials could successfully degrade through thermal treatment, chemical degradation by a catalyst, irradiation and mechanical treatment [2]. By using these methods, fine particles and fibers can be obtained that in its turn could be easily utilized as fillers and /or reinforcement additives in future composites' structures fabrication.

In the present work, an innovative, sustainable, and low-cost method for glass fiber reinforced plastics (GFRPs) wastes' recycling is proposed. This method is based on chemical oxidation of three-dimensional GFRP structures while assisted at its final step by using microwave treatment. More precisely, in the present work an 8-layered, uni-directional GFRP plate was immersed into hydrogen peroxide (H_2O_2) solvent and after that it was placed into a microwave oven for a short period. This process decomposes the GFRP composite to a layer-by-layer configuration and was repeated for several times up to the entire decomposition of the under-investigation material. Prior and after each step the GFRP sample was weighted. At the end of this process the glass fiber layers were remained intact while the resin material was collected separately.

Finally, after recycling process the reclaimed glass fiber layers were reused to fabricate a new a GFRP structure. After fabrication the new composites was subjected to mechanical tests, and it was shown that the mechanical behaviour of the new material was very close to the virgin GFRP composite structure prior recycling process. Taking into consideration the obtained results, this

recycling approach can be considered as a viable solution for the end-of-life treatment of GFRPs, since it has also the upscaling capacity.

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SURFACE CHARACTERIZATION OF 3D BIOMEDICAL SCAFFOLDS WITH ENHANCED BIO-INTEGRATION

M. Thabet[1], D. Portan[1], G. Michanetzis [1], V. Kostopoulos[2], A. Kotrotsos[2], D. Kouzoudis[3]

[1]*Laboratory of Biomechanics and Biomedical Engineering, Department of Mechanical Engineering and Aeronautics, University of Patras, 265 04 Patras, Greece*

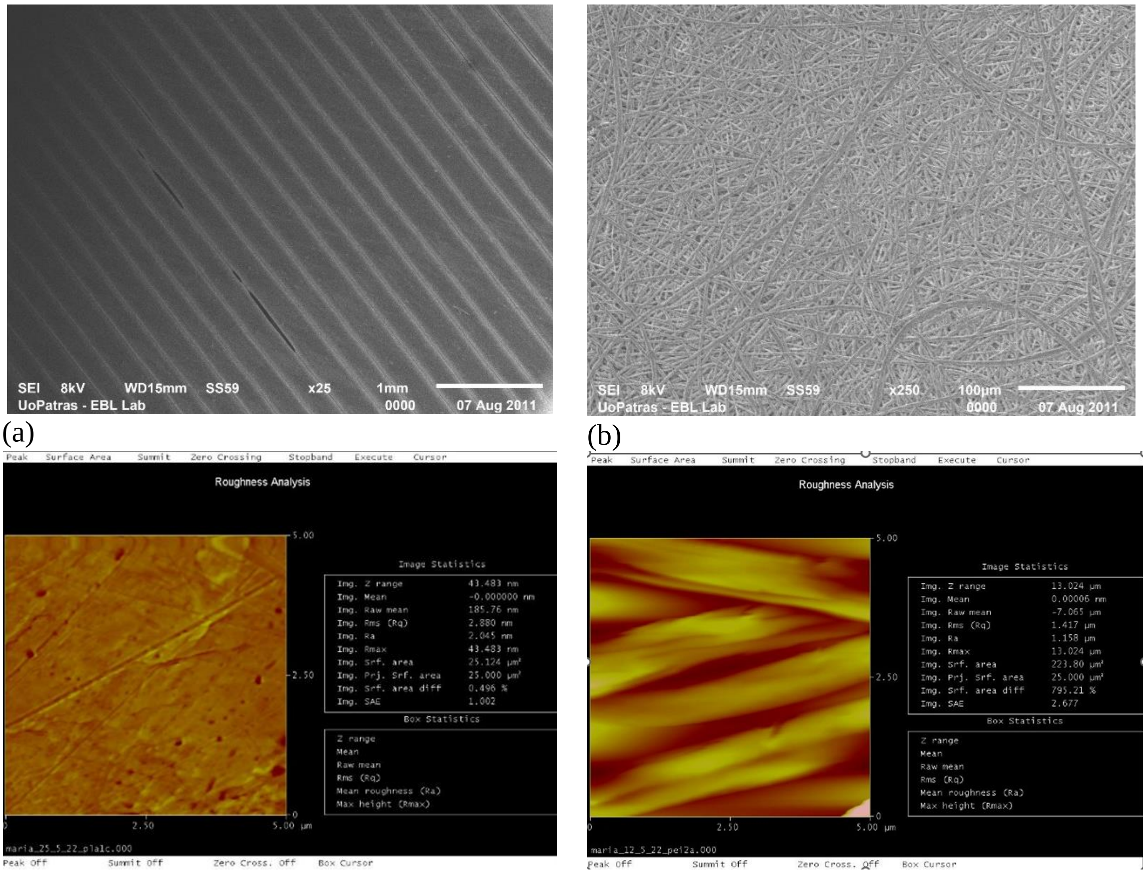
[2]*Applied Mechanics & Vibrations Laboratory, Department of Mechanical Engineering and Aeronautics, University of Patras, 265 04 Patras, Greece*

[3]*Dept. of Chemical Eng., Section of Materials Science and Technology, University of Patras, 265 04 Patras, Greece*

ABSTRACT

Biomedical engineering and tissue engineering are coming to meet the needs of modern medicine and so, the development of suitable biomaterials is necessary. The creation of three-dimensional artificial microstructures, so-called scaffolds, is based on advanced manufacturing technologies such as 3D printing and electrospinning. A new challenge is the development of biomimetic biomaterials, which are usually porous materials and have properties like those of the natural tissues. This can be achieved with the help of the above-mentioned techniques, 3D printing and the electrospinning, respectively. 3D printing, or additive manufacturing, is a method that allows the construction of complex structures by adding materials, layer-by-layer, and it has applications mainly in bone engineering [1]. The electrospinning method is being used to create fibrous scaffolds and it is often preferred for applications in wound healing [2].

The purpose of the present study was to investigate the surface properties of 3D scaffolds manufactured by 3D printing and electrospinning. The employed materials were bulk polylactic acid (PLA), bulk polyetherimide (PEI), hydroxyapatite (HAp) reinforced PEI, and graphene nanoplatelets (GNPs) reinforced PEI, which were previously investigated [3, 4]. The key surface properties of biomaterials are roughness, which affects the adhesion quality of the human cells to the material, and stiffness, which affects cells' differentiation, while both play an important role in biorecognition. The reinforcement percentages were as follows: 1% HAp reinforced PEI, 0.5% GNPs reinforced PEI, 1% HAp&0.5% GNPs reinforced PEI. Specimens were of two types: *(i)* compact PLA 3D printed and *(ii)* 3D scaffolds produced by electrospinning (PEI and its composites) (Figure 1a, b). Scanning electron microscope (SEM) images were taken to observe the morphology of the materials (Fig. 1a, b). In addition, the morphology and the roughness of both types of scaffolds (PLA and PEI) were examined by Atomic Force Microscopy (AFM). Further on, the mechanical properties of the scaffolds, such as elastic modulus and hardness were studied by nanoindentation technique. The applied indentation forces in different areas of the scaffolds were: 600, 2000 and 5000 μN (Fig. 1c, d).



(a) (b) (c) (d)

Figure 1SEM & AFM micrographs showing surface texture of: (a) compact PLA sample - SEM; (b) PEI electrospun scaffold - SEM; (c) Roughness analysis for a compact PLA specimen - AFM and (d) Roughness analysis for a Hap and GNPs reinforced PEI - AFM

Some outcomes are: *(1)* The AFM technique is sensitive making the analysis of scaffolds difficult and requires and therefore multiple samples are needed for each case; *(2)* The roughness of the double reinforced - HAp and GNPs - PEI specimens was significantly higher comparing to the other substrates. This is expected and is due to conglomerates formation. It is known that for plastics, the increased roughness results in an improved bio integration rate [5] *(3)* The compact PLA samples are highly organized at macro level, but this is not valid at micro-level. On the other hand, the 3D electrospun scaffolds are fibrous and present empty porous regions due to their nanoarchitecture – therefore, the two types of scaffolds induce different adhesion and multiplication dynamics of the cell population and finally *(4)* All materials exhibit singularities and inhomogeneities at nano level.

Acknowledgements

This paper is co-funded by European Union's Horizon 2020 research and innovation programme under grant agreement No 101112347, project NerveRepack (Intelligent neural system for bidirectional connection with exoprostheses and exoskeletons) and supported by the CHIPS Joint Undertaking and its members.

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ENHANCED ELECTROACTIVE PHASES OF POLYVINYLIDENE FLUORIDE NANOFIBERS FOR BONE TISSUE ENGINEERING APPLICATIONS

**A. Zaszczyńska[1], A. Gradys[1], R. Tymkiewicz[1],
M. Lewandowska-Szumieł[2], P.Ł. Sajkiewicz[1]**

[1] *Institute of Fundamental Technological Research, Laboratory of Polymers and Biomaterials, Polish Academy of Sciences, Pawinskiego 5B St., 02-106 Warsaw, Poland*

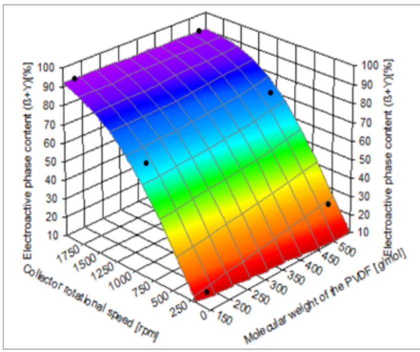
[2] *Medical University of Warsaw; Centre for Preclinical Research and Technology, Warsaw, Poland*

ABSTRACT

Nanofibrous materials produced by electrospinning processes have attracted considerable interest in tissue regeneration, including bone reconstruction. A range of novel materials and processing tools have been developed to mimic the native bone extracellular matrix for potential applications as tissue engineering scaffolds and ultimately to restore degenerated functions of the bone. Currently, there is high interest in designing a material resembling bone tissue, and many scientists are trying to design materials applicable to bone tissue engineering (BTE) with piezoelectricity similar to bone. One of the prospective candidates is highly piezoelectric polyvinylidene fluoride (PVDF), which was used for fibrous scaffold formation by the electrospinning technique [1,2]. In this study, the effect of PVDF molecular weight, fiber spatial arrangements, and electrospinning parameters on polymorph content was investigated. A multi-technique procedure combining spectroscopy and microscopy was used to investigate the phase content in PVDF. The author's idea is to fabricate fibrous scaffolds to enhance cell adhesion, migration, and proliferation.

Two grades of PVDF with low and high molecular weight were investigated along with various electrospinning parameters, such as the rotational speed of the collector, applied voltage, and solution flow rate. A multi-technique approach of microscopy and spectroscopy allows for determining the effect of molecular weight and processing parameters on the content of the electroactive phases.

It is evident from the data in Fig. 1 that the effect of the collector's rotational speed on the content of electroactive phases is strong. In the electrospinning technique, the speed of the collector can be controlled, and it affects the content of the electroactive phases [3]. Such a strong increase in the content of electroactive phases with collector rotational speeds is related to an increase in stretching forces leading to better molecular alignment and orientation in the nanofibers. The influence of molecular weight on the content of electroactive phases is evident only at the lowest rotational speed.



Sample – collector rotational speed [rpm]	F(α) (%)	F(β) + F(γ) (%)	F(β) (%)	F(γ) (%)
1 – 200	88±0.2	12 ±1.2	9 ±3	3 ±4
2 – 1000	35±1.4	65 ±0.7	52 ±6.1	13 ±3.3
3 – 2000	8±2.2	92 ±4	47 ±2	45 ±4.8
4 – 200	76±3	24 ±0.4	15 ±0.6	9 ±4.2
5 - 1000	28±1.9	72 ±2.9	57 ±0.9	15 ±1.3
6 - 2000	11±3.3	91 ±6.3	60 ±2	29 ±1.2

FIGURE 1 The relation between collector rotational speed, polymer molecular weight, and electroactive phases content (left); Electroactive phases content in PVDF nanofibers (right).

Cell viability ADSC cells cultured on PVDF scaffolds with the highest amount of electroactive phases and different rotational speeds of the collector (200, 1000, and 2000rpm), applied voltage 22 kV and flow rate 0.8 ml/h in the presence of ultrasound for 3, 14, and 21 days post-seeding were investigated (Figure 2). The in-vitro analysis shows the non-toxic properties of all specimens. There was slightly lower viability in samples compared to the control. Moreover, all scaffolds reached ≥ 70% values of viability, which is in accordance with the ISO 10993-5 standard connected to the living cells and non-toxic materials. The introduction of piezoelectric scaffolds with the presence of ultrasound has been previously reported and has a positive impact on cell behavior [4]. Ultrasound stimulation can emphatically enhance the properties of the nanofibrous scaffolds due to their bioactivity and biocompatibility [5].

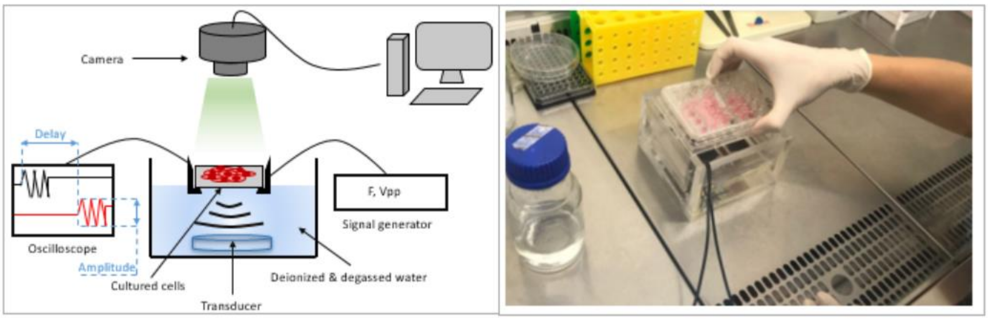


FIGURE 2 Ultrasound Stimulation as a non-invasive mechanical stimulation of cultured cells

It can be concluded that the higher molecular weight of the PVDF increases nanofibers' dimensions and electroactive phase content. Various electrospinning technique parameters show changes in electroactive phases with the maximum applied voltage of 22 kV and flow rate of 0.8 ml/h. Moreover, the presence of ultrasound during cell culture of human adipose-derived stromal cells proved positive impact on cell behavior. This study can serve as a good reference for the effect of molecular weight and processing parameters on the morphology and properties of electrospun PVDF fibers.

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