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Editorial

Editorial for the Special Issue on Characterization and Modelling of Composites, Volume II

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Abstract: The increasing demands for more durable, lighter, and smarter structures have led to the development of new and advanced composites. Increased strength and simultaneous weight reduction have resulted in energy savings and applications in several manufacturing industries, such as the automotive and aerospace industries as well as in the production of everyday products. Their optimal design and utilization are a process, which requires their characterization and efficient modeling. The papers published in this Special Issue of the *Journal of Composites Science* will give composite engineers and scientists insight into what the existing challenges are in the characterization and modeling for the composites field, and how these challenges are being addressed by the research community. The papers present a balance between academic and industrial research, and clearly reflect the collaborative work that exists between the two communities, in a joint effort to solve the existing problems.

Keywords: composites; composite structures; nanocomposites; additive manufacturing; characterization; modeling; finite element analysis; simulation; experiments

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The last few decades have seen extraordinary progress in the science and technology of composites. Their distinctive characteristics make composites desirable for engineering applications in a wide variety of industrial sectors. New manufacturing methods are driving cost reduction, and emerging areas such as nanocomposites, green composites, 2D/3D textile composites, multifunctional composites, and smart composites have been the focus of much exciting and innovative research activity. This Special Issue is the continuation of the successful first companion Special Issue [1,2]. It contains a snapshot of the research typical of this activity, and includes thirty-two papers on topics such as additive manufacturing of composites, structural and failure analysis, process modeling, fundamental mechanisms at nano- and microscales in both nano- and biocomposites, and non-destructive testing methods for advanced carbon composites.

Fiber-reinforced polymer matrix composites continue to attract scientific and industrial interest since they offer superior strength-, stiffness-, and toughness-to-weight ratios. The research of Youssef et al. [3] characterizes two sets of E-Glass/Epoxy composite skins: stressed and unstressed. The stressed samples were previously installed in an underground power distribution vault and were exposed to fire while the unstressed composite skins were newly fabricated and never-deployed samples. The mechanical, morphological, and elemental composition of the samples were methodically studied using a dynamic mechanical analyzer, a scanning electron microscope (SEM), and an x-ray diffractometer, respectively. Sandwich composite panels consisting of E-glass/Epoxy skin and balsa wood core were originally received, and the balsa wood was removed before any further investigations. Skin-only specimens with dimensions of ~12.5 mm wide, ~70 mm long, and ~6 mm thick were tested in a Dynamic Mechanical Analyzer in a dual-cantilever beam configuration at 5 Hz and 10 Hz from room temperature to 210 °C. Micrographic analysis using the SEM indicated a slight change in morphology due to the fire event but confirmed the effectiveness of the fire-retardant agents in quickly suppressing the fire. Accompanying Fourier transform infrared and energy dispersive X-ray spectroscopy studies corroborated the mechanical and morphological results. Finally, X-ray diffraction showed that the fire event consumed the surface level fire-retardant and the structural attributes of the E-Glass/Epoxy remained mainly intact. The results suggest the panels can continue field deployment, even after short fire incident.

Mechanical properties of fiber-reinforced engineering materials often depend on their local orientation of fibers. Analytical orientation models such as the Folgar Tucker model are widely applied to predict the orientation of suspended non-spherical particles. The accuracy of these models depends on empirical model parameters. Dietemann et al. [4] assess how well analytical orientation models can predict the orientation of suspensions not only consisting of fibers but also of an additional second particle type in the shape of disks, which are varied in size and filling fraction. They mainly focus on the FT model and compare its accuracy to more complex models such as Reduced-Strain Closure model, Moldflow Rotational Diffusion model, and Anisotropic Rotary Diffusion model.

Building owners have become interested in a sustainable and healthy environment, which is a trend favoring ecological materials with outstanding performance. In addition, currently thermal insulation can be considered to be a hot issue for civil engineering that tries to reduce cooling and heating costs and, at the same time, eliminate CO_2 emissions. Ninikas et al. [5] investigate the technical feasibility of manufacturing low density insulation particleboards that were made from two renewable resources, namely hemp fibers (Cannabis sativa) and pine tree bark, which were bonded with a non-toxic methyl cellulose glue as a binder. Four types of panels were made, which consisted of varying mixtures of tree bark and hemp fibers (tree bark to hemp fibers percentages of 90:10, 80:20, 70:30, and 60:40). An additional set of panels was made, consisting only of bark. The results showed that addition of hemp fibers to furnish improved mechanical properties of boards to reach an acceptable level. The thermal conductivity unfavorably increased as hemp content increased, though all values were still within the acceptable range. Based on cluster analysis, board type 70:30 (with 30% hemp content) produced the highest mechanical properties as well as the optimal thermal conductivity value. It is concluded that low density insulation boards can be successfully produced using these waste raw materials.

Recently, a rapid development has been observed concerning drive shafts made of composite materials that, in addition to their low weight, are able to respond effectively to their functional demands. The potential performance improvement of specific mechanical components due to the use of nanomaterials has not been extensively reported yet. Georgantzinos et al. [6] carried out the modal and linear buckling analysis of a laminated composite drive shaft reinforced by multi-walled carbon nanotubes using an analytical approach, as well as the finite element method. Their theoretical model is based on classical laminated theory. The fundamental frequency and the critical buckling torque were determined for different fiber orientation angles. The Halpin–Tsai model was employed to calculate the elastic modulus of composites having randomly oriented nanotubes. The effect of various carbon nanotube volume fractions in the epoxy resin matrix on the material properties of unidirectional composite laminas was also analyzed. The fundamental frequency and the critical buckling torque obtained by the finite element analysis and the analytical method for different fiber orientation angles were in good agreement with each other. The results were verified with data available in the open literature, where possible. For the first time in the literature, the influence of carbo nanotube fillers on various composite drive shaft design parameters such as the fundamental frequency, critical speed, and critical buckling torque of a hybrid fiber-reinforced composite drive shaft was predicted.

During construction works, it is advisable to prevent strong thawing and an increase in the moisture content of the foundations of engineering structures in the summer. Since the density of water and ice differ, due to the difference bulging of the foundation sections can occur when it freezes back in winter. Sivtsev et al. [7] numerically investigated the effect of fiber-reinforced piles on the thermal field of the surrounding soil; that is, the study of the influence of aggregates with high and low thermal-physical properties on the temperature of frozen soils is conducted. Basalt and steel fiber reinforcement were compared. The difficulty of this work is that the inclusions inside piles are too small compared to the pile itself. Therefore, to solve the Stefan problem, a generalized multiscale finite element method (GMsFEM) was used. In the GMsFEM, the usual conforming partition of the domain into a coarse grid was used. It allowed reducing problem size and, consequently, accelerating the calculations. Results of the multiscale solution were compared with fine-scale solution, the accuracy of GMsFEM was investigated, and the optimal solution parameters were defined. Therefore, GMsFEM was shown to be well suited for the designated task. Collation of basalt and steel fiber reinforcement showed a beneficial effect of high thermal conductive material inclusion on freezing of piles in winter.

The demand for high strength and lightweight steel is inevitable for technological, environmental, and economic progress. Umar et al. [8] uses EBSD data of two thermo-mechanically processed medium carbon (C45EC) steel samples to simulate micromechanical deformation and damage behavior. Two samples with 83% and 97% spheroidization degrees are subjected to virtual monotonic quasi-static tensile loading. The ferrite phase is assigned already reported elastic and plastic parameters, while the cementite particles are assigned elastic properties. A phenomenological constitutive material model with critical plastic strain-based ductile damage criterion is implemented in the DAMASK framework for the ferrite matrix. At the global level, the calibrated material model response matches well with experimental results, with up to ~97% accuracy. The simulation results provide essential insight into damage initiation and propagation based on the stress and strain localization due to cementite particle size, distribution, and ferrite grain orientations. In general, it is observed that the ferrite–cementite interface is prone to damage initiation at earlier stages triggered by the cementite particle clustering. Furthermore, it is observed that the crystallographic orientation strongly affects the stress and stress localization and consequently nucleating initial damage.

The mechanical and ring stiffness of glass fiber pipes are the most determining factors for their ability to perform their function, especially in a work environment with difficult and harmful conditions. Usually, these pipes serve in rough underground environments of desert and petroleum fields; therefore, they are subjected to multi-type deterioration and damage agents. In polymers and composite materials, corrosion is identified as the degradation in their properties. Hassan et al. [9] carried out tension and compression tests before and after preconditioning in a corrosive agent for 60 full days to reveal corrosion influences. Moreover, the fracture toughness is measured using a standard single edge notch bending. Ring stiffness of such pipes which, are considered characteristic properties, is numerically evaluated using the extended finite element method before and after preconditioning. The results reported that both tensile and compressive strengths degraded nearly more than 20%. Besides the fracture toughness decrease, the stiffness ring strength is reduced, and the finite element results are in good agreement with the experimental findings.

Components made from multidirectional fiber-reinforced composite laminates experience several distinct damage mechanisms when exposed to fatigue loads. A model that predicts the stiffness degradation in multidirectional reinforced laminates due to off-axis matrix cracks is proposed by Drvoderic et al. [10] and evaluated using data from fatigue experiments. Off-axis cracks are detected in images from the fatigue tests with automated crack detection to compute the crack density of the off-axis cracks which is used as the damage parameter for the degradation model. The purpose of this study is to test the effect of off-axis cracks on laminate stiffness for different laminate configurations. The hypothesis is that off-axis cracks have the same effect on the stiffness of a ply regardless of the acting stress components if the transverse stress is positive. This hypothesis proves to be wrong. The model can predict the stiffness degradation well for laminates with a ply orientation such as the one used for calibration but deviates for plies with different in-plane shear stress. This behavior can be explained by the theory that off-axis cracks develop by two different micro damage modes depending on the level of in-plane shear stress. It is found that besides influencing the initiation and growth of off-axis cracks, the stiffness degradation is also mode dependent.

Lack of cost information is a barrier to acceptance of 3D woven preforms as reinforcements for composite materials, compared with 2D preforms. A parametric, resource-based technical cost model (TCM) was developed by Clarke et al. [11] for 3D woven preforms based on a novel relationship equating manufacturing time and 3D preform complexity. Manufacturing time, and therefore cost, was found to scale with complexity for seventeen bespoke manufactured 3D preforms. Two sub-models were derived for a Weavebird loom and a Jacquard loom. For each loom, there was a strong correlation between preform complexity and manufacturing time. For a large, highly complex preform, the Jacquard loom is more efficient, so preform cost will be much lower than for the Weavebird. Provided production is continuous, learning, either by human agency or an autonomous loom control algorithm, can reduce preform cost for one or both looms to a commercially acceptable level. The TCM cost model framework could incorporate appropriate learning curves with digital twin/multi-variate analysis so that cost per preform of bespoke 3D woven fabrics for customized products with low production rates may be predicted with greater accuracy. A more accurate model could highlight resources such as tooling, labor, and material for targeted cost reduction.

In tape placement process, the laying angle and laying sequence of laminates have proven their significant effects on the mechanical properties of carbon fiber reinforced composite material, specifically, laminates. To optimize these process parameters, an optimization algorithm is developed by Mou et al. [12] based on the principles of genetic algorithms for improving the precision of traditional genetic algorithms and resolving the premature phenomenon in the optimization process. Taking multi-layer symmetrically laid carbon fiber laminates as the research object, this algorithm adopts binary coding to conduct the optimization of process parameters and mechanical analysis with the laying angle as the design variable and the strength ratio R as the response variable. A case study was conducted, and its results were validated by the finite element analyses. The results show that the stresses before and after optimization are 116.0 MPa and 100.9 MPa, respectively, with a decrease in strength ratio by 13.02%. The results comparison indicates that, in the iterative process, the search range is reduced by determining the code and location of important genes, thereby reducing the computational workload by 21.03% in terms of time consumed. Through multiple calculations, it validates that "gene mutation" is an indispensable part of the genetic algorithm in the iterative process.

In industrial applications where contact behavior of materials is characterized, fretting-associated fatigue plays a vital role as a failure agitator. While considering connection, it encounters friction. Biomaterials such as polytetrafluoroethylene (PTFE) and ultra-high-molecular-weight polyethylene (UHMWPE) are renowned for their low coefficient of friction and are utilized in sophisticated functions such as the hip joint cup and other biomedical implants. In addition to the axial stresses, some degree of dynamic bending stress is also developed occasionally in those fretting contacts. Shah et al. [13] investigated the fracture behavior of a polymer PTFE under bending fretting fatigue. Finite element analysis justified the experimental results. A mathematical model is proposed by developing an empirical equation for fracture characterization in polymers such as PTFE. It was found that the bending stiffness exists below the loading point ratio (LPR) 3.0, near the collar section of the specimen. Along with fretting, the bending load forces the specimen to crack in a brittle-ductile mode near the sharp-edged collar where the maximum strain rate, as well as stress, builds up. For a loading point ratio of above 3, a fracture takes place near the fretting pads in a tensile-brittle mode. Strain proportionality factor, k was found as a life optimization parameter under conditional loading. The microscopic analysis revealed that the fracture striation initiates perpendicularly to the fretting load. The fretting fatigue damage characteristic of PTFE may have a new era for the biomedical application of polymer-based composite materials.

Conveyor belts are used in a wide range of applications such as supermarkets, logistic centers, and mining. The conveyor belts in mining are reinforced with steel cables to reach the high strengths required. Frankl et al. [14] introduces a finite element model of a steel cable-reinforced conveyor belt to accurately compute stresses in the splice. In the modelled test rig, the belt runs on two drums and is loaded with a cyclic longitudinal force. An explicit solver is used to efficiently handle the high number of elements and contact conditions. This, however, introduces some issues of dynamics in the model, which are subsequently solved: (a) the longitudinal load is applied with a smooth curve and damping is introduced in the beginning of the simulation, (b) residual stresses are applied in regions of the belt that are initially bent around the drums, and (c) supporting drums are introduced at the start of the simulation to hinder oscillations of the belt at low applied forces. To accurately capture the tensile and bending stiffness of the cables, they are modelled by a combination of solid and beam elements. The results show that numerical artefacts can be reduced to an acceptable extent. In the region of highest stresses, the displacements are additionally mapped onto a submodel with a smaller mesh size. The results show that, for the investigated belt, the local maximum principal stresses significantly increase when this region of highest stresses comes into contact with, and is bent by, the drum. Therefore, it is essential to also consider the belt's bending to predict failure in such applications.

The microstructure-based finite element modeling (MB-FEM) of material representative volume element (RVE) is a widely used tool in the characterization and design of various composites. However, the MB-FEM has a number of deficiencies, e.g., time-consuming in the generation of a workable geometric model, challenge in achieving high volume-fractions of inclusions, and poor quality of finite element mesh. Luo [15] first demonstrate that for particulate composites the particle inclusions have homogeneous distribution and random orientation, and if the ratio of particle characteristic length to RVE size is adequately small, elastic properties characterized from the RVE are independent of particle shape and size. Based on this fact, it is proposed a microstructure-free finite element modeling (MF-FEM) approach to eliminate the deficiencies of the MB-FEM. The MF-FEM first generates a uniform mesh of brick elements for the RVE, and then a number of the elements, with their total volume determined by the desired volume fraction of inclusions, is randomly selected and assigned with the material properties of the inclusions; the rest of the elements are set to have the material properties of the matrix. Numerical comparison showed that the MF-FEM has a similar accuracy as the MB-FEM in the predicted properties. The MF-FEM was validated against experimental data reported in the literature and compared with the widely used micromechanical models. The results show that for a composite with small contrast of phase properties, the MF-FEM has excellent agreement with both the experimental data and the micromechanical models. However, for a composite that has large contrast of phase properties and high volume-fraction of inclusions, there exist significant differences between the MF-FEM and the micromechanical models. The proposed MF-FEM may become a more effective tool than the MB-FEM for material engineers to design novel composites.

In recent years, finite element analysis (FEA) models of different porous scaffold shapes consisting of various materials have been developed to predict the mechanical behavior of the scaffolds and to address the initial goals of 3D printing. Although mechanical properties of polymeric porous scaffolds are determined through FEA, studies on the polymer nanocomposite porous scaffolds are limited. Kakarla et al. [16] carried out FEA with the integration of material designer and representative volume elements (RVE) on a 3D scaffold model to determine the mechanical properties of boron nitride nanotubes (BNNTs)-reinforced gelatin (G) and alginate (A) hydrogel. The maximum stress regions were predicted by FEA stress distribution. Furthermore, the analyzed material model and the boundary conditions showed minor deviation (4%) compared to experimental results. It was noted that the stress regions are detected at the zone close to the pore areas. These results indicated that the model used in this work could be beneficial in FEA studies on 3D-printed porous structures for tissue engineering applications.

Variable stiffness composite laminates can improve the structural performance of composite structures by expanding the design space. Carvalho et al. [17] explores the application of variable stiffness laminated composite structures to maximize the fundamental frequency by optimizing the tow angle. To this end, an optimization framework is developed to design the fiber angle for each layer based on the maximization of the fundamental frequency. It is assumed that the design process includes the manufacturing constraints encountered in the automated fiber placement process and a linear fiber angle variation. The current study improves existing results by considering embedded gap defects within the optimization framework. The plates are assumed symmetric, with clamped and simply supported boundary conditions. The optimal results and a comparison between the non-steered and steered plates with and without gaps are presented. Results show that, although gaps deteriorate the structural performance, fiber steering can still lead to an increase in the fundamental frequency depending on the plate's geometry and boundary conditions.

Sandwich structures benefit from the geometrical stiffening effect due to their high cross-sectional area moment of inertia. Transferred to carbon fiber-reinforced plastic (CFRP) components, the needed amount of carbon fiber (CF) material can be reduced and with it the CO_2 footprint. The combination of a light foam core with continuous fiber-reinforced face sheets is a suitable material combination for lightweight design. Traditionally, CFRP sandwich structures with a foam core are manufactured in a two-step process by combining a prefabricated foam core with fiber-reinforced face sheets. However, in addition to the reduction in the used CFRP material, manufacturing processes with a high efficiency are needed. Behnisch et al. [18] investigated sandwich manufacturing and characterization by using the Direct Sandwich Composite Molding (D-SCM) process for the one-step production of CFRP sandwich structures. The D-SCM process utilizes the resulting foaming pressure during the reactive polyurethane (PUR) foam system expansion for the impregnation of the CF-reinforced face sheets. The results of this work show that the production of sandwich structures with the novel D-SCM process strategy is feasible in one single manufacturing step and achieves good impregnation qualities. The foam density and morphology significantly influence the core shear properties and thus the component behavior under a bending load.

The quadratic function of the original Tsai–Wu failure criterion for transversely isotropic materials is re-examined by Li et al. [19]. According to analytic geometry, two of the troublesome coefficients associated with the interactive terms—one between in-plane direct stresses and one between transverse direct stresses—can be determined based on mathematical and logical considerations. The analysis of the nature of the quadratic failure function in the context of analytic geometry enhances the consistency of the failure criterion based on it. It also reveals useful physical relationships as intrinsic properties of the quadratic failure function. Two clear statements can be drawn as the outcomes of the present investigation. Firstly, to maintain its basic consistency, a failure criterion based on a single quadratic failure function can only accommodate five independent strength properties, viz. the tensile and compressive strengths in the directions along fibers and transverse to fibers, and the in-plane shear strength. Secondly, amongst the three transverse strengths—tensile, compressive and shear—only two are independent.

Thermoset polymers offer great opportunities for mass production of fiber-reinforced composites and are being adopted across a large range of applications within the automotive, aerospace, construction and renewable energy sectors. They are usually chosen for marine engineering applications for their excellent mechanical behavior, including low density and low cost compared to conventional materials. In the marine environment, these materials are confronted by severe conditions, thus there is the necessity to understand their mechanical behavior under critical loads. The high strain rate performance of bonded joints composite under hygrothermal aging has been studied by Lagdani et al. [20]. Initially, the bonded composite specimens were hygrothermal aged with the conditions of 50 °C and 80% in temperature and relative humidity, respectively. After that, gravimetric testing is used to describe the moisture diffusion properties for the adhesively bonded composite samples and exhibit lower weight gain for this material. Then, the in-plane dynamic compression experiments were carried out at different impact pressures ranging from 445 to 1240 s^{-1} using the SHPB (Split Hopkinson Pressure Bar) technique. The experimental results demonstrated that the dynamic behavior varies with the variation of strain rate. Buckling and delamination of fiber are the dominant damage criteria observed in the sample during in-plane compression tests.

Haas et al. [21] tried to enhance and validate a systematic approach for the structural finite element (FE) analysis of thermoplastic impregnated 3D filament winding structures (fiber skeletons). The idealized modeling of geometrically complex fiber skeletons used in previous publications is refined by considering additional characteristic dimensions and investigating their mechanical influence. Moreover, the modeling approach is transferred from the meso- to the macro-level in order to reduce modeling and computational effort. The properties of meso- and macro-level FE models are compared using the example of simple loop specimens. Based on the results, respective application fields are defined. In the next step, the same modeling approach is applied to a more complex, three-dimensional specimen—the inclined loop. For its macro-level FE model, additional material characterization and modeling, as well as enhancements in the modeling of the geometry, are proposed. Together with previously determined effective composite properties of fiber skeletons, these results are validated in experimental tensile tests on inclined loop specimens.

For some categories of aircraft, such as helicopters and tiltrotors, fuel storage systems must satisfy challenging crash resistance requirements to reduce or eliminate the possibility of fuel fires and thus increase the chances of passenger survival. Therefore, for such applications, fuel tanks with high flexibility (bladder) are increasingly used, which can withstand catastrophic events and avoid fuel leakages. The verification of these capabilities must be demonstrated by means of experimental tests, such as the cube drop test (MIL-DTL-27422). To reduce development costs, it is necessary to execute experimental tests with a high confidence of success, and, therefore, it is essential to have reliable and robust numerical analysis methodologies. Cristillo et al. [22] tried to provide a comparison between two explicit FE codes (i.e., Abaqus and Ls-Dyna), which are the most frequently used for such applications according to experimental data in the literature. Both codes offer different material models suitable for simulating the tank structure, and therefore, the most suitable one must be selected by means of a specific trade-off and calibration activity. Both can accurately simulate the complex fluid–structure interaction thanks to the use of the SPH approach, even if the resulting sloshing capabilities are quite different from each other. Additionally, the evolution of the tank's deformed shape highlights some differences, and Abaqus seems to return a more natural and less artificial behavior. For both codes, the error in terms of maximum impact force is less than 5%, but, even in this case, Abaqus can return slightly more accurate results.

Additively manufactured parts play an increasingly important role in structural applications. Fused Layer Modeling (FLM) has gained popularity due to its cost-efficiency and broad choice of materials, among them, short fiber reinforced filaments with high specific stiffness and strength. To design functional FLM parts, adequate material models for simulations are crucial, as these allow for reliable simulation within virtual product development. Witzgall et al. [23] presented a new approach to derive FLM material models for short fiber reinforced parts; it is based on simultaneous fitting of the nine orthotropic constants of a linear elastic material model using six specifically conceived tensile specimen geometries with varying build direction and different extrusion path patterns. The approach is applied to a 15 wt.% short carbon-fiber reinforced PETG filament with own experiments, conducted on a Zwick HTM 5020 servo-hydraulic high-speed testing machine. For validation, the displacement behavior of a geometrically more intricate demonstrator part, printed upright, under bending is predicted using simulation and compared to experimental data. The workflow proves stable and functional in calibration and validation.

The quality of the fiber orientation of injection molding simulations and the transferred fiber orientation content, due to the process–structure coupling, influence the material modeling and thus the prediction of subsequently performed structural dynamics simulations of short-fiber reinforced, thermoplastic components. Existing investigations assume a reliable prediction of the fiber orientation in the injection molding simulation. The influence of the fiber orientation models and used boundary conditions of the process–structure coupling is mainly not investigated. Kriwet and Stommel [24] investigated the influence of the fiber orientation from injection molding simulations on the resulting structural dynamics simulation of short-fiber reinforced thermoplastic components. The Advani–Tucker Equation with phenomenological coefficient tensor is used in a 3- and 2.5-dimensional modeling approach for calculating the fiber orientation. The prediction quality of the simulative fiber orientations is evaluated in comparison to experiments. Depending on the material modeling and validation level, the prediction of the simulated fiber orientation differs in the range between 7.3 and 347.2% averaged deviation significantly. Furthermore, depending on the process–structure coupling and the number of layers over the thickness of the model, the Kullback–Leibner divergence differs in a range between 0.1 and 4.9%. More layers lead to higher fiber orientation content in the model and improved prediction of the structural dynamics simulation. The investigations prove that the influence of the fiber orientation on the structural dynamics simulation is lower than the influence of the material modeling. With a relative average deviation of 2.8% in the frequency and 38.0% in the amplitude of the frequency response function, it can be proven that high deviations between experimental and simulative fiber orientations can lead to a sufficient prediction of the structural dynamics simulation.

Abbasi et al. [25] conducted an FE numerical study to assess the effect of size on the shear resistance of reinforced concrete (RC) beams strengthened in shear with externally bonded carbon fiber-reinforced polymer (EB-CFRP). Although a few experimental studies have been performed, there is still a lack of FE studies that consider the size effect. Experimental tests are time-consuming and costly and cannot capture all the complex and interacting parameters. In recent years, advanced numerical models and constitutive laws have been developed to predict the response of laboratory tests, particularly for issues related to shear resistance of RC beams, namely, the brittle response of concrete in shear and the failure modes of the interface layer between concrete and EB-CFRP (debonding and delamination). Numerical models have progressed in recent years and can now capture the interfacial shear stress along the bond and the strain profile along the fibers and the normalized main diagonal shear cracks. This paper presents the results of a nonlinear FE numerical study on nine RC beams strengthened in shear using EB-CFRP composites that were tested in the laboratory under three series, each containing three sizes of geometrically similar RC beams (small, medium, and large). The results reveal that numerical studies can predict experimental results with good accuracy. They also confirm that the shear strength of concrete and the contribution of CFRP to shear resistance decrease as the size of beams increases.

Lithium-based batteries with improved safety performance are highly desired. At present, most safety hazard is the consequence of the ignition and flammability of organic liquid electrolytes. Dry ceramic-polymer composite electrolytes are attractive for their merits of non-flammability, reduced gas release, and thermal stability, in addition to their mechanical strength and flexibility. Denney and Huang [26] fabricated free-standing solid composite electrolytes made up of polyethylene oxide (PEO), $LiBF_4$ salt, and $Li_{1+x}Al_xGe_{2-x}(PO_4)_3$ (LAGP). This study is focused on analyzing the impacts of LAGP on the thermal decomposition characteristics in the series of PEO/$LiBF_4$/LAGP composite membranes. It is found that the appropriate amount of LAGP can (1) significantly reduce the organic solvent trapped in the polymer network and (2) increase the peak temperature corresponding to the thermal degradation of the PEO/$LiBF_4$ complex. In the presence of LAGP, although the peak temperature related to the degradation of free PEO is reduced, the portion of free PEO, as well as its decomposition rate, is effectively reduced, resulting in slower gas release.

Mechanical properties of fiber-reinforced polymers are sensitive to environmental influences due to the presence of the polymer matrix but inhomogeneous and anisotropic due to the presence of the fibers. Hence, structural analysis with mechanical properties as a function of loading, environment, design, and material condition produces more precise, reliable, and economic structures. Esha et al. [27] developed an analytical model that can predict engineering values as well as non-linear stress–strain curves as a function of six independent parameters for short fiber-reinforced polymers manufactured by injection molding. These parameters are the strain, temperature, humidity, fiber content, fiber orientation, and thickness of the specimen. A three-point test matrix for each independent parameter is used to obtain experimental data. To insert the effect of in-homogenous and anisotropic distribution of fibers in the analytical model, microCT analysis is conducted. Similarly, dynamic mechanical thermal analysis (DMTA) is performed to insert the viscoelastic effect of the material. The least mean square regression method is used to predict empirical formulas. The standard error of regression for the fitting of the model with experimental stress–strain curves is closely controlled below 2% of the stress range. This study provides user-specific material data for simulations with specific material, loading, and environmental conditions.

Spiral steel cables feature complex deformation behavior due to their wound geometry. In applications where the cables are used to reinforce rubber components, modeling the cables is not trivial, because the cable's outer surface must be connected to the surrounding rubber material. There are several options for modeling steel cables using beam and/or solid elements for the cable. So far, no study that lists and evaluates the performance of such approaches can be found in the literature. Pletz et al. [28] investigate such modeling options for a simple seven-wire strand that is regarded as a cable. The setup, parameter calibration, and implementation of the approaches are described. The accuracy of the obtained deformation behavior is assessed for a three-cable specimen using a reference model that features the full geometry of the wires in the three cables. It is shown that a beam approach with anisotropic beam material gives the most accurate stiffness results. The results of the three-cable specimen model indicate that such a complex cable model is quite relevant for the specimen's deformation. However, there is no single approach that is well suited for all applications. The beam with anisotropic material behavior is well suited if the necessary simplifications in modeling the cable–rubber interface can be accepted. The present work thus provides a guide not only for calibrating but also for selecting the cable-modeling approach. It is shown how such modeling approaches can be used in commercial FE software for applications such as conveyor belts.

Recent investigations have highlighted the multi-resolution and high throughput characteristics of the spherical indentation experimental and analysis protocols. Millan-Espitia and Kalidindi [29] further demonstrate the capabilities of these protocols for reliably extracting indentation stress–strain (ISS) responses from the microscale constituents as well as the bulk scale of dual phase materials exhibiting bimodal microstructures. Specifically, we focus on bimodal microstructures produced in an α–β Ti6242 sample. Combining the multi-resolution indentation responses with microstructural statistics gathered from the segmentation of back-scattered electron images from the scanning electron microscope allowed for a critical experimental evaluation of the commonly utilized Rule of Mixtures based composite model for the elastic stiffness and plastic yield strength of the sample. The indentation and image analyses protocols described in this paper offer novel research avenues for the systematic development and critical experimental validation of composite material models.

Due to the high design freedom and weight specific properties carbon fiber reinforced plastics (CFRP) offer significant potential in light-weighting applications, specifically in the automotive sector. The demand for medium to high production quantities with consistent material properties has paved the way for the use of high-pressure resin transfer molding

(HP-RTM). Due to high experimental cost and number of the operational parameters the development of numerical simulations to predict part quality is growing. Despite this, erroneous assumptions and simplifications limit the application of HP-RTM models, specifically with regard to the energy models used to model the heat transfer occurring during infiltration. Sherratt et al. [30] investigate the operating parameters at which the thermal non-equilibrium energy model's increased computational cost and complexity is worth added accuracy. It was found that in nearly all cases, using the thermal non-equilibrium is required to obtain an accurate prediction of the temperature development and resulting final properties within the mold after the infiltration process.

Additive manufacturing or 3D printing has been utilized for parts built of composite materials. Both developing composite materials by adding reinforcement particles and printing such a combination of materials can cause a certain kind of defect and anomaly generation in printed parts or the inappropriate functionality of the 3D printers. Baechle-Clayton et al. review [31] the potential failures and flaws associated with fused deposition modeling (FDM) or fused filament fabrication (FFF) 3D printing technology. The focus is on presenting the failures and flaws that are caused by the operational standpoints and which are based on the many years of experience with current and emerging materials and equipment for the 3D printing of polymers and composites using the FDM/FFF method. This study provides discussions and insights into the potential factors that can cause the failure of 3D printers when producing a part and presents the type and characteristics of potential flaws that can happen in the produced parts. Common defects posed by FDM printing have been discussed, and common nondestructive detection methods to identify these flaws both in-process and after the process is completed are discussed. The discussions on the failures and flaws in machines provides useful information on troubleshooting the process if they happen, and the review on the failures and flaws in parts helps researchers and operators learn about the causes and effects of the flaws in a practical way.

Robust finite element models are utilized for their ability to predict simple to complex mechanical behavior under certain conditions at a very low cost compared to experimental studies, as this reduces the need for physical prototypes while allowing for the optimization of components. Rabiee and Ghasemnejad [32] reviewed various parameters in finite element techniques to simulate the crushing behavior of glass/epoxy tubes with different material models, mesh sizes, failure trigger mechanisms, element formulation, contact definitions, single and various numbers of shells and delamination modeling. Six different modeling approaches, namely, a single-layer approach and a multi-layer approach, were employed with 2, 3, 4, 6, and 12 shells. In experimental studies, 12 plies were used to fabricate a 3 mm wall thickness GFRP specimen, and the numerical results were compared with experimental data. This was achieved by carefully calibrating the values of certain parameters used in defining the above parameters to predict the behavior and energy absorption response of the finite element model against initial failure peak load (stiffness) and the mean crushing force. In each case, the results were compared with each other, including experimental and computational costs. The decision was made from an engineering point of view, which means compromising accuracy for computational efficiency. The aim is to develop an FEM that can predict energy absorption capability with a higher level of accuracy, around 5% error, than the experimental studies.

The benefit of fiber-reinforced composites originates from the interaction between the fiber reinforcement and the matrix. This interplay controls many of its mechanical properties and is of utmost importance to enable its unique performance as a lightweight material. However, measuring the fiber−matrix interphase strength with micromechanical tests, such as the Broutman test, is challenging, due to the many, often unknown boundary conditions. Vogtmann et al. [33] use state-of-the-art, high-resolution X-ray computed microtomography (XRM) as a tool to investigate post mortem the failure mechanisms of single carbon fibers within an epoxy matrix. This was conducted at the example of single carbon fiber Broutman test specimens. The capabilities of today's XRM analysis were shown in comparison to classically obtained light microscopy. A simple finite element model was used to enhance the understanding of the observed fracture patterns. In total, this research reveals the possibilities and limitations of XRM to visualize and assess compression-induced single fiber fracture patterns. Furthermore, comparing two different matrix systems with each other illustrates that the failure mechanisms originate from differences in the fiber−matrix interphases. The carbon fiber seems to fail due to brittleness under compression stress. Observation of the fiber slippage and deformed small fracture pieces between the fragments suggests a nonzero stress state at the fragment ends after fiber failure. Even more, these results demonstrate the usefulness of XRM as an additional tool for the characterization of the fiber−matrix interphase.

Finally, in this Special Issue established by Georgantzinos et al. [34] the concept of six-dimensional (6D) printing as a new branch of additive manufacturing investigating its benefits, advantages as well as possible limitations concerning the design and manufacturing of effective smart structures. The concept of 6D printing, to the author's best knowledge, is introduced for the first time. The new method combines the four-dimensional (4D) and five-dimensional (5D) printing techniques. This means that the printing process is going to use five degrees of freedom for creating the final object while the final produced material component will be a smart/intelligent one (i.e., will be capable of changing its shape or properties due to its interaction with an environmental stimulus). A 6D printed structure can be stronger and more effective than a corresponding 4D printed structure, can be manufactured using less material, can perform movements by being exposed to an external stimulus through an interaction mechanism, and it may learn how to reconfigure itself suitably, based on predictions via mathematical modeling and simulations.

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