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Editorial

Special Issue on Recent Advances in Theoretical and Computational Modeling of Composite Materials and Structures

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1. Introduction

The advancement in manufacturing technology and scientific research have improved the development of enhanced composite materials with tailored properties depending on their design requirements in many engineering fields, as well as in thermal and energy management. Some representative examples of advanced materials in many smart applications and complex structures rely on laminated composites, functionally graded materials (FGMs), and carbon-based constituents, primarily carbon nanotubes (CNTs), and graphene sheets or nanoplatelets, because of their remarkable mechanical properties, electrical conductivity, and high permeability. For such materials, experimental tests usually require a large economical effort because of the complex nature of each constituent, together with many environmental, geometrical, and/or mechanical uncertainties in nonconventional specimens. At the same time, the theoretical and/or computational approaches represent a valid alternative for the design of complex manufacts with more flexibility. In such a context, the development of advanced theoretical and computational models for composite materials and structures is a subject of active research, as explored here for a large variety of structural aspects, involving static, dynamic, buckling, and damage/fracturing problems at different scales.

Citation: Tornabene, F.; Dimitri, R. Special Issue on Recent Advances in Theoretical and Computational Modeling of Composite Materials and Structures. *Appl. Sci.* **2022**, *12*, 4715. https://doi.org/10.3390/app12094715

Received: 28 April 2022
Accepted: 5 May 2022
Published: 7 May 2022

2. Enhanced Theoretical and Computational Models

In a context where an increased theoretical/computational demand is required to solve solid mechanics problems, this Special Issue has collected 13 papers regarding the application of high-performing computational strategies and enhanced theoretical formulations to solve different linear/nonlinear problems, even from a multiphysical perspective. To this end, classical and nonclassical theories have been proposed together with multiscale approaches, homogenization techniques, and different fracturing models.

The first paper, authored by S. Brischetto and R. Torre [1], proposes a steady-state hygro-thermomechanical stress analysis of single-layered and multilayered plates and shells with FGMs under different moisture conditions and introduces a novel exact solution as a valid benchmark for moisture diffusion problems in composite materials. Different environmental conditions (primarily temperature and moisture) of structural components can significantly affect their internal stress distributions and overall response during their service life, with possible premature damage and failure mechanisms. Among advanced composite materials, FGMs represent heterogeneous materials with enhanced stiffness properties, hardness, thermal conductivity, moisture diffusivity, and corrosion resistance due to the combination of two of more different phases, primarily metallic and ceramic phases, as shown in more common examples [2]. In this setting, several recent works in literature focused on structures embedding FGMs, even with possible defects and porosities, and developed innovative analytical and numerical models combined with different higher-order assumptions to handle uncoupled or coupled multiphysical problems [3–8]. For multiscale electromechanical applications (i.e., sensors, actuators, and energy conversion devices), piezoelectric materials with functionally graded properties (FGPMs) are increasingly attracting the interest of many researchers [9–12]. This interest is mainly related to their capability to produce large displacements while minimizing the internal stress concentration, creep fatigue proneness, and interfacial failures, with improved reliability and life cycle in many intelligent devices, generally in the form of flexible cantilever elements [13]. As detailed in the work by H.X. Jing et al. [13], indeed, purely FGMs and FGPMs can exert bimodular effects to a certain degree, which can modify the mechanical behavior of structures, with a further influence on design applications of electromechanical devices based on piezoelectric effects.

Nowadays, with the advancement of nanotechnology, CNTs and graphene sheets represent two valid alternatives of structural reinforcement due to their outstanding properties. This has led to extensive research on the behavior of sandwich structures reinforced with nanocomposites [14–18]. Among different reinforcement possibilities, graphene nanoplatelets (GPLs) provide uniform reinforced assembly, as well as the easiest manufacturing process. In the work by M.S. Nematollahi [17], for example, a higher-order laminated beam theory is applied to include the shear and rotation effects on a thick GPL-reinforced sandwich beam, where the nonlinear governing equations of the problem are solved in a straightforward manner by means of the multiple timescale method. The sensitivity of the vibration response to the total amount of GPLs is explored by the authors, together with the possible effect related to the power-law parameter, structural geometry, and environmental conditions. Unlike traditional engineering structural problems, the design of micro-electromechanical systems (MEMS) usually involves microstructures, novel materials, and extreme operating conditions, where multisource uncertainties usually exist. In such a context, the work by M. Safarpour et al. [18] determines a general thermoelasticity solution to treat both the static and frequency problems of functionally graded, GPL-reinforced composite plate structures under different boundary conditions and embedding foundations, as typically applied in many lightweight mechanical and biomedical components, as well as in membranes and flexible wearable sensors and actuators. Another kind of carbon-based reinforcement relies on CNTs, in lieu of conventional fibers, for which different molecular dynamic simulations have been successfully performed in the literature to exploit the elastic properties of polymer–CNT composites embedded in polymeric matrices [19,20]. Among sandwich CNT-based nanostructural applications, the work authored by A.A Daikh et al. [21] provides a mathematical continuum model to investigate the buckling behavior of cross-ply, single-walled, CNT-reinforced curved beams in thermal environment, based on a novel quasi-3D higher-order shear deformation theory and nonlocal strain gradient method accounting for any possible nanoscale size effect. An efficient numerical model based on a fractional calculus is, instead, established by D. Gritsenko and R. Paoli [22,23] to study the viscoelastic flow in circular pipes, for different geometrical radii, fractional orders, and elastic moduli ratios, compared to classical models. This mathematical tool allows for a significant improvement of predictive power for numerous practical applications from heat conduction to anomalous diffusion and viscoelastic properties of fluids and solids.

The extensive use of composite materials and structures in many engineering applications with complex microstructures and manufacturing processes requires a thorough attention to their mechanical performances, such as the structural deflection damage and load capacity [24,25], as well as the buckling and dynamic behavior [26], along with possible related uncertainties and stochastic variations. In this setting, the work authored by J. Chen et al. [24] provides a damage investigation of carbon-fiber-reinforced plastic laminates with fasteners accounting for a complex multiphysics coupling process. A theoretical study on prestressed pipes is also provided in [25], showing that high-strength prestressing wires withstand an internal high water pressure and external load, and a mortar coating protects the wires and cylinder against corrosion. As also highlighted in the work by C. Shen et al. [26], the characteristics of a coarse–fine composite structure and the complexity of dynamics modeling affect the entire system's high precision control performance. In this last work, the authors apply a finite element analysis and theoretical study of the stress and deflection of a two-axis, four-gimbal, coarse–fine composite, UAV electro-optical pod, with useful insights for aerospace applications.

3. Future Developments

Although this Special Issue has been closed, further developments on the theoretical and computational modeling of enhanced structures and composite materials are expected, including their static, dynamic, and buckling responses and fracture mechanics at different scales, which will be useful for many industrial applications.

Author Contributions: Conceptualization, F.T. and R.D.; methodology, F.T. and R.D.; formal analysis, F.T. and R.D.; investigation, F.T. and R.D.; data curation, F.T. and R.D.; writing—original draft preparation, F.T. and R.D.; writing—review and editing, F.T. and R.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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