Composites: Part B 43 (2012) 2493–2494

Contents lists available at SciVerse ScienceDirect

Composites: Part B

journal homepage: www.elsevier.com/locate/compositesb

Editorial Preface

Special Issue of Composites Part B: Homogenization and Micromechanics of Smart and Multifunctional Materials

The ever-evolving computational technology enables modeling and simulation of diverse materials across disciplinary boundaries, as well as across multiple spatial and temporal scales. Rapid development of a new generation of materials with tailored functionalities for a wide range of applications requires the use of accurate and efficient modeling techniques capable of consistently and seamlessly spanning multiple scales to establish structure–property connection through underpinning mechanisms that lead to observed response. Physics-based simulation capabilities coupled with optimization algorithms help to reduce new material development and implementation cycle through the identification of engineered material architectures that produce targeted response. Concomitantly, they help to eliminate myriad of material-microstructural combinations that arise from the rapid manufacturing advances and advanced material concepts that are being developed and implemented with increasing frequency.

Homogenization and micromechanics-based analytical and numerical techniques, together with optimization algorithms, play a key role in the above enterprise which provides motivation for this special issue. Reflecting the importance of homogenization, micromechanics and optimization techniques, as well as characterization of new material and structural systems, in the rapid development and implementation of advanced materials concepts, experts working in the above areas were invited to contribute refereed papers which are arranged accordingly as briefly described in the sequel.

The special issue opens with the contribution by Tsalis, Chatzigeorgiou and Charalambakis which describes an asymptotic homogenization framework for materials with generalized periodicity, and offers illustrations of new material concepts involving wavy multilayers and cylindrically periodic fibrous composites. This is followed by the contribution of Stratis and Yannacopoulos who describe the construction of a two-scale homogenization theory for electromagnetic media based on an auxiliary elliptic problem. Next, Cavalcante, Pindera and Khatam give an overview of the finite-volume micromechanics approach for periodic materials with linear and nonlinear elastic, and elastic–plastic phases based on the 0th order homogenization theory, and illustrate its suitability for simulation of multiphase and multifunctional materials with complex microstructures. Specific micromechanics approaches and solutions to technologically important problems are presented next, starting with the contribution of Danas and Aravas who describe a micromechanics-based constitutive model for elastic–plastic porous materials undergoing finite deformations. This is followed by the contribution of Collard and Zineb who combine self-consistent and Mori–Tanaka approaches in a multiscale setting to simulate the response of shape memory alloys, starting at the single crystal grain level. Similarly, Chatzigeorgiou, Seidel and Lagoudas employ a combination of Mori–Tanaka and composite cylinder approaches to generate mechanical properties of fuzzy fiber composites, quantifying the effect of carbon nanotubes on the homogenized moduli in this new material system with potentially enhanced interfacial properties. Batra, Gopinath and Zheng develop a homogenized model for the inelastic response of unidirectional composites with pressure-dependent yield effects, wherein the homogenized yield surface parameters are obtained from micromechanics considerations, which may be efficiently employed in a higher-level analysis. The effect of fiber/matrix interfacial properties is rigorously investigated by Tzounis, Gergidis, Matikas and Charalambopoulos via a three-dimensional elasticity solution of the composite cylinder boundary value problem, highlighting the transition from perfect to completely debonded interface and the concomitant measurable change in the axial modulus. The difficult problem of wave propagation in a cylindrical waveguide with microstructure is solved analytically by Charalambopoulos, Gergidis and Kartalos, using dyadic cylindrical harmonics, laying the groundwork for the determination of dispersion curves in cortical bones as a diagnostic tool. Next, a theoretical framework for a moving singular surface in heterogeneous materials, which may be employed to model the difficult problems of crack and phase-transition boundary propagation is provided by Arvanitakis, Chronaiou and Kalpakides. The homogenization and micromechanics part of the special issue closes with the contribution of Tsakmakis, Brose and Sfyris who describe and compare two approaches for the solution of gradient plasticity problems which naturally arise in heterogeneous media, highlighting the advantages of one over the other.

The second sequence of papers deals with optimization of heterogeneous microstructures, which plays an important role in the efficient design of materials with engineered architectures. Vatanabe, Paulino and Silva use a topology optimization algorithm to investigate the influence of pattern gradation on energy conversion devices that employ piezoelectric materials, highlighting the role of constraints in enhancing electric power output. An evolutionary-hybrid optimization algorithm is proposed by Kaminakis and Stavroulakis for the design of compliant microstructures with homogenized negative Poisson's ratios based on design space discretization with truss elements, and an iterative local search method which overcomes some of the problems associated with global optimization. Finally, Kalpakides, Patsouras, Hadjigeorgiou and Stavroulakis describe an optimization procedure based on material forces for the design of plane trusses which may be useful in the design of energy absorbing sandwich materials.

1359-8368/$ - see front matter
http://dx.doi.org/10.1016/j.compositesb.2012.04.024

The third sequence of papers deals with material and structural characterization, including health monitoring techniques. The first paper by Kordatos, Aggelis and Matikas describes a combined thermographic and acoustic emission approach for monitoring crack growth in heterogeneous materials under fatigue loading, which delivers life prediction capability important to the development of sustainable material and structural designs. Next, Grammatikos and Paipetis investigate the effectiveness of carbon tube networks in polymeric matrix composites in providing sensing capabilities through electrical resistance variation, an important issue in the development of multifunctional composites. Gkikas, Barkoula and Paipetis characterize the effect of sonication-based dispersion of carbon nanotubes on thermo-mechanical properties of nanocomposites, including toughness, demonstrating significant property increases with improved dispersion. Stefanidou and Papayianni investigate the influence of nanoparticles on the properties of Portland cement paste, demonstrating the influence of volume fraction on material density (porosity) and strength. Finally, Njuguna, Yan, Hu, Bell and Yarlagadda characterize the response of a nanocomposite strain sensor fabricated by sandwiching carbon nanotube film between two polymer layers, demonstrating high sensitivity to mechanical strain and environmental temperature.

This special issue grew out of the Minisymposium on Micromechanics and Modeling of Multifunctional Materials 2011 that took place at the Aristotle University of Thessaloniki during July 14–15, 2011 in the historic city of Thessaloniki, Greece. The Minisymposium was followed by the Summer School on Composite and Smart Materials: Theory and Applications held at the University of Ioannina during July 18–22, 2011. Both events were organized jointly by the University of Ioannina, Aristotle University of Thessaloniki and Texas A&M University with the support of the National Science Foundation Grant No. DMR-0844082 which is gratefully acknowledged.

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Available online 22 April 2012