Preface

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Biographical notes: Rashid K. Abu Al-Rub is an Assistant Professor of Civil Engineering at Texas A&M University. He received his BS and MS in Civil Engineering from Jordan University of Science & Technology, and his PhD in Civil Engineering from Louisiana State University. His research interests include computational solid mechanics, size-scale effects, nanocomposites, and constitutive modelling of the inelastic, damage, and fracture behaviour of a wide range of engineering materials.

Next generation models to support design of fracture-resistant materials must directly incorporate information related to the material microstructural features. Therefore, there is a large need for a theory that bridges the material length scales. However, the problem in developing a macroscopic model embedded with a micromechanical-based theory which also accounts for long range interactions with microstructure and can be used as an engineering theory for both the analysis and in computer-aided design of materials is a topical and still unsolved material science problem. Attempts to construct such a theory are faced with the difficulties in describing the microscopic structure of materials in terms of macroscopic mechanics. On the other hand, at the present time, it is still not possible to perform quantum and atomistic simulations on realistic time scale and structures. It is estimated that it will be 80 years before the atomistic simulation of fracture of a 1 cm cube of copper is feasible, according to the current rate of growth of computational power. When load is applied, the inelastic deformation that occurs in most cases is not homogeneous, but reveals fluctuations on various length and time scales. This heterogeneity plays a key role in determining the macroscopic properties of materials. A number of different multiscale modelling schemes have been introduced with the intent of spanning multiple length and time scales. While those multiscale methods perform well, they are:

1 computationally very expensive such that they do not offer the flexibility necessary for materials design

2 their incapability to represent long range microstructural interactions and to represent size-scale effects.

This special issue, with its collection of ten papers, brings several theories that can be used in bridging the material length scales through development of multiscale constitutive equations that are motivated by micromechanical mechanics and experimental observations.

There are various experimental and material design techniques that are concerned about increasing the material strength or ductility. However, these techniques were not successful in increasing both strength and ductility simultaneously due to the lack of better understanding of the effect of microstructural features on the overall macroscopic response of the material. Therefore, this special issue opens with a novel paper by Clayton on the development of a two-scale constitutive and computational model based on the laws of thermodynamics which can effectively predict the effect of material microstructure on the its strength and ductility under different dynamic loading conditions. The capability of the proposed model is demonstrated for several microstructural and texture conditions of an aluminium alloy in order to gain better insight of their effect on the material performance under dynamic and impact loading conditions.

The emerging areas of micro- and nano-devices exhibit important strength differences that result from continuous modification of the material microstructural characteristics with changing size; whereby, the smaller is the size the stronger is the response. This resulted in an increasing need for basic research to better understand the underlying deformation mechanisms at the micron and nano-length scales. For example, experimental works have shown increase in strength by decreasing the particle size in particle-reinforced composites, the diameter of thin wires in micro-torsion and uniaxial compression, the thickness of thin films in micro-bending and uniaxial tension, the grain size of polycrystalline materials, void size in porous media, the indentation depth in micro/nano indentation tests, etc. Therefore, the three papers by Abu Al-Rub and co-authors are concerned about the development of non-local continuum-based theories that can explain and help us understand the origin of size-scale effects in emerging micro- and nano-technologies. Abu Al-Rub and Faruk present a dislocation-based model which can be used in predicting the hardness values from micro- and nano-indentation tests. Their model can overcome the shortcoming of the commonly used Nix-Gao indentation size effect model in overestimating the hardness values from nano-indentation. Moreover, they found out through comparisons with many experimental indentation data that the material length scale parameter necessary for predicting scale effects cannot be considered a constant but is an internal variable which evolves as a function of the material microstructural features. The work by Graham et al. is concerned with the development of a non-local theoretical model that can predict the adhesive force for different probe tip sizes when using atomic force microscope (AFM) to study the mechanical properties of materials at the nano-scale. The model uses fundamental surface potential laws at the nano-scale to study adhesive and repulsive surface interactions. The model is very useful in extracting the mechanical properties of nano-materials; especially, bio-materials. Whereas, the work of Abu Al-Rub on size-scale effects in micro- and nano-systems in concerned with the development of strain gradient plasticity theory based on the principle of virtual power and laws of thermodynamics through the incorporation of interfacial effects at free surfaces and interfaces. The effects of the thickness of metallic thin films and their interactions with hard, intermediate, and soft substrates are investigated.

Another crucial issue that needs to be addressed is the mesh-dependency problem. Once the strain localisation is activated due to micro-damage deformation processes or development of shear bands of very localised deformation fields, the computational results are considerably sensitive to the adapted discretisation technique (e.g., the finite element computations are affected by the mesh size and alignment), which yields

non-physical descriptions of the micro-damage and failure mechanisms in materials. This is attributed to the absence of a physical intrinsic material length scale in the classical material constitutive relations which takes into consideration the effects of size and distribution of microstructural features on the overall macroscopic response. The work of Svendsen et al. is concerned with modifying the Gurson-Needleman-Tvergaard (GTN) model for ductile fracture by including length scale effects in the void coalescence constitutive equation through the incorporation of a first-order damage gradient. Comparisons between the local and the modified non-local GTN models for simulating crack propagation through the microstructure of metal matrices reinforced with hard ceramic particles are carried out. The proposed non-local damage model can solve the problem of mesh-dependency. On the other hand, the work by Abed is concerned with the development of novel dislocation-based constitutive models that incorporate length scale effects through the viscoplasticity theory. The models can be used in obtaining mesh-objective results of adiabatic shear banding in various types of metallic materials of various microstructures. The effects of temperature and strain rate on the characteristics of shear bands in metallic materials are thoroughly investigated.

Asphalt concretes are multiscale materials. Therefore, in modeling asphaltic mixes, three scales are of interest:

a The micro-scale where fine fillers of 1–100 μm size exist surrounded by binder-based matrix (i.e., the scale of the mastic phase). Therefore, asphalt mastic refers to a composite that comprises of the asphalt binder and mineral fines, where the asphalt binder refers to any generic neat or polymer modified asphalt binder.

b The meso-scale where fine aggregates exist surrounded by the mastic matrix. Therefore, fine aggregate matrix refers to the composite that comprises of the asphalt mastic and fine mineral aggregates (ranging from 1 mm to 100 μm in size).

c The macro-scale where the overall mechanical properties are determined. The material behaviour of each scale will differ considerably.

The work by Saadeh and Masad is concerned with linking the microstructure of asphalt concrete to their overall mechanical response. The calibration of the proposed viscoelastic and viscoplastic constitutive equations and identification of the corresponding material constants based on novel microstructural characterisation techniques are thoroughly investigated in this work.

In summary, this special issue presents a wide range of novel works on bridging the gap between material length scales through the development of continuum-based models that can effectively predict the effect of material microstructure on the overall macroscopic mechanical response. Therefore, hopefully that this special issue can stimulate researchers working in this direction.