A micromorphic computational homogenization framework for heterogeneous materials

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ABSTRACT

The first-order computational homogenization approach is restricted to problems where the macro characteristic length scale is much larger than the underlying RVE. In this contribution, focusing on matrix-inclusion composites, a novel computational homogenization framework is proposed such that standard continuum models at the micro-scale translate onto the macro-scale to recover a micromorphic continuum. Departing from the conventional FE^2 framework where a macroscopic strain tensor characterizes the average deformation within the RVE, our formulation introduces an additional macro kinematic field to characterize the average strain in the inclusions. The two macro kinematic fields, each characterizing a particular aspect of deformation within the RVE, thus provide critical information on the underlying rapid fluctuations. The net effect of these fluctuations, as well as the interactions between RVEs, are next incorporated naturally into the macroscopic virtual power statement through the Hill-Mandel condition to recover a micromorphic continuum at the macro-scale. The length scale parameter associated with the higher-order term characterizes the nonlocal interaction between neighbouring micro-mechanisms, which in turn provides a regularization effect and enables an accurate prediction of the size-effect. The excellent predictive capability of the proposed homogenization approach is illustrated through two examples, benchmarked against reference DNS solutions. Considering a shear wave loading problem, it is shown that the homogenized micromorphic model adequately captures the material responses, even in the absence of a clear separation between the loading wavelength and the RVE size. A shear localization problem illustrates a regularizing effect of the micromorphic approach. In the presence of large spatial gradients spanning across only a few RVEs, an accurate shear band is predicted, in contrast to an erroneous localized deformation obtained with the first-order computational homogenization approach. For the examples considered, it is furthermore demonstrated that the homogenized solutions are independent on the choice of the underlying RVE for a given microstructure.