Accelerating multi-scale microstructure simulations by exploiting local macroscopic quasi-homogeneities

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ABSTRACT

Multi-scale simulations in material modelling are known to be computationally expensive, in particular if a direct embedding of fine-scale models inside coarse-scale models is considered. In practical applications, such as FE modelling of component-scale metal forming operations, the direct embedding still remains computationally too demanding. This can be considerably relieved by employing a hierarchical approach (e.g. [1]), yet it does not eliminate the need to evaluate the fine-scale model at virtually every integration point in the macroscopic FE mesh. In this paper we present an approach that can accelerate a multi-scale model of metal forming by a factor of 25 while introducing a modelling error below 1%.

It is often observed that fine-scale state variables of similar RVEs subjected to nearly identical macroscopic boundary conditions evolve along nearly identical trajectories. One can make a verifiable assumption that the derived macroscopic properties would be similar as well. Furthermore, it is often possible to identify regions in the macroscopic FE mesh where the field primarily responsible for evolution of the fine-scale model is quasi-homogenous. Under certain circumstances it is possible to exploit these two observations to accelerate the multi-scale simulation [2]. Technically, a number of adjacent integration points in the macroscopic FE mesh can be clustered together, so they share the same fine-scale state variables and, as a consequence, they have identical material properties. The evolution of the fine-scale variables can be then computed just at representative points of the clusters, provided the loading conditions of all the points belonging to an individual cluster are sufficiently similar.

We investigate this concept in the context of the hierarchical multi-scale framework for crystal plasticity [1]. We compare static and adaptive clustering schemes that specify when the clusters of integration points are formed. Likewise, we analyse various clustering criteria that measure similarity between integration points and in turn decide how the integration points are grouped in clusters. The discrepancies between cluster members in terms of the fine-scale state variables and macro-scale properties are assessed. We conclude that large performance gains (speedup of factor 25) are obtained at the expense of introducing only a minor modelling error.

REFERENCES

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