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Advanced mean-field homogenization models incorporating debonding in inclusion-reinforced composites

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ABSTRACT

This work addresses micromechanical modelling of polymer matrix composites reinforced with short fibers or micro or nano-inclusions. We focus on two scale-transition methods allowing to predict the influence of the micro-structure on the composite's overall properties. The first approach is mean-field homogenization (MFH), which is based on assumed relations between per-phase volume averages of strain and stress. MFH is based on simplifying assumptions and only gives average information in each phase. However, when the conditions of its application are met, it offers the best solution in terms of cost and ease-of-use for a given accuracy. Another approach is finite element analysis (FEA) of a representative volume element (RVE), which is very general and gives accurate and detailed micro-fields, but suffers from a high computational cost and important meshing difficulties for realistic microstructures.

One of the limitations of MFH is that is assumes perfect bonding between the matrix and the inclusions, and the aim of our recent research is to remove that assumption. Therefore, we consider that each interface obeys a cohesive zone model (CZM), which relates the traction at the interface to the displacement jump (discontinuity). We proceed along the following lines.

Firstly, a semi-analytical MFH is proposed in the case of simple loadings (hydrostatic tensile loading) and microstructures (spherical particles or infinitely long fibers). The methodology is similar to the one proposed by Inglis et al. [1] for linear elasticity. However, the novelty and difficulty of the present work concerned the extension of MFH to finite strain hyperelastic materials. The modeling does not rely on Eshelby's solution of the equivalent inclusion problem. Instead, the deformation of the isolated inclusion is computed numerically using a finite element discretization. This permits circumventing difficulties related to the particle debonding and the non-linear response. The Mori-Tanaka model is extended by adopting Benveniste's interpretation of the original model. Accordingly, the average strain in the real matrix phase is the imposed far-field strain for the single inclusion sub-problem. The behavior (both at macro at micro levels) is predicted up to complete debonding, and comparisons with FEA [2] are provided.

Secondly, we are working on extending MFH for more general loadings and microstructures, and this involves the generalization of Eshelby's fundamental solution to investigate the effect of a non linear interface debonding on the overall constitutive behavior of a composite, under

rather general boundary conditions. Different forms of cohesive zone models are being employed to characterize the non linear interface response. The models are typically expressed as function of normal and tangential tractions in terms of separation distances. In order to extend well-known homogenizations schemes and make them valid under non linear interface debonding, an incremental formulation was developed. An incremental tensor relation between the interface traction and separation was also proposed, facilitating the derivation of the explicit expression of the modified Eshelby tensor ([3], [4]) for imperfect interfaces through an iterative procedure. An explicit numerical algorithm was developed and coupled with the dilute solution, the Mori- Tanaka and self consistent methods in order to compute the overall response of the composite. The results obtained are compared to the few theoretical ones present in the literature and to finite element simulations. The effect of the size of particles and their volume fraction is investigated.

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