Abstract

Mean-field homogenization (MFH) methods are known for their accurate estimation of effective properties of various heterogeneous materials, including but not limited to short-fibre reinforced composites. Contrary to finite element (FE)-based approaches, the MFH methods are easy to set up and require less computational resources. However, finite element approaches can provide accurate stress/strain fields at every point. On the other hand, MFH methods formulated with the aim of relating phase average stresses with the effective properties are unable to predict the properties at individual inclusions and the interphase. It is imperative to develop models within the MFH framework that can offer significantly improved precision at smaller length scales whilst retaining the low computation cost advantage. This thesis demonstrates the predictive capabilities of established MFH techniques documented in the literature across several length scales, including individua inclusions and the interphase. Throughout the thesis, the models developed have been benchmarked with full FE results involving both "*real*" and "*virtual*" RVEs.

In this thesis, initially a comprehensive comparison is conducted between two prevalent MFH approaches - the Mori-Tanaka (MT) and the MT-Voigt methods. Comparisons are conducted for various loading conditions, and modulus mismatch with the inclusion and the matrix at multiple length scales. The MT-Voigt approach is recommended as it circumvents physical and mathematical admissibilities linked to the MT method with comparable predictive abilities. Neither of the two approaches could address the variation of stresses in individual inclusions within a particular phase.

Next, features of the existing differential-MT approach were examined and adapted to account for the scatter of stresses in the individual inclusions within a phase. In addition to the effective property's predictions, stresses in individual inclusions and the interphases were estimated leading to significantly improved micromechanics. Demonstration of possibility of estimating the stresses in individual inclusions under the MFH framework is a major achievement of this thesis.

Subsequently, the Differential MT method was found to be associated with certain physical infeasibilities. Therefore, a method called Modified Differential MT (MDMT) involving tweaks to the existing scheme is introduced and implemented. The proposed scheme overcomes the physical admissibility problems and is shown to lead to better representation of the stresses in individual inclusions across the entire range of inclusions.

Finally, the MDMT approach is extended to accommodate length and orientation distribution in the fibres which is present in short fibre reinforced composites. A two-step homogenization strategy involving MDMT at the bi-phase composite and Voigt at the second step is proposed. The proposed model successfully captures the scatter in individual inclusions for fibres with different lengths and orientations. The chapter ends with validation of the proposed model with "real" microstructure generated using parameters derived from micro-CT analysis.

Keywords: Mean-field homogenization, Mori-Tanaka, Differential Method, Stress in individual inclusions, Damage modelling