Data driven improved micro-mechanics of short fibre composites

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1. INTRODUCTION & OBJECTIVE

The increasing use of discontinuous short fibre composites in our daily lives is driven by their superior strength-to-weight ratio, durability and low cost . However, prior to their deployment in real-world applications, it is essential to develop predictive tools for precisely evaluating their effective properties and response to loading (including damage modelling). While mean field homogenization (MFH) [1] methods are well-established for estimating the effective properties of fibrous composites, they prove inadequate for damage modelling in discontinuous short fibre composites, highlighting the need for alternative approaches. This limitation arises from MFH's assumption that all inclusions within a Representative Volume Element (RVE) has the same state of stress and hence indicates same state of damage. Such an assumption leads to unrealistic damage predictions, as it overlooks the complex micro-mechanical interactions between inclusions. In reality, the state of stress in individual inclusions is influenced by various factors, including local volume fraction, which vary significantly from inclusion to inclusion. Alternatively, finite element analysis (FEA) can be employed to accurately calculate the state of stress in each inclusion, providing detailed, full-field stress distributions throughout the domain. However, FEA is computationally intensive, time-consuming and challenging to set up, especially when compared to the relatively straightforward implementation of MFH methods..

To address these challenges, a novel and efficient stress prediction approach has been developed for heterogenous materials including short fibre composites, utilizing the MFH based Mori-Tanaka (MT) [2] method to accurately predict the stress state in individual inclusions. This method facilitates the estimation of effective properties while enabling damage modelling.

The RVE (comprised of the matrix and the inclusion phases, is segmented into smaller subdomains inspired by pseudo-grain discretization, with each subdomain having a varying local volume fraction of inclusions while maintaining a constant global inclusion volume fraction. The local volume fraction distribution is determined using data driven methods. The MT method is then applied to each subdomain to calculate the stress in the individual inclusions, followed by volume averaging to determine the effective properties of the RVE.

2. RESULTS & HIGHLIGHTS OF IMPORTANT POINTS

The proposed model has been trained and calibrated by implementing FEA on 9 RVEs with varying aspect ratios and volume fractions [3]. After the training and the calibration has been done, the model is tested on RVEs with varying volume fractions (v_f) and aspect ratios(AR), yielding an excellent match with the FEA results (see **Figure**). Worth noting here that the prevalent MFH methods yield same value of stresses for all the inclusions.

This model successfully blind predicts the maximum stress in an inclusion corresponding to wide range of aspect ratio and volume fraction. The proposed model significantly reduces

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computation time by several orders of magnitude compared to FEA while still achieving comparable results in terms of stress distribution in the individual inclusions. Additionally, damage modelling has been conducted using micromechanical analysis, incorporating stochastic methods to simulate damage within the composite. An improvement of

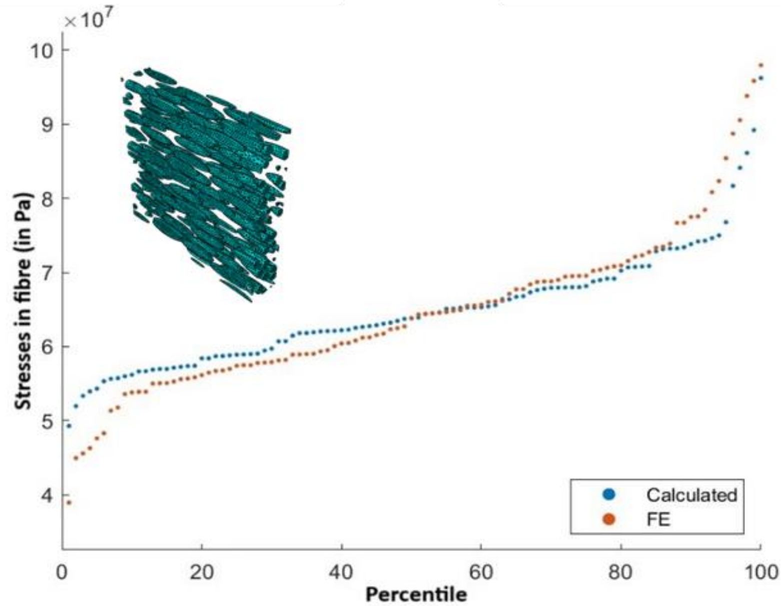

Figure 1. Representative results of stresses in individual inclusions by the proposed model and FE results for the RVE (AR = 5, v_f = 20%), FE model of the RVE is depicted in the inset.

This approach effectively balances accuracy with computational efficiency, offering a practical solution for damage modelling in discontinuous short fibre composites, which was not possible using traditional MFH methods.

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