Uncertainty quantification of unidirectional composite material properties using a multi-scale framework

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Composite materials are widely used in many industries mainly because of their ability to withstand harsh conditions while being light weight. However, there is inherent variability in their performance induced by the uncertainties in their constituent properties, fibre directions, structural geometry, loading conditions and manufacturing process. This variability could lead to failure when variation in loading or fibre orientation occurs. It is desirable to manufacture a composite whose performance (ex: ability to take loads) is less sensitive to varying external conditions (ex: Loads).

The variation in the material property is due to the fact that the fibres are packed randomly in the matrix. In addition, there is variation in the dimension of the fibres. For a particular volume fraction, one can obtain different microstructures (i.e layout of fibres in matrix). Since the variation in microstructure leads to variation in material property, understanding the variations at the micro scale provides a quantification of the material property at the meso scale. It is important to characterize the uncertainty from micro to macro-scale, and the corresponding influence of randomness in system parameters such as material properties.

In a multiscale framework, a micro mechanical model in the form of a Representative Volume Element (RVE) is coupled to a macro-mechanical model. Usually, the RVE is subjected to appropriate loads and analysed using FE approaches to compute the non homogenous stress and strain. The ratio of the averaged stress to the averaged strain over the volume provides the effective moduli. In the microstructure, the spatial arrangement of the fibre is not periodic and this can be captured using a Statistically Equivalent RVE (SERVE). Given the volume fraction and variation in fibre diameter, this work uses an algorithm proposed in literature to generate a SERVE while the fibre placement inside the SERVE is not under control.

Current Status

The existing algorithm in literature allows one to generate RVEs' with 50% volume fraction. We have developed a modified algorithm to generated RVEs' upto 61% volume fraction. A numerical approach that uses nearest neighbour distance distribution was used to model the composite microstructure by generating a random distribution of fibres. A considerable number of RVE samples were analysed to generate a frequency distribution of elastic moduli. The elastic constants predicted by the SERVE agree well with existing theoretical predictions and available experimental data.

Future work

In order to characterize the uncertainty using a probabilistic distribution, a large sample size is required which translates into exorbitant computational expense. Therefore, one could characterize the uncertainty by a non-parametric cumulative distribution (CDF). The final

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paper will paper will include this uncertainty quantification in a design framework to design composites under uncertainties. This work will try to answer the question on how much the variation in microstructure affects the variability of the material property. Also, a study of the effect of elements that leads to variability of microstructure will be performed. We hope that these results will help a designer and a manufacturer to manage dilemmas when addressing risk and cost involved.