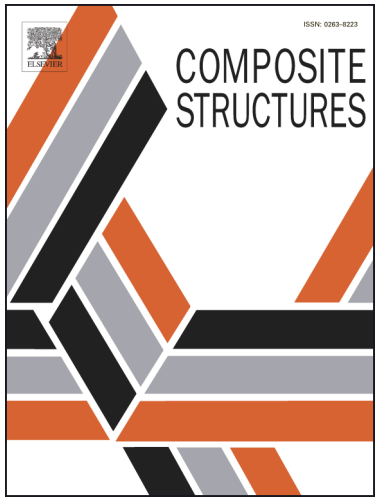

Influence of Micro-scale Uncertainties on the Reliability of Fibre-Matrix Composites

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Influence of Micro-scale Uncertainties on the Reliability of Fibre-Matrix Composites

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Abstract

This study investigates the effect of micro-scale geometric and material property uncertainties on the elastic properties and reliability of fibre reinforced composite materials. Composite materials are often designed using conservative design factors to account for a limited understanding of how multi-scale uncertainties effect reliability. Structural reliability analysis can produce more efficient designs, but requires an understanding of how all sources uncertainty effect probability of failure. Previous studies have not considered micro-scale geometrical uncertainties and their combinations in a multi-scale probabilistic-based reliability framework. Thus, this study will investigate the effect of numerous combinations of micro-scale material property and geometric uncertainties on the homogenised elastic properties. Furthermore, to account for the effect in a reliability-based framework, a novel surrogate modelling technique is developed to represent the uncertainties efficiently. The study concluded that the geometrical fibre stacking uncertainty is as influential as the widely investigated constituent material stiffness uncertainties. Consequently, representing the micro-scale geometric uncertainties within the developed multi-scale probabilistic-based framework improves the estimated stiffness. Thus probability of failure is reduced, compared with considering material property uncertainties only. Moreover, the framework clarified and highlighted the importance of representing fibre geometrical stacking uncertainty for a deeper understanding of their effect on composite stiffness properties.

Keywords: FRP; Uncertainty; RVE Homogenisation; Surrogate model; Reliability

1. Introduction

Composite materials are being used widely in many industries for the improved stiffness-weight ratio compared with alloys. However, the heterogeneous nature and the manufacturing process of composites open the door to many material and geometrical uncertainties to occur within all scales [1]. Thus, composites are often designed with high factors of safety to ensure reliability [2, 3]. To avoid imposing such high factors of safety, it is important to detect and quantify the effect of these uncertainties at their occurrence scale and propagate their effect into higher scales of the composite component. Thus, a clear understanding of the overall composite properties under all possible uncertainties can be obtained. Clarifying this could lead to safer designs and more efficient use of composites.

In Fibre Reinforced Polymer composites (FRP), micro-scale is the smallest scale where the contribution of all constituent materials occurs. It is usually presented as a Representative Volume Element (RVE) as defined by Hill [4]. The micro-scale is an important building block for the composite as it is used to estimate the effective elastic properties used in higher scales [1]. Therefore, much research has been carried out to account for the effect of uncertainties at this scale. For instance, a recent study investigated the uncertainty of constituent materials properties and their probabilistic propagation from micro-scale to upper scales [5]. In addition to material uncertainty, other studies looked into the effect of some geometrical uncertainties in failure related behaviour using larger RVEs (containing many fibres). For example, a numerical study by Brockenbrough et al. [6] looked into the deformation behaviour of edge-stacked square fibres, square diagonal-stacking of square fibres, and triangle-stacking of hexagonal fibres. Based on observed effects, the study concluded that reliable methods need to be developed that account for the distribution of fibres to ensure reproducibility of composite properties. Another study by Nikopour [7] addressed 2D modelling of matrix/voids ratio uncertainty by systematic matrix absence between fibres and its deterministic effect on the elastic properties. A study by Huang [8] focused on the effect of random and systematic fibre placement within an RVE on elastic properties, again in a deterministic approach, where it was concluded that all arrangements have a similar effect. It is important to note that Huang used a large RVE that is