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Virtual testing framework for hybrid aligned discontinuous composites

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Abstract

The inherent brittleness of conventional high-performance composites can be addressed by the use of discontinuous fibres or hybridisation of fibre-types. In this paper, we propose the first models in the literature to predict the stress-strain curve of hybrid discontinuous composites, with either a brick-and-mortar or an intermingled-fibre microstructure. The models consider a shear-lag stress-transfer between the hybrid reinforcement units, and show that this stress transfer becomes less efficient with hybridisation. The model for intermingled-fibre hybrids also considers stochastic fibre strengths and fibre fragmentation, and can therefore predict a brittle or pseudo-ductile response of hybrid discontinuous composites as observed experimentally, as well as hybrid effects. These models can be used to perform virtual testing and microstructural design of hybrid aligned discontinuous composites.

Keywords: A. Hybrid composites, A. Short-fibre composites, B. Non-linear behaviour, C. Modelling, C. Stress transfer

1. Introduction

High performance composites have been widely used over the last decades, as they exhibit high specific strength and specific stiffness when compared to most metallic materials. However, the main drawback of composites lays in their inherent brittleness, triggering a catastrophic failure mode with no damage warning, and leading to over-designed structures. Great efforts are put in understanding the mechanics of composites to develop more "ductile" composites, which would not only allow a more efficient use of composites, but would also expand further their range of applications in industry.

One widely known strategy to achieve ductile composites is hybridisation, i.e. by combining different types of inclusions varying in geometry and mechanical properties [1]. Hybridisation offers numerous advantages among which are the possibility to include a cheaper type of reinforcement, the ability to tailor the properties of the composite, improved fatigue life and impact resistance [2, 3], and the existence of various synergistic effects within a hybrid composite [1].

The potential advantages of hybridisation led to numerous studies on hybrid composites [4–8]. While manufacturing technologies used to be limited to hybridisation at the ply [9] or at the bundle [10] level, Yu et al. [11, 12] recently developed a new manufacturing process capable of producing, for the first time, *intermingled* (i.e. hybridisation at the fibre-level) *discontinuous* hybrid composites.

Hybrid composites are affected by non-linear hybrid effects (deviations from the rule-of-mixtures), which are challenging to understand and predict, as recognised in a recent review [1]. These effects are magnified with the use of intimate intermingled of the fibre-types [1, 10], and also by the use of discontinuous fibres [11, 12]. Moreover, the design space of intermingled hybrid discontinuous composites is very wide (including different fibre diameters and lengths, fibre strengths, volume ratio between the fibre types, fibre arrangements, matrix properties, ...), and therefore experiments cannot provide an exhaustive analysis of the effects of all parameters. Therefore, virtual testing models can provide a more effective way to (i) predict the mechanical response and hybrid effects in hybrid discontinuous composites, and (ii) provide guidance for the design of optimised hybrid microstructures.

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