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Modelling hybrid effects on the stiffness of aligned discontinuous composites with hybrid fibre-types

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Abstract

Hybrid discontinuous composites offer the possibility to tailor the composite properties for specific applications, improve their manufacturability, and reduce cost by introducing cheaper fibres. However, the mechanical behaviour of hybrid composites often shows hybrid effects which cannot be modelled by the rule-of-mixtures and are therefore challenging to predict and explain. This paper presents models to calculate the Young's modulus of different discontinuous hybrid composites, which is affected by such hybrid effects. The models are based on shear-lag and consider two types of hybrid discontinuous architectures: (i) a deterministic "brick-and-mortar" architecture consisting of perfectly staggered platelets with two different Young's moduli and thicknesses, and (ii) a stochastic architecture of aligned fibres with two different Young's moduli and diameters, with randomly allocated fibre-ends and random or organised intermingling. The models show good agreement with numerical and experimental validations; their results show that hybrid interactions between different types of fibres or platelets reduce the Young's modulus of hybrid discontinuous composites, which justifies the negative hybrid effects observed.

Keywords: A. Short-fibre composites, A. Hybrid composites, C. Elastic properties, C. Statistics, C. Stress transfer

1. Introduction

Fibre reinforced polymers are often used for their remarkably high specific stiffness (corresponding to a high stiffness to weight ratio) but are expensive, both in terms of material and manufacturing costs. Hybrid discontinuous composites combine hybrid fibre-types with a discontinuous microstructure; therefore, this type of composite allows a reduction of material and manufacturing costs, opens new possibilities of hybridisation (e.g. with intimate intermingling of fibre-types), and extends further the ability to tailor the properties of composites in terms of stiffness, strength or toughness [1–3]. Hybrid discontinuous composites have already been manufactured [2–5] and confirmed the advantages listed previously; however, "hybrid effects" can be observed in the experimental data of hybrid discontinuous composites, not only in the measured strength and failure strain, but also on the stiffness [2–4, 6].

The effects of discontinuities and hybridisation on the stiffness of composites have already been investigated separately. The shear-lag theory developed by Cox [7] predicts the Young's modulus of discontinuous composites $E^{\mathcal{C}}_{\mathrm{Cox}}$, assuming that the inclusions carry longitudinal stresses only, while the matrix transmits stresses through shear:

$$E^{\mathcal{C}}_{\mathrm{Cox}} = V^{\mathrm{f}} \cdot E^{\mathrm{f}} \left(1 - \frac{\tanh(\lambda_{\mathrm{Cox}} \cdot \alpha)}{\lambda_{\mathrm{Cox}} \cdot \alpha}\right) + V^{\mathrm{m}} \cdot E^{\mathrm{m}}, \text{ with } \lambda^2_{\mathrm{Cox}} = \frac{2 \cdot E^{\mathrm{m}}}{E^{\mathrm{f}} \cdot (1 + \nu^{\mathrm{m}}) \cdot \ln(P^{\mathrm{f}}/V^{\mathrm{f}})}, \tag{1}$$

where V^{f} and V^{m} represent the volume fractions, and E^{f} and E^{m} the Young's moduli of the inclusions and the matrix respectively; ν^{m} is the matrix Poisson's ratio, α is the aspect ratio of the inclusions, and P^{f} is a fibre-packing geometric factor [7].

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