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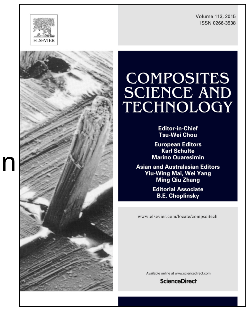

A computationally–efficient hierarchical scaling law to predict damage accumulation in composite fibre–bundles

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A computationally–efficient hierarchical scaling law to predict damage accumulation in composite fibre–bundles

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Abstract

Unidirectional composites under longitudinal tension develop damage through the accumulation and clustering of fibre–breaks, which may lead to catastrophic failure of an entire structure. This paper uses a hierarchical scaling law to predict the kinetics of fibre–breakage and its effect on the stress–strain response of composites under longitudinal tension; due to its analytical formulation based on the statistical analysis of hierarchical fibre–bundles, the scaling law predicts the response of composite bundles up to virtually any size in less than one second. Model predictions for the accumulation and clustering of fibre–breaks are successfully validated against experiments from the literature. These results show that the present model is a much more computationally–efficient alternative to other state–of–the–art models based on Monte–Carlo simulations, without sacrificing the accuracy of predictions when compared against experiments.

Keywords: A. Polymer–matrix composites, B. Fragmentation, B. Stress/strain curves, C. Modelling, C. Probabilistic methods

1. Introduction

The response of UD-FRPs under longitudinal tension is characterised by the progressive accumulation and clustering of fibre–breaks, in a process which eventually creates a critical cluster of broken fibres that often triggers the unstable failure of the structure [1, 2]. This response is governed by (i) the variability of the strength of individual fibres (commonly assumed to follow a Weibull distribution [3], although this has been debated in the literature [4–7]) and (ii) the stress–redistribution near fibre–breaks (controlled by the matrix) [8–11].

These two features have been incorporated in several fibre–bundle models to predict the strength of UD-FRPs and the associated size effects. The earlier models [12–15] were analytical, and could predict the average or the full strength distribution of either small [13] or asymptotically–large bundles [12, 14, 15]. Further analytical developments have studied the effect of different load–sharing schemes, but required parameters fitted through computational simulations [5, 16–19]. Most analytical models have not been validated experimentally [12–14, 16–19], apart from isolated comparisons on the mean strength only [5, 15] (with models overpredicting experiments by at least 10%).

More recently, the increase in computational power enabled several researchers to propose Monte–Carlo simulations for the tensile failure process in UD-FRPs [5, 16–30]. These models aim to represent stress fields near single fibre–breaks accurately, although most assume regular packing [5, 17–25, 27, 30]; many models [16, 18, 25, 26] also neglect the increase in the stress–recovery length near broken clusters, which was shown to overestimate bundle strength [30]; moreover, all models [5, 16–27, 30] consider simplified matrix constitutive laws (e.g. neglecting progressive matrix fracture), neglect dynamic stress concentrations, and assume perfectly–aligned fibres (the only exceptions [28, 29] considered very small representative volume elements). In addition, simulation results are often not compared against experiments [16–20, 26, 28, 29], and when compared they tend to overpredict the average strength of composites [5, 21, 22, 24, 25]; they also significantly underpredict the variability of strength distributions [25], and underpredict (or fail to predict)

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