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A *hybrid* probabilistic-deterministic approach to model the mechanical response of helically arranged hierarchical strands

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Abstract

Very recently, a Weibull-based probabilistic strategy has been successfully applied to bundles of wires to determine their overall stress-strain behaviour, also capturing previously unpredicted nonlinear and post-elastic features of hierarchical strands. This approach is based on the so-called "Equal Load Sharing (ELS)" hypothesis by virtue of which, when a wire breaks, the load acting on the strand is homogeneously redistributed among the surviving wires. Despite the overall effectiveness of the method, some discrepancies between theoretical predictions and *in silico* Finite Element-based simulations or experimental findings might arise when more complex structures are analysed, e.g. helically arranged bundles. To overcome these limitations, an enhanced *hybrid* approach is proposed in which the probability of rupture is combined with a deterministic mechanical model of a strand constituted by helically-arranged and hierarchically-organized wires. The analytical model is validated comparing its predictions with both Finite Element simulations and experimental tests. The results show that generalized stress-strain responses - incorporating tension/torsion coupling - are naturally found and, once one or more elements break, the competition between geometry and mechanics of the strand microstructure, i.e. the different cross sections and helical angles of the wires in the different hierarchical levels of the strand, determines the no longer homogeneous stress redistribution among the surviving wires whose fate is hence governed by a "*Hierarchical* Load Sharing (HLS)" criterion.

1. Introduction

Fibre Bundle Models (FBM) were first introduced in the 1920s and first comprehensively developed by Daniels about twenty years later (Daniels, 1945) to describe failure processes in a large number of materials and settings, the success of the approaches depending on their relative simplicity, the clear underlying physics and the capability of preserving some key aspects which ensured to capture with sufficient richness the overall mechanical behaviour of the structures. Essentially, at a certain scale the material is modelled as a network of fibres, arranged in parallel and/or in series and subject to uniaxial force, with failure mechanisms governed by a statistical (Weibull) distribution of wire yield strengths. An Equal Load Sharing (ELS) hypothesis is assumed and, when fibres progressively fracture or reach a stress threshold as the external load increases, the

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