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Grafting carbon nanotubes onto carbon fibres doubles their effective strength and the toughness of the composite

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ABSTRACT

Bioinspiration can lead to exceptional mechanical properties in a number of biological materials as a result of their internal structure. In particular, the hierarchical arrangement of nano-to macro-components can bring to complex energy dissipation mechanisms and unprecedented resistance to crack growth. In this work, we propose to exploit this approach, combining in a multiscale composite structure carbon nanotubes with conventional carbon fibre reinforcements in a polyvinyl butyral matrix. We show that grafting the nanotubes onto the carbon microfibres improves their interface properties with the matrix considerably, effectively doubling their apparent strength. At the same time, the addition of nanotubes to microfibre reinforcements helps to improve the composite toughness, reaching more than twice the value for the conventional, non-hierarchically reinforced composite. Numerical simulations and fracture mechanics considerations are also provided to interpret the results.

1. Introduction

Recent developments in nanotechnology have opened the way to a new generation of polymer matrix composites that employs nanomaterial fillers to enhance specific mechanical, electrical and thermal properties. Very often, these nanofillers are based on carbonaceous materials such as graphene or carbon nanotubes (CNTs), although clays are also widely used [1]. The main issue in the employment of carbon nanomaterials in composite manufacturing lies in the difficulty in endowing the final material with the superior properties of the nanofiller, i.e. transferring nanoscale properties to a macroscopic material [2].

Perhaps the best examples of how microscale and nanoscale morphologies can be arranged into a macroscopic material to yield exceptional mechanical properties are provided by natural systems [3]. For example, bone composite structure comprises different hierarchical levels, from macro to nano scale and it has been observed that effective stress transfer along the different length scales leads to exceptional mechanical performance from relatively weak constituents [4,5]. These observations have led to significant interest in the development of so-called "bioinspired materials" i.e. artificial materials that mimic some of the specific structures observed in nature, in order to achieve similar properties [6]. When mimicking the characteristics of natural hierarchical assemblies it is possible to further improve the overall mechanical performance of the obtained structures by employing constituent materials that displays a high intrinsic strength [7]. Carbonaceous materials provide great potential for this type of application because of the high strength due to the presence of carbon-carbon bonds in their structures, and are available in several sizes and morphologies (fibres, nanotubes, graphene, etc.), allowing the creation of a multiscale, hierarchical structure [8,9]. Several studies have been conducted on the manufacturing of multiscale-reinforced materials based on carbon fibres (CFs) and CNTs to reinforce polymeric matrices in composites [10].

A simple method to prepare CF-CNT multiscale composites consists in dispersing the CNTs in the polymer and then producing a

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