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On the mechanical response of randomly reinforced chopped-fibers composites: Data and model

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Abstract

Based on a substantial amount of stiffness and failure data for a randomly reinforced, chopped carbon fiber-strand, polymeric composite, this article presents a mechanics based material model that strives to explain the above phenomena. The model simulates the random geometry of the material and utilizes basic ideas of composite laminate theory to predict material properties and failure. In addition, statistical studies are performed in order to assess aspects of size effects on the measured response of this material.

Keywords: A. Polymeric composites; A. Random reinforcement; A. Statistical aspects; A. Stiffness; A. Creep; A. Failure; A. Size effects

1. Introduction

A polymeric composite, consisting of randomly oriented, chopped carbon fiber strands, embedded in urethane resin, is a candidate material for automotive structural applications. The main advantages of this material are its rapid processing and low cost. Previous investigations concerning the thermo-mechanical response of cross-ply and quasi-isotropic layups of straight and continuous strands, consisting of the same fiber and polymer, established the basic strand properties and various aspects of layup behavior [1,2]. In the present article, attention is focused on the effects of randomness on stiffness and strength, with some additional information regarding creep response.

The subject of random reinforcement was studied extensively by several investigators. In two closely related articles [3,4] the equivalent modulus of such composites was evaluated by means of a series model, where each element in the series was assumed to possess a distinct stiffness magnitude. The variation of the stiffness along the longitudinal axis was considered to take a certain functional form and the equivalent modulus was evaluated through integration. Additional random geometrical configurations of reinforcement, such as dispersed discs or spheres, were considered elsewhere [5,6]. Since those reinforcements were formed of essentially disconnected inclusions they lent themselves to be modelled in the context of powerful and well-established statistical methods, and possibly by means of stochastic finite elements as well. For a FEM approach to be useful, the size of the elements should exceed the diameter of the disc or sphere by no less than one order of magnitude. In contrast, the current circumstance of randomly oriented strands involves a much more complex geometry. This is due to the fact that these strands, each about 5 cm (2 in.) long, overlap each other at several locations and are stacked on top of each other in seven to thirteen ‘‘layers’’. As will be shown in Section 2 below, the variability in recorded data decreases rather significantly with increasing sample

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Fig. 1. A photograph of a dry preform of a chopped strand mat.

size (or, alternately, with the length of the measuring gage), and attains reasonable uniformity only for samples that are more than 20 cm long. Furthermore, due to the inherent length of the strands they overlap adjacent finite elements (or representative volume elements) of sizes normally employed in analyses and computations. Consequently, the additional connectivity in material phases renders the above approaches unsuitable to the present circumstance.

2. Experimental

The composite under consideration consists of randomly oriented, chopped fiber strands mat embedded in urethane resin supplied by the automotive composite consortium (ACC). Each strand contains approximately 200 individual fibers and strands are blown onto a mandrel to create a perform which is then injected by urethane resin in a rapid injection process. A photo of dry perform is shown in Fig. 1.

The basic properties of reinforcement by straight longitudinal strands were established in previous works [1,2][2] based upon the geometry shown in Fig. 2(a) and (b) and are listed below

$$Q_{11} = 95.7, \quad Q_{22} = 2.24, \quad Q_{12} = 3.1,$$
$$Q_{66} = 3.3, \text{ all in GPa.} \tag{1}$$

Over 600 experiments were performed to evaluate the stiffness and failure stress of the randomly reinforced composites [7]. The experiments employed 203.8 mm (8 in.) long and 25.4 (1 in.) wide specimens divided into two groups, namely with thickness of either 3 or 1.5 mm. The above thicknesses correspond to a stacking of either 13 or 7

a

b

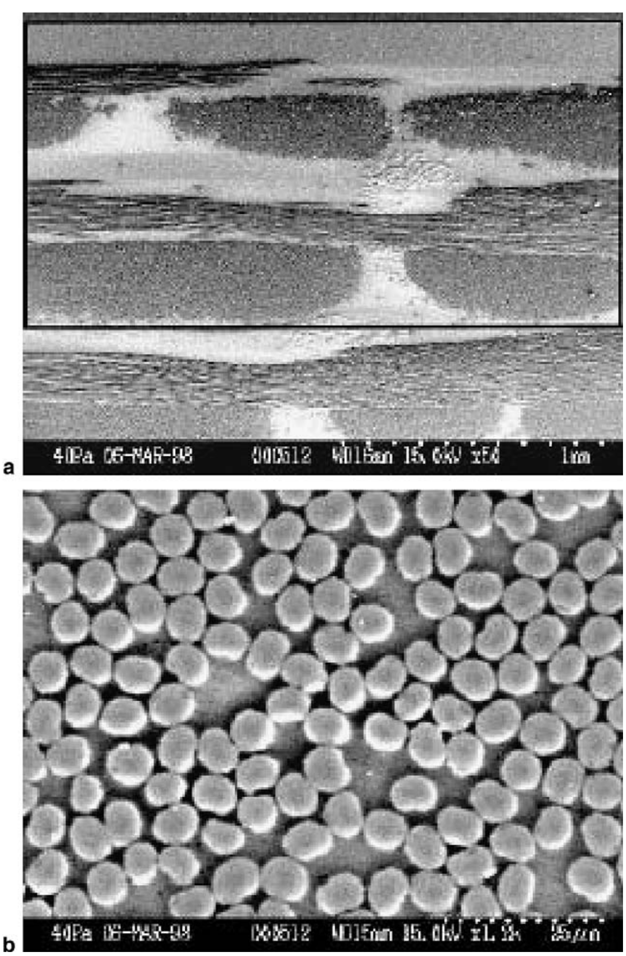

Fig. 2. Micrographs of a cross-ply urethane resin composite reinforced by carbon fiber strands: (a) an overview and (b) fibers within a single strand.

[2] While $(Q_{11} + Q_{22})$, Q_{12} and Q_{66} can be recovered from stress–strain data for cross-ply laminates, Q_{22} required the utilization of micromechanics. The latter value is therefore of lesser certainty.