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Estimating mechanical properties of 2D triaxially braided textile composites based on microstructure properties

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ABSTRACT

Textile composites manufactured using Resin Transfer Modeling (RTM) can offer advantages in some automotive applications including reduction in weight, while being relatively simpler to fabricate than standard laminated composites used for aerospace applications. However, one of the challenges that arise with these textile composite materials is that the mechanical properties are inherently dependent on the local and final (*in-situ*) architecture of the textile itself as a result of the molding and curing processes. While this provides additional latitude in the composite design process it also necessitates the development of analytical models that can estimate the mechanical properties of a textile composite based on the textile architecture and the properties of the manufactured component.

In this paper, an analytical model is developed and its estimations are compared against experimental in-plane engineering properties for composites with various textile architectures. Results from the model are also compared against finite element (FE) based computational results. The microstructures of the 2D triaxially braided composite (2DTBC) studied were extensively characterized. The microstructure properties thus measured were used in the analytical model to estimate the mechanical properties. Uniaxial tension and V-notched rail shear tests were conducted on 2DTBC with different textile architectures. Good agreement between the analytical, computational, and experimental results were observed and are reported here. Furthermore, computational estimations of matrix mechanical properties are limited to the linear elastic range of a representative material volume (unit cell) and coupon data. Full mechanical response of larger 2DTBC structures, albeit of prime interest, is beyond the scope of this work and could be the focus of follow up studies.

1. Introduction

Textile composites are finding increased applications as a structural material in a wide variety of engineering applications, as discussed in the review paper by Bogdanovich [1]. Past work on textile composites, including plain weave textiles and 2D and 3D woven glass fiber epoxy laminates have focused on studies related to response under mechanical loading and the development of models to predict stiffness and strength, as for example, reported in [2–6]. The present paper is concerned with 2D triaxially braided composites (2DTBC), where carbon fiber tows are impregnated with a polymer matrix.

The 2DTBCs consist of axial tows, bias tows, and a matrix material. The axial tows all run in the 1-direction, as shown in Fig. 1, and the bias tows are braided around the axial tows at prescribed angles of $\pm\theta$. These braided carbon fiber mats (or plies) are then stacked together and infused with an epoxy resin and cured to form the textile composite in a process known as Resin Transfer Molding (RTM).

The textile composite samples that are the focus of this study contain axial tows composed of 24,000 T700 carbon fibers, while each bias tow consists of 12,000 T700 carbon fibers. The bias tows were prescribed to be woven at 30, 45, or 60 degrees for each ply. Stacks of 8 plies (all with the same angle braid and orientation) were infused with Epon™ 862 epoxy and cured to produce the final textile composite. Fig. 2 shows sample images of the final cured textile composites for each of the prescribed braid angles. All experimental results in this paper were obtained from textile composite samples taken from the same set of plaques that are shown in this figure. Additionally, each of the plaques was manufactured to a constant design thickness of 7.62 mm (0.3 in.), regardless of braid angle. The as-manufactured thickness was found to average 7.51 mm ± 0.14 mm across all three braid angles.

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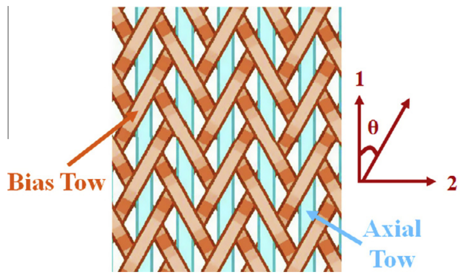

Fig. 1. 2DTBC overview [6].

In order to obtain accurate values for the in-plane elastic properties of the 2DTBC's a step-by-step approach was taken which involved the following:

1. Measure the detailed microstructure of all three 2DTBCs.
2. Directly measure the in-plane elastic properties of the 2DTBCs.
3. Create a detailed Finite Elements (FE) model of the microstructure of one of the 2DTBCs (30° braids in this case) in order to back out the *in-situ* (or as cured) matrix properties. The 30° braid angle was selected for ease of modeling.
4. Develop a MATLAB® based code to estimate the in-plane mechanical properties of all three 2DTBCs based on the composite microstructure and the fiber and matrix properties.

This step-by-step approach allows for the determination of the necessary geometric and constitutive properties that form the inputs necessary to analytically estimate the elastic properties of the 2DTBCs.

2. Microstructure

In order to effectively model textile composites it is important to have understanding of the microstructure of the composite as it is received from the manufacturer. The 2DTBC can be broken into four primary constituents: Axial tows, +bias tows, −bias tows, and matrix. First, the actual angle between the bias tows and the axial tows was measured at different locations for all three manufactured (cured) composites. Second, the cross sections of the axial and bias tows were measured to determine the dimensions and approximate shape of the cross section of the tows, Figs. 3–4. Closer inspection of these cross sections was used to look at the carbon fibers dispersed within each type of tow and determine the average volume fraction of each constituent tow, Fig. 5. Next, cross-section images were taken perpendicular to the undulations of the bias tows. These images were used to determine the average amplitude and wavelength of the undulations as well as the shape of the path taken by the undulating tow, Fig. 6.

For all of the aforementioned measurements a sample size of 20 was used for each tow type per braid angle. To measure the cross sections, three sets of material samples were cut from each of the plaques (30°, 45°, and 60°). The sets were cut perpendicular to the axial tow cross-section, the bias tow cross-section, or the undulation of the bias tow. The samples were ground and polished, and images were taken with a high resolution camera or Scanning Electron Microscope (SEM) depending on the detailed required for the measurement.

The measured microstructure properties are listed in Tables 1–3. The carbon fiber and *in-situ* matrix properties are listed in Table 4 for completeness. The results in Table 3 show deviations between prescribed bias tow angles and as-manufactured bias tow angles.

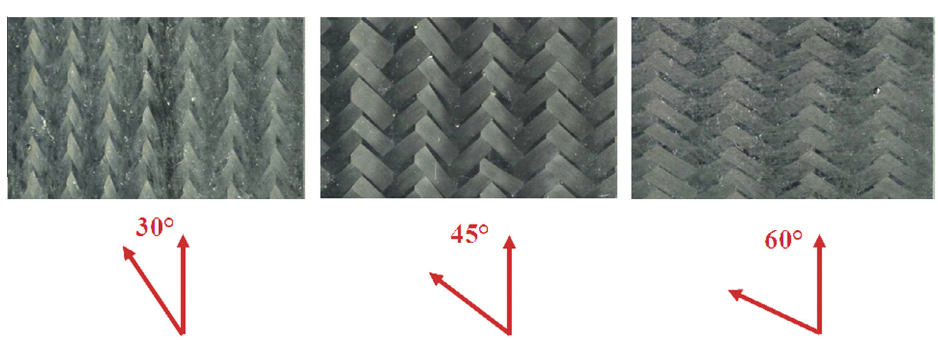

Fig. 2. Cured textile composites with prescribed braid angles.

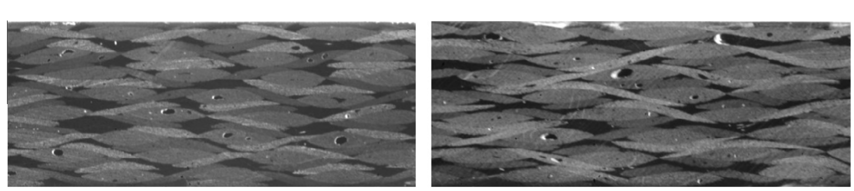

Fig. 3. Cross section images for 30° axial (left) and bias (right) tows.

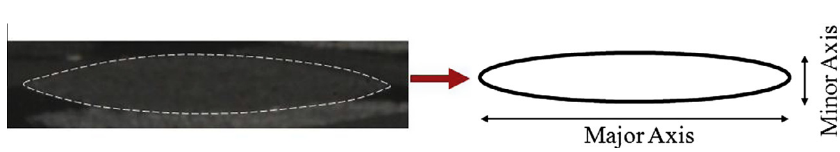

Fig. 4. Close-up of 30° axial tow shape.