Aspects of the mechanical response of randomly reinforced, chopped fiber strand, polymeric composites

Y.J. Weitsman*and A. Ioniţă

The University of Tennessee
Knoxville, TN 37996, USA

Urethane resin composites, randomly reinforced by chopped carbon-fiber strands are candidate materials for automotive structural applications. A dry preform of such a composite is shown in Fig. 1.

Extensive stiffness and failure data, collected by 1 inch long extensometer, resulted in significant scatter as shown by the bar diagrams in Figs. 2. It was also noted that data scatter depended on the length of the measuring device, increasing substantially with diminishing device length.

The random layup shown in Fig.1 was simulated numerically, where the random geometry is depicted by the "moving" window shown in Fig. 3. The simulation employed a random selection of strand central locations and orientations, and can also select random strand lengths and widths. The number of strands N in the single randomly oriented "layer" shown in Fig. 3 is determined by the requirement that the of the projected areas A_i of all strands covers the area A of the "window", i.e. $\sum_{i=1}^{N} A_i = A$. ($A_i = w_i l_i$, where l_i abd w_i denote strand length and width respectively. (w_i is not shown in Fig. 3).

The in-plane stiffness of a single layer is obtained by a concept akin to laminate theory. Accordingly, let $\overline{Q}_{pq}^{(i)}$ of the $i^{\underline{th}}$ strand be its stiffnesses oriented into the common coordinates of the coupon, and $\mu_i = A_i/A$ the projected area fraction, then $\overline{Q}_{pq}$ of the entire layer is given by $\overline{Q}_{pq} = \sum_{i=1}^{N} \mu_i \overline{Q}_{pq}^{(i)}$.

The corresponding overall stiffnesses of the layered lay-up, A_{ij}, B_{ij} and D_{ij} are obtainable from $\overline{Q}$ by a straightforward application of laminate theory. Since the presumed common thickness h of the strands is known the number of layers k is obtained from the total coupon thickness H.

In this manner it is possible to generate values of the stiffness E (and Poisson's ratio ν) by simulating a large number of random geometries shown in Fig. 3, for various window dimensions. A typical simulation, shown in Fig. 4, illustrates the dependence of scatter on window size, i.e. length measuring device. Though not shown here, data scatter for 1 inch long window resemble the data shown in Fig. 2.

The simulation also enables to evaluate departures from isotropy and homogeneity. While departure from isotropy resembles essentially the trends exhibited in Fig. 4, departure from homogeneity reflects the extent of strand continuity between adjacent windows. It turns out that strands straddling neighboring "windows" tend to reduce the inhomogeneity when the distances between window centers is less than about twice the strand length, beyond which material inhomogeneity becomes random, i.e. uncorelated.

The foregoing observations have important ramifications regarding modeling and computations of the mechanics of random, chopped reinforcement. For instance, since size of RVE -if such exists- should exceed the strands length by at least of one order of magnitude, it assumes a structural dimension. Also, in view of the aforementioned strand overlap phenomenon, it would be erroneous to employ, say, a stochastic finite element method that does not account for an appropriate degree of continuity between neighboring elements.

A simulation of failure stresses was performed by means of a strand discount approach, akin to the ply discount method in laminate failure analysis. Though this approach resulted in failure levels that departed from recorded data, it predicted scatter resonably well.

*Also, Metals and Ceramics Division, Oak Ridge National Laboratory, Oak Ridge, TN, USA.

Figure 1: A photograph of a dry preform of a chopped strand mat.

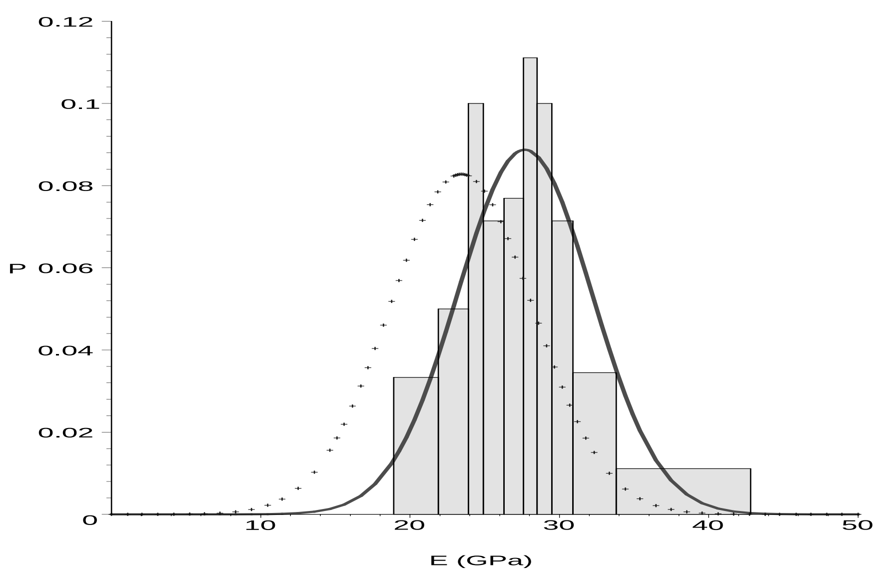

Figure 2: Distribution of longitudinal modulus E as recorded by a 25.4 mm (one inch) long extensometer. Samples thickness $H = 3$ mm. Bar diagrams and "best" Gaussian distribution fit with $\overline{E} = 27.68$ GPa. Dotted line corresponds to $H = 1.5$ mm

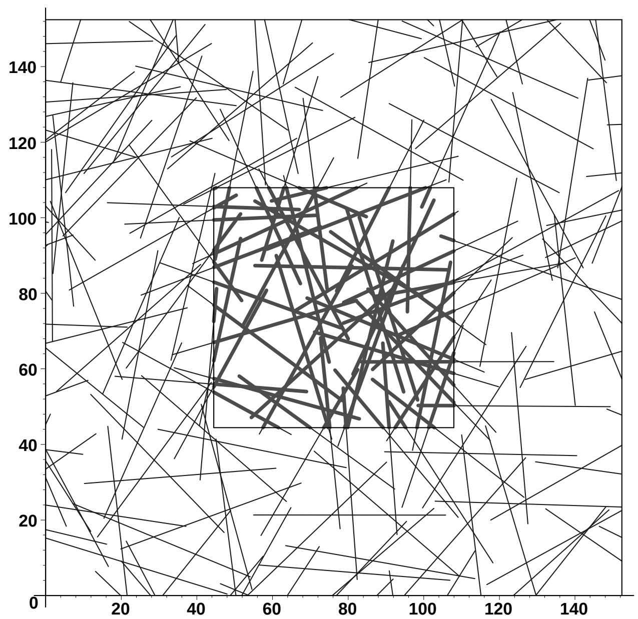

Figure 3: Random generation of strands of $L = 50.8$ mm. A typical "moving window" used for strands selection. Only the strands, or the portions of strands, inside the window are selected.

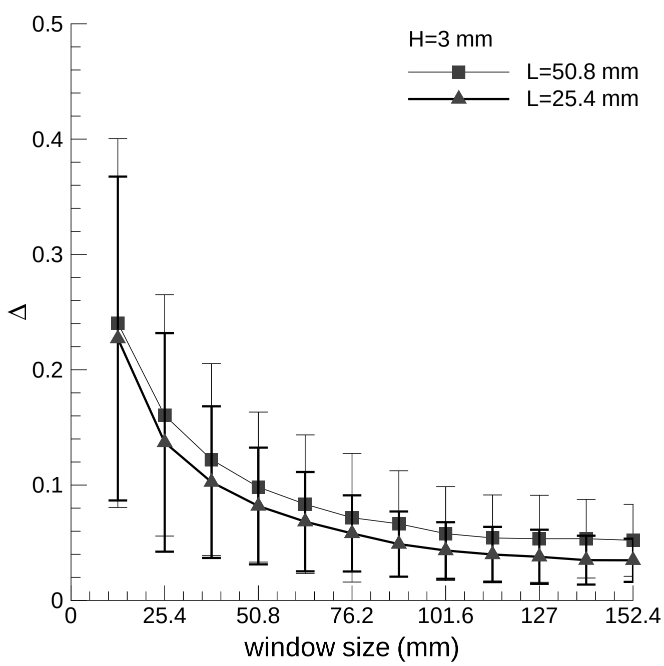

Figure 4: Departure from isotropy, as measured by the parameter Δ, vs. window size for two strand lengths and sample thickness of $H = 3$ mm, (i.e. 13 strand "layers").