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EFFECT OF THE DISTRIBUTION OF FIBERS ON THE TRANSVERSE MECHANICAL PROPERTIES OF GLASS-FIBER COMPOSITE

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ABSTRACT

The dependence of the transverse elastic and strength properties of unidirectional glass-fiber composites on the distribution of fibers in the matrix was studied numerically using a finite element homogenization framework employing Representative Volume Element (RVE) and periodic boundary conditions.

An In-house developed Swelling and Random Migration algorithm was used to generate random distributions of fibers in an RVE, where after initial placement of fibers with relatively low volume fraction an iterative process of fiber swelling and collision detection with the subsequent random migration of fibers was performed. The process is controlled by two main parameters: the swelling rate and the intensity of “Brownian” motion, where every fiber is randomly shifted by a certain amount at each iteration, avoiding collision with other fibers and enforcing the periodicity of the RVE. These parameters allow the generation of statistically different distributions of fibers. When the intensity of “Brownian” motion during the swelling process is minimized, the fibers tend to stick to each other and a clustered distribution with several tight fiber clusters and large resin-rich zones is generated as seen in the composite cross-section (Figure 1a). A large intensity of “Brownian” motion results in an equilibrium distribution of fibers, corresponding to the most random distribution of impenetrable disks representing fibers in the cross-section (Figure 1d). For the current study, a clustered distribution with 200 fibers and a volume fraction of 0.6 was generated initially (Figure 1a). Then additional iterations were performed with the swelling rate equal to zero and increased “Brownian” motion intensity, leading to more random distributions (Figure 1bc), until an equilibrium distribution was obtained (Figure 1d). As a result, a series of RVEs with a transition from clustered to equilibrium distribution with several intermediate states was generated.

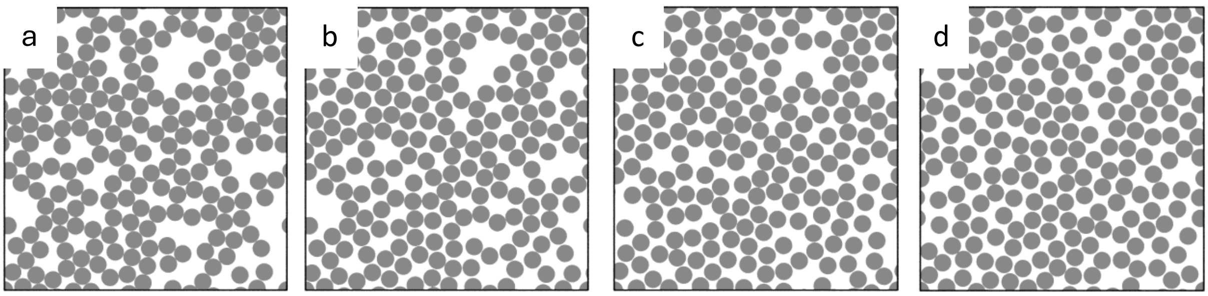

Figure 1: Transition from clustered (a) to equilibrium (d) distribution of fibers through several intermediate states (b, c).

Finite element modeling of the composite under transverse tension was performed by ABAQUS. Plain strain quad elements CPE4R were used to model the matrix and fibers. Cohesive elements COH2D4 were introduced in the model to simulate damage of the interface between fibers and matrix and delamination crack propagation. Linear elastic traction-separation behavior followed by linear damage evolution after damage initiation was used for cohesive elements. Damage initiation in cohesive elements occurs after the quadratic stress criterion reaches a critical value. Fibers were modeled as a linear elastic material with typical properties of glass fibers. The built-in linear Drucker–Prager plasticity model with a ductile fracture criterion was used for the matrix. An explicit solver was chosen for analysis to avoid convergence problems. To reduce the time necessary for simulation, mass scaling was used.

The effective properties were calculated for a model glass-fiber unidirectional composite with Young's moduli of constituents equal to 74 and 3.35 GPa, and Poisson's ratios equal to 0.2 and 0.35 for the glass fiber and the matrix, respectively. The tensile strength of the matrix was equal to 80 MPa. The interface strength between fiber and matrix in tension and shear was equal to 53 and 75 MPa with fracture toughness equal to 2 and 5 J/m^2, respectively.

The nearest neighbor distribution was calculated for the analyzed RVEs, and the average nearest neighbor's distance d normalized by the fiber's radius R was used as a measure of the "randomness" of a generated distribution of fibers. Two sets of RVEs with transition from clustered to equilibrium distributions were analyzed. Effective stiffness and strength were calculated in two orthogonal directions for each RVE, and average results are presented in Figure 2, where the dependence of stiffness and strength on the average nearest neighbor's distance is shown. The calculated values were normalized by the matrix stiffness and strength, respectively.

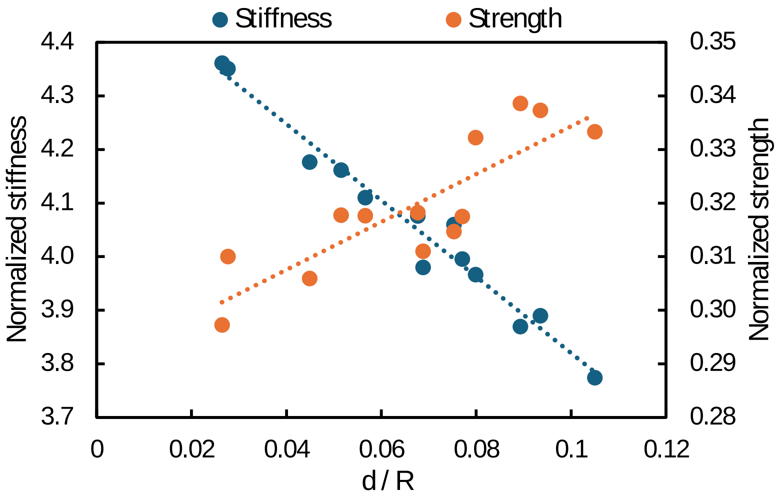

Figure 2: Dependence of the effective transverse stiffness and strength of a unidirectional composite on the average nearest neighbor's distance of fibers at a fiber volume fraction of 0.6.

The obtained results show that the simulated effective transverse stiffness and strength of the unidirectional composite vary linearly with the average nearest neighbor's distance, i.e. the degree of "randomness" of the fiber distribution. The effective stiffness has the highest value for clustered distribution (small nearest neighbor's distance) and decreases gradually for more random distributions with a minimum at equilibrium state. On the contrary, the simulated transverse strength increases as the nearest neighbor's distance increases. The difference in the effective transverse properties between the clustered and equilibrium distributions may reach 15% for a typical glass-fiber/epoxy composite with a 60% volume fraction of fibers.

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