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MULTISCALE ANALYSIS OF THE EFFECT OF MICROVOIDS IN THE FRACTURE BEHAVIOR OF FIBER-REINFORCED COMPOSITES

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The effective fracture behavior of a fiber-reinforced composite laminate depends on a series of design and manufacturing factors that include the material properties of the fiber and the matrix as well as the ply configuration (e.g., fiber volume fraction) [1-3]. An additional factor that influences the onset and propagation of micro-cracks at the sub-ply length scale are defects that appear during manufacturing. At that scale, defects may appear as micro-voids inside the matrix or as gaps between closely-spaced fibers that prevent filling. To study the influence of these micro-defects on the effective traction-separation response of a composite, a multiscale analysis is conducted where the defects are explicitly accounted for in finite element simulations. A recently-developed multiscale theory is expanded to account for voids in the computational domain. It is shown that the Hill-Mandel condition may be separated into two terms, one accounting for the actual crack and one for the voids that contribute to the crack process. The simulations are carried out using a separate traction-separation relation for each constituent (matrix, fiber and matrix-fiber interface) and for distinct mixed mode loading conditions until complete fracture is achieved. A convergence analysis is carried out to establish the existence of a representative volume element that includes voids of each type (matrix voids and fiber-gaps). Through a parametric analysis of configurations with a given void type and volume fraction, the influence of the void content on the effective fracture strength and the effective fracture energy of a composite can be quantified. Results show that for a mode II loading condition, both the effective fracture energy and strength decrease with increasing void content, while for mode I only the effective energy decreases. These effects only become significant when the void content exceeds a critical value, which depends on the type of voids evaluated.

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