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Macro Model for 3D Fiber Reinforced Polymer Composites

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Introduction: A Fiber Reinforced Polymer Composite (FRPC) has a very complex behavior that spans several scales of physical dimensions due to the interaction between the resin matrix and the fiber reinforcement. In this paper we confine our model to the simplest finite element model possible for the FRPC. We generalize the Macro Model first used by Buyukozturk,O. And Marcal, P.V. , [1] for Reinforced Concrete. In nonlinear analysis with the Macro Model, it was soon discovered that Fracture Mechanics formed a lower bound to our models. In this study, we present our Macro Model and apply it to problems with continuous fibers as well as discrete fibers. We compare our results with experiments. The study is confined to layered planar fiber reinforcement, although we provide a result that includes stitching in the third direction. It is noted here that even though the FRPC layers may be in plane stress, a Fracture Mechanics analysis involves fracture through the thickness so that it requires a full 3D Analysis.

Finite Element Macro Model: In this model we model the resin matrix and each fiber layer aligned in a particular direction as a series of parallel elements occupying the same element topology [2]. The element stiffnesses contribute to the element topology as a ratio of their volume. In practice, we model the element topology with a 27 node element. Then the element stiffness for the resin matrix assumes an isotropic elastic-plastic behavior, while the fibers are modeled directly as space bars that follow the displacement constraints of the element assumed displacement function. It is conveniently simulated with an anisotropic material behavior where the only significant stiffness lies along the fiber direction. Once the element stiffnesses are calculated, the direct stiffness of the displacement method takes over and the FEM follows the usual solution path. The model has ben applied to study fracture of continuous as well as discontinuous fibers. The basic fracture model consists of three layers of planar elements through the thickness. The first layer models the current depth of the initial crack which is usually determined by the transverse butt joins of the layers which may also be staggerred. In the second layer, the thickness is assumed to be that thickness that the crack propagates through. It is assumed to be equal to the thickness that includes all the fiber directions plus the matrix resin thickness (this is also the layer thickness assumed for the original mesh depth). The final layer is the remaining depth for all the rest of the thickness respectively. The three layers are sufficient to determine the fracture load by FEM and classic fracture mechanics [2] In the case of discrete fibers, we treated the fibers as being quasi-isotropic with an assumed initial crack depth equal to 4 thicknesses of fibers and matrix. In our analysis, we assumed a J-integral value of 80 J/mm. This is slightly lower than the value measured in [3].

Discussion of Results :The results agreed with experiments[4,5,6] over a wide range of specimens with and without holes.
It is noted that fracture analysis always provided a lower bound to the full nonlinear analysis, and in some cases for the C-Ply materials of [4], the fracture load was found to be 1/7 of the limit load. Finally in an attempt to mitigate the weakening effects of the implied initial gaps, we analyzed the transverse C-Ply specimen with a model that included through the thickness stitching (added a 3% fiber in the thickness direction). Surprisingly this produced a strengthening of the fracture load by a factor of ten. (still needs a comparison with experiment). The models used for the FEM required about 2 mins. each of computing on a PC. This may be compared with the multiscale models used for example in [3] that required at least two orders of magnitude in compute times.

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