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A Novel, Multiscale High Fidelity Progressive Damage and Failure Modeling Approach for Laminated Fiber Reinforced Composites

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ABSTRACT

A novel, physics based, multiscale computational methodology (MCM) has been developed to model the damage and failure modes observed in FRPs. Progressive microdamage, more specifically the growth of microvoids or fissures present in the epoxy phase of a FRPs, is modeled using the thermodynamically based Schapery Theory (ST) [1]. Failure, however, is evaluated using a micromechanical theory, the Generalized Method of Cells (GMC) [2], by resolving the global stresses to subcecell stresses, which act on individual constituent subcells. Failure criteria are then evaluated at each constituent subcell, and appropriate action is taken if the criteria are met.

In conjunction with the commercial code ABAQUS, and through the use of user defined subroutines, MCM has been implemented. At each integration point in a finite element, the damage state variable, S, is calculated using ST and the strains provided by ABAQUS. Since microdamage is only observed in the matrix phase, the lamina principal material properties, E_{22} and G_{12} are degraded according to damage functions. The damage functions, $E_{220}e_s(S)$ and $G_{120}g_s(S)$, are obtained from uniaxial tension tests. Once the microdamage state has been characterized, the reduced elastic modulus of the matrix phase can be calculated using a similar damage function, $E_m e_m(S)$. The matrix modulus and Poisson's ratio, along with the fiber elastic properties, produce global properties that are consistent with those observed in experiment. GMC is used to calculate the stress state in each constituent. If these stresses satisfy a failure criterion, the subcell properties are reduced to nearly zero and the global properties and stresses are recalculated.

This method provides a level of refinement not observed in most damage/failure theories. Figure 1 displays the failure contours acquired by implementing the Tsai-Hill failure criterion to constituent subcells using a 2 x 2 GMC representative volume element (turquoise indicates one failed matrix subcell, green indicates two failed matrix subcells, yellow indicates three failed matrix subcells, and red indicates a failed fiber subcell), in addition to ST at the global scale. When compared to Figure 2, a photograph of a failed specimen, it is clear that coupling of progressive damage (ST) and constituent failure is able to capture the observed failure mechanisms.

Additionally, Figure 3 shows the microdamage patterns generated by using ST with microlevel failure. This figures indicates that although progressive damage and failure are separate mechanisms, they are not isolated phenomena. Increasing microdamage leads to the redistribution of stresses, which, in turn, affects the subsequent failure modes. Similarly, redistribution of stresses and strains, resulting from failure, influence the progression of damage.

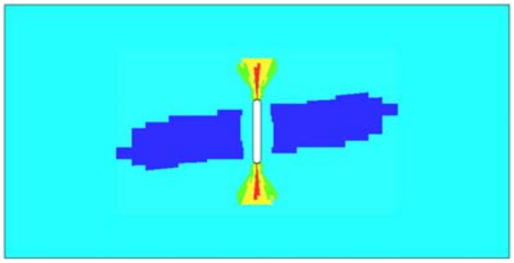

Figure 1. Failure pattern produced by ST coupled with microlevel T-H failure criterion.

Figure 2. Photograph of failed specimen, from Satyanarayana et al., 2006.

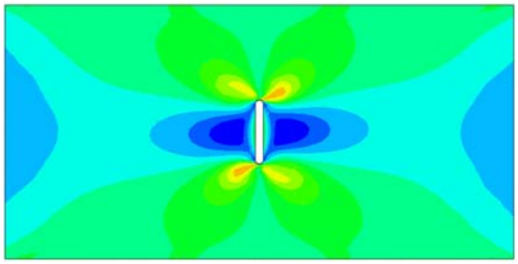

Figure 3. Microdamage pattern produced by ST with microlevel T-H failure criterion.

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