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Multiphysics analysis of state changes during progressive damage of composite materials

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ABSTRACT

For advanced heterogeneous materials in many applications, material state changes occur during service. The evolution of local details (damage initiation, accumulation, growth, and interaction) controls the progress of global property degradation, and they control the development of the final fracture event, i.e., the life of the engineering component. Traditional damage analysis approaches focus on the detection and location of flaws and defects, not on interactions or relationships between flaws or on the general change of state of the material. However, the changes in stiffness, thermal and electrical conductivity, dielectric permittivity, and structural integrity as a function of those properties are essential information. Therefore, a definitive definition and understanding of the multiphysics changes at the material level is needed. Because creation of a single microscopic crack or other distributed events does not directly affect the strength or life of the composite materials, what is needed is a method of integrating material state changes over the history of events associated with a specific history of applied fields into methodology for predicting remaining strength, stiffness, and life. The approach discussed in this article is founded on the method of Reifsnider, et al., as codified in his text on "Damage Tolerance and Durability of Material Systems" (Wiley, 2003), and on subsequent developments associated with the Energy Frontier Research Center on Heterogeneous Functional Materials led by the University of South Carolina (www.HeteroFoaM.com). As a result of capabilities developed in connection with the HeteroFoaM center, a multiphysics capability has been developed for prognosis in the presence of progressive damage. One of the most interesting aspects of that work is the "generalized compliance method" in which electrical (or thermal) conductivity, dielectric permittivity, and mechanical state variables are tracked and predicted as a method of assessing changes in material and structural integrity for progressive damage. As it happens, the relationship between changes in conduction, for example, and dielectric permittivity as a function of nonconservative deformation history is not linear and must be predicted from first principles solutions to the correct set of multiphysics equations. We have successfully illustrated this capability for polymer-based composites. We will discuss this and other details of this multidisciplinary approach.