A MULTI-SCALE FRAMEWORK FOR THE THERMO-RHEOLOGICALLY COMPLEX MULTI-LAYERED COMPOSITES

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Fiber reinforced plastic (FRP) composites exhibit time-dependent behaviors due to their soft polymeric matrix. Multi-layered laminated composites can have complex material and structural responses due to heterogeneities at multiple scales: laminate, ply, and fiber/matrix phases. Moreover, elevated temperature and humidity intensify the nonlinear and time-dependent deformation, which lead to material deterioration and damage. Time-dependent effective properties, performance, and durability of FRP structures are strongly influenced by the material microstructure: fiber, matrix, interface/interphase characteristics, and voids, among others. However, time-dependent viscoelastic response is often modeled at the laminate level by assuming an anisotropic homogenized response with separate (unrelated) creep compliances.

The present study introduces a multi-scale modeling approach that includes time-stress-temperature dependent behaviors for the matrix constituents. Three-dimensional (3D) homogenizations are carried out at each lamina (recognizing the fiber and matrix constituents) and at the sublaminate level to generate the continuum response for a repeating stacking sequence. The (3D) multi-scale material framework is built by using micromechanical models with efficient homogenization techniques and stress-updates. Previously developed micromechanical models for unidirectional and randomly oriented fibers are used [1, 2]. This framework generates an effective thermo-mechanical-viscoelastic response and is implemented to represent the response at a material model (Gaussian integration points) in finite element (FE) structural analyses. In this study, new constitutive formulations with numerical algorithms are used for thermo-rheologically complex materials (TCM). The proposed modeling approach allows incorporating stress and temperature dependence of the time-dependent modulus/compliance for the isotropic matrix and is integrated in the proposed multi-scale framework. The homogenization schemes also include stress correction algorithm at each scale to enhance computational efficiency and accuracy. Short-term (30 minutes) creep tests for off-axis multi-layered specimens under combined stresses and temperatures are performed. Time temperature superposition principle (TTSP) is then applied to create long-term material behaviors from the available short-term creep data. Calibration of the in-situ fiber and matrix properties and prediction of the overall time-stress-temperature responses are carried out using the short-term creep data. Verification of the multi-scale material framework is also done using the overall long-term responses. Finally, numerical applications of long-term structural analyses of multi-layered composite structures under thermo-mechanical loadings are performed to demonstrate the effectiveness of the proposed multi-scale analysis framework.

References:

[1] Haj-Ali, R. and Muliana, A., "Micromechanical Models for the Nonlinear Viscoelastic Behavior of Pultruded Composite Materials," Int. J. Solids and Structures, 40, pp. 1037, 2003.
[2] Muliana, A. and Haj-Ali, R., "Nested Nonlinear Viscoelastic and Micromechanical Models for the Analysis of Pultruded Composite Structures," Mech. of Matr. (MOM), 36, pp. 1087, 2004.