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A MULTI-SCALE STUDY FOR THERMO-VISCOELASTIC ANALYSIS OF FIBER METAL LAMINATES

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ABSTRACT

This study presents a multi-scale framework for analyzing the nonlinear thermo-viscoelastic response of fiber metal laminates (FML). FMLs are hybrid composite systems with alternating layers of fiber-reinforced polymer (FRP) lamina and metal sheets [1]. The mechanical properties of each constituent (fiber, polymer and metal) of FMLs often vary with time, stress, temperature and moisture. Significant progress with regards to understanding linear elastic and elastic-plastic properties of FMLs has recently been made. However, very limited studies have been done in understanding their nonlinear viscoelastic and long-term behavior. New development of FMLs also requires a rigorous structural analysis and structural design that can be applied to such a designed material. FMLs have been analyzed using finite element (FE) method by generating detailed meshes for each layer. Such an approach is computationally expensive. Alternatively, micromechanical-modeling approach has been widely used to provide effective homogenous responses of composite systems. In fact, different scales of homogenization are often needed, which lead to a multi-scale modeling approach. In order to analyze structural components with complex geometries and loadings, it is necessary to successfully incorporate these constitutive material models and homogenization procedures or the micromechanical models into the FE analyses.

A nonlinear viscoelastic constitutive behavior of FMLs is studied. Such a behavior can be exhibited due to the visco-elasticity in the constituents of FML i.e. the fibers, polymer matrix and metal. A previously developed numerical algorithm for modeling the viscoelastic constitutive behavior of orthotropic materials [2] is used. The nonlinearity due to stress and temperature is incorporated. This algorithm can also be easily reduced to obtain the results for isotropic materials. In this study, this algorithm is used to analyze thermo-viscoelastic responses of FRP and metal sheets in the FMLs through the following approaches:

1. Using layered composite elements and directly implementing the algorithm at the Gaussian points of each layer in a layered composite element.

2. Using a sublaminate homogenization scheme to homogenize the viscoelastic responses of the constituent layers of FMLs and then sampling at the Gaussian points of a 3D continuum or a shell element.

In the first approach, the lamina level constitutive orthotropic and isotropic viscoelastic material properties are provided for calculation at the respective Gaussian points of each layer and the overall response of the FML is obtained. In case of the second approach, the response obtained for each layer is homogenized using a sublaminate model that is based on the 3D lamination theory assuming a perfect bond between layers. This approach was proposed by Haj-Ali et al.[3]. An incremental formulation is used and the average stresses and strains across the effective FML continuum are related to the average stresses and strains in each layer. The homogenized anisotropic response is then sampled at the Gaussian points of a 3D continuum element and the overall response of FML is obtained.

In both approaches, it is possible to incorporate a micromechanical model for the FRP layers by considering the constitutive behavior of constituent fiber and matrix. The use of micromechanical model can be very useful for design of new material systems of FMLs with variety of combinations of fiber and matrix systems and fiber volume fraction of each system. A Micromodel is developed for unidirectional FRP [4] with an assumption of perfect bond between fiber and matrix and a four square cells idealization with incremental formulation in terms of the average stress and strains in each subcell. An isotropic nonlinear viscoelastic model is assumed for the matrix while the fiber is assumed to be orthotropic and nonlinear viscoelastic.

The application of the numerical algorithm to FMLs is verified by comparison of results with experimental data. The results of the various approaches are also compared in terms of computational accuracy and computational efficiency by comparing them with the results from a detailed FE analysis with 3D continuum elements for each layer. These approaches are then applied for analyzing practical structural components made of FMLs, such as aircraft fuselage. A simplified model of an aircraft fuselage subject to internal and external pressures and temperatures will be analyzed.

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