TIME DEPENDENT RESPONSE OF SMART SANDWICH COMPOSITES

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Abstract. This study presents analysis of the time-dependent response of smart sandwich composites comprising of glass fiber reinforced polymer (GFRP) skins, polyurethane foam core, and lead zirconate titane (PZT) crystals embedded in the GFRP skins. A multi-scale model is developed to integrate different constitutive models of the constituents in the sandwich structures. Quasi-static and creep tests are conducted for bulk epoxy, GFRP, polyurethane foam, and sandwich specimens under uniaxial tension and bending, at room temperature and at 80oC. The experimental data are used for material characterization and model verification.

1 INTRODUCTION

Polymer foam sandwiched between two thin fiber reinforced polymer (FRP) laminated composite skins provide high strength and stiffness and lightweight structural components. The use of polymer matrix in the facesheets and polymer foam core leads to significant time-dependent (viscoelastic) response. Extreme temperature changes and humid environmental condition influence the rate of relaxation and creep, and can significantly change (degrade or enhance) the stiffness and strength of the constituents in the sandwich composites, affecting short- and long-term performance of the entire sandwich structure. This work presents a multi-scale model of the time-temperature-dependent behavior of smart sandwich composite structures. PZT wafers are placed within the layers in the FRP facesheets, and potentially could be used to monitor damage in sandwich structures.
2 EXPERIMENTS

The specimens constructed for this project are divided into three groups: Group A, baseline/control sandwich specimens (with no sensors); Group B, conditioned sandwich specimens (with embedded PZT sensors); Group C, as-received foam material and monolithic facesheets, the individual components of the sandwich specimens, whose response was required for the calibration of the material parameters in the constitutive models. There were three different facesheet lay-ups: [0]₈, [90]₈ and [±45]₄. The piezoelectric transducers were positioned during lay-up between the 4th and the 5th layers of one facesheet, which was to be in tension during the bending tests. Two types of experiments were conducted: uniaxial tension and three-point bending tests, which were used to calibrate material properties of the constituents and verify the multi-scale model. Detailed experimental discussion can be found in Farrugia et al. [1].

3 MULTI-SCALE MODEL

The multi-scale model consists of the following components: constitutive models of the constituents in the sandwich structures, a micromechanical model for plaid unidirectional fiber composites, and a composite beam structure. At the structural scale, finite element (FE) is used to obtain creep deformation of the studied sandwich beams under three point bending. The constitutive and micromechanical models of each constituent and component of the sandwich beams are implemented at each material (Gaussian) points within three-dimensional (3D) continuum elements of the sandwich beam models.

A linear viscoelastic constitutive model for solid materials is used for the polymer resin in the FRP and polymer foam core:

\[ \varepsilon_{ij}^t = \varepsilon_{ij}(t) = \frac{1}{2} \int_0^t \frac{dS_{ij}^s}{ds} \, ds + \frac{1}{3} \delta_{ij} \int_0^t B(t-s) \frac{d\sigma_{kk}^t}{ds} \, ds \]  

(1)

where \( J \) and \( B \) are the time-dependent shear and bulk compliances, respectively, \( S_{ij}^t \) and \( \sigma_{kk}^t \) are the components of the deviatoric and volumetric stress at time \( t \), respectively, \( \delta_{ij} \) is the delta Kronecker, and the superscript \( s \) and \( t \) denote the representative of the previous time and current time, respectively. The glass fibers in the GFRP facesheets are modeled as linearly elastic, while a typical linear electro-mechanical relation is used for the PZT crystals:

\[ \varepsilon_{ij} = S_{ijkl} \sigma_{kl} + d_{ijkl} E_k \]

\[ D_i = d_{ijk} \sigma_{jk} + \kappa_{ij} E_j \]  

(2)

where \( S_{ijkl}, d_{ijkl}, \) and \( \kappa_{ij} \) are respectively the scalar components of the elastic compliance tensor, piezoelectric constant, and dielectric constant of the PZT; \( E_i \) and \( D_i \) are the scalar components of the electric field and electric displacement, respectively.

Each FRP skin in the sandwich composites consists of eight fiberglass/epoxy plies and each ply comprises of unidirectional fiber bundles, which are held together by weaving fiber yarns perpendicular to the unidirectional fiber directions. This system forms predominantly
unidirectional fiber layers with relatively low reinforcements in the transverse fiber direction. The effective properties of each ply are obtained by considering a stack of 0/90 fiber layup with different thicknesses and fiber volume contents for the 0° and 90° fiber directions. We refer the 0° fiber as ‘layer 1’ and the 90° fiber as ‘layer 2’. The effective properties for layer 1 and layer 2 are determined using a four-cell micromechanical model of unidirectional GFRP composites (Haj-Ali and Muliana, 2004). The micromechanical model was derived based on the assumptions that a) fibers are fully surrounded by matrix (no contact between fibers is taken into account), and b) perfect bonding is imposed at the interfaces between the fibers and polymer matrix. Two levels of homogenization are performed to determine the effective properties of each ply in the GFRP skins.

4 RESULTS AND DISCUSSION

Figure 1 illustrates the micromechanical prediction of the creep response of FRP skins subjected to uniaxial tension stress at room temperature. The multi-scale prediction of the smart sandwich beam is given in Fig. 2. Overall good predictions are observed.

![Figure 1: Creep Response of FRP skins under uniaxial loading at 25°C](image1)

![Figure 2: Creep Response of smart sandwich beam under bending at 80°C](image2)
A multi-scale framework, comprising of constitutive material models for different constituents (fiber, epoxy, foam core, and PZT crystals), a micromechanical model for FRP facesheets, and a structural beam model have been developed for predicting time-temperature dependent response of smart sandwich structures. The micromechanical model is shown to be capable of calibrating fiber volume contents of the FRP skins by matching the effective elastic material properties of the tested FRP skins and predicting creep responses of the FRP skins at various fiber orientations, i.e., $0^\circ$, $45^\circ$, and $90^\circ$. The integrated viscoelastic constitutive model and FE model are capable of capturing the creep deformation in the polyurethane beam under bending at temperature $80^\circ$C. We show the ability of our multi-scale model in predicting overall creep deformations of sandwich beams with and without embedded PZT crystals at elevated temperature $80^\circ$C. The effect of the soft epoxy matrix at $80^\circ$C on the overall creep deformation of the sandwich beam is insignificant since the high rigidity of the foam core is dominating the bending deformation of the sandwich beam. The calculated electric potential in the PZT crystals varies with time during the creep deformation of the sandwich beams; this shows the capability of piezoelectric materials of monitoring lifetime performance of sandwich structures.

REFERENCES
