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Viscoelastic response of higher laminate composite and sandwich plates

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1. INTRODUCTION& FORMULATION

Composites and sandwich structures are widely applicable in industry due to their excellent mechanical properties, especially high strength-to-weight ratio. Considering the time dependent properties of viscoelastic composite laminates, the mechanical behaviour of laminated composites lead to creep and relaxation response [1].

In present study, the efficient analysis for viscoelastic composite laminates are investigated based on higher order plate theories including efficient higher-order plate theory (EHOPT) [2]. By applying Laplace transformation instead of direct time integrations and inversing in time domain, the accuracy increase significantly. This Laplace transform approach on viscoelastic behavior of plates/shells is applicable to not only displacement-based zigzag higher order theories but also mixed formulation which has independently assumed transverse stress field.

As the constitutive equation of viscoelastic materials, the Boltzmann's superposition principle for linear viscoelastic materials is employed as follows:

$$\sigma_{ij}(t) = \int_0^t Q_{ijkl}(t-\tau)\frac{\partial}{\partial \tau}\varepsilon_{kl}(\tau)\,d\tau \tag{1}$$

where t is time, τ is time variable of integration, $\sigma_{ij}(t)$ and $\varepsilon_{kl}(t)$ are the time-dependent stress and strain, respectively; $Q_{ijkl}(t)$ is time-dependent relaxation modulus which can be approximately determined by mastering curve from experimental data [3]. By taking the Laplace transform with respect to time, the Boltzmann superposition integral equation in Laplace domain can be derived as follows:

$$\sigma_{ij}^*(s) = sQ_{ijkl}^*(s)\,\varepsilon_{kl}^*(s) \tag{2}$$

Following EHOPT, the form of the displacement fields, determined by the requirements that the transverse shear stresses should vanish on the upper and lower surface of the plates, including the interface between the laminas, is shown as follows:

$$\begin{cases} u_\alpha^* = \left(-w_{,\alpha}^* + c_{\alpha\gamma}\phi_\gamma^*\right)z - \dfrac{1}{2h}e_{\alpha\gamma}\phi_\gamma^* z^2 + \phi_\alpha^* z^3 + \displaystyle\sum_{k=1}^{n-1} b_{\alpha\gamma}^k \phi_\gamma^*(z-z_k)H(z-z_k) \\ u_3^* = w^* \end{cases} \tag{3}$$

where $b_{\alpha\gamma}{}^k$, $e_{\alpha\gamma}$ and $c_{\alpha\gamma}$ denote the matrices in the Laplace transformed domain which depend on both the material properties and the thickness of each ply. The procedures determining them are omitted because of the limited space.

2. NUMERICAL RESULTS

The [0/90/0/90] laminated composite plate is chosen as illustrative numerical examples. The material properties as well as time-dependent relaxation modulus of GY70/399 are

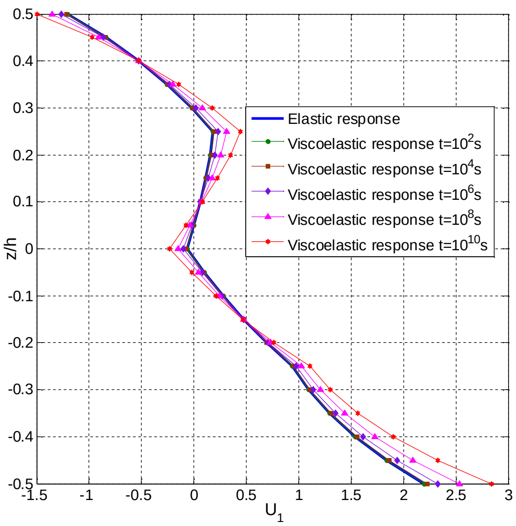

Fig.1 Nondimensional in-plane displacement U1 variation along the thickness

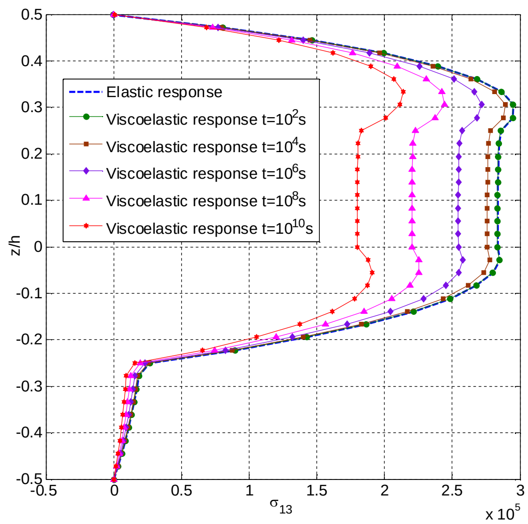

Fig.2 Transverse stress σ13 variation along the thickness

employed. In this version, the analytical solutions for cylindrical bending problem are presented. The displacement-based zigzag models and transverse stress-based mixed models are evaluated and the performances are compared with each other for viscoelastic behaviors.

The distributions through the thickness of in-plane displacement variation U_1 are shown in Fig. 1. The viscoelastic response has the same solution with the elastic one at the initial time. After that, it deviates from the elastic response as time goes but still keep the zigzag pattern through the thickness of laminates.

The transverse shear stress variations through the thickness are shown in Fig. 2 for the relaxation process. The amplitude of transverse stress decreases with respect to time, but still keeps the similar through-the-thickness stress distribution compared to elastic counterpart.

3. FUTURE WORK

In the present study, EHOPT has been applied to the viscoelastic materials in order to investigate viscoelastic response of the composite laminates. With the advantages of EHOPT, Laplace transformation method, the present theory can predict accurately, adequately and efficiently the time-dependent mechanical behaviour. For various loading and boundary condtions, the proposed approach should be implemented in finite element framework. This work is under progress.

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