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Discussion

Vibration behavior of ACLD treated beams under thermal environment

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1. Introduction

Sandwich structures are heavily used as sub-components in the construction of airplane, missile and spacecraft structures. Sandwich structures with viscoelastic cores are particularly useful in vibration damping over a wide range of frequencies. This is known as passive constrained layer damping (PCLD) treatment. Though viscoelastic materials are highly reliable in suppressing vibration they add additional weight to the structure, which puts a limit to their usage beyond a certain limit. Piezoelectric actuators on the other hand are efficient in suppressing vibration without adding much of additional weight to the structure. This is known as active layer damping (ALD) treatment. However, these materials are inefficient at high-frequency range and are not highly reliable. Hybrid damping treatment, popularly known as active constrained layer damping (ACLD) judiciously combines the advantages of the two, by having a viscoelastic core sandwiched between the base beam and active piezoelectric constrained layer. Khatua and Cheung [1] presented a finite element formulation for bending and vibration of multilayer sandwich beams and plates, with constrained cores. Rao and Nakra [2] carried out analysis of vibration of unsymmetrical sandwich beams and plates with viscoelastic cores. Rao [3] derived the complete set of equations of motion and boundary conditions governing the vibration of sandwich beams using energy approach. Park and Baz [4] studied the dynamics of plates treated with ACLD and compared the finite element formulations obtained using two theories namely classical laminate theory and layerwise laminate theory. Balamurugan and Narayanan [5] presented a finite element formulation and active vibration control of beams with smart constrained layer damping. In their work the frequency dependent characteristics of viscoelastic materials have been accounted by the well-known GHM method. Hau and Fung [6] studied the effect of ACLD treatment configuration on damping performance of a flexible beam. They have used equivalent single layer theory for the combined base and sensor layers and individual layer theory for the sandwich beam system. They have incorporated frequency dependent characteristics of viscoelastic layer (VEL) by using GHM method. In general viscoelastic material properties are dependent both on the frequency and temperature. Many researchers have focused their attention towards incorporating the frequency dependent characteristics in modeling. But there exists very few papers incorporating the temperature dependent material properties of VEL. Ganesan and Pradeep [7] have

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considered the buckling and vibration behavior of viscoelastic sandwich beams under thermal environment considering the temperature dependence of shear modulus of the VEL core. Trindade et al. [8] have given a finite element formulation for frequency–temperature dependent hybrid damping. However, their study ignores the initial stress effects because of the thermal environment. To the author's knowledge, there is no work reported in the literature on hybrid damping under thermal environment considering thermally induced pre-stresses and temperature dependent shear modulus of the core. The present work deals with a clamped–clamped ACLD beam subjected to a tip temperature. The loss factor variation and frequency variation with respect to temperature considering the temperature dependent core shear modulus and temperature dependent material loss factor of the core are reported. Two different core VEL materials are considered. A parametric study with thickness of the core, core material and control gain has been conducted. The relative comparison between active and passive damping has been attempted.

2. Finite element formulation

To evaluate the damping and vibration behaviors of the beam under thermal environment, thermally induced pre-stresses in the beam have to be calculated. The present formulation is a de-coupled thermo-mechanical formulation. The temperature field in the beam is calculated by using 4 noded rectangular elements. The sensor is rigidly bonded to the base beam and in between the sensor and constraining layer is the VEL as shown in Fig. 1.

The following are the assumptions made in constructing the finite element model:

1. The sensor layer is perfectly bonded to the base beam.
2. The combined base beam and sensor layer will behave like an equivalent single layer.
3. The transverse shears in the stiff layers are neglected.
4. The core material is viscoelastic with temperature dependent complex shear modulus (for details see Ref. [10]).

Fig. 1 shows a beam treated with ACLD along with the degrees of freedom used for modeling the beam. The expressions for stiffness matrix, mass matrix, thermal load vector and geometric stiffness matrix are not presented for brevity. These are well-known expressions given by Kautua et al. and Ganesan et al. [1,7].

The equation of motion of the sandwich beam under thermal environment is given by

$$[M]\{\ddot{\delta}_G\} + [C]\{\dot{\delta}_G\} + [[K] + [K_G]]\{\delta_G\} = 0, \tag{1}$$

where $[M]$, $[C]$, $[K]$, $[K_G]$, $\{\delta_G\}$ are the elemental mass matrix, piezoelectric damping matrix, complex stiffness matrix resulting due to viscoelastic core, geometric stiffness matrix, and array of global displacements, respectively. The averaged sensor voltage over an element is given by [9]

$$\bar{\phi}_s = \frac{-t_s b}{\varepsilon_{33} A_s}\left(\int_x \left\{e_{31} \quad \frac{t_b + t_s}{2} e_{31} \quad 0 \quad 0 \quad 0\right\}[B]\{\delta\}\,\mathrm{d}x + \int_x \{p\} T\,\mathrm{d}x\right), \tag{2}$$

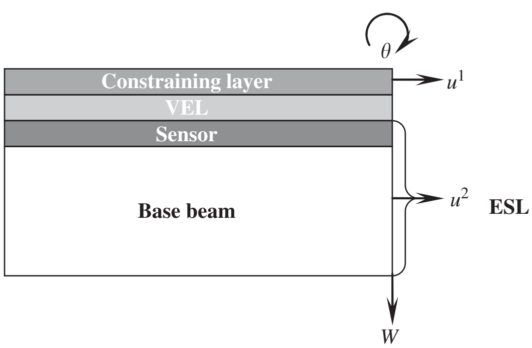

Fig. 1. Beam with hybrid damping treatment.