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Effects of Normal Strain in Core Material on Modal Property of Sandwich Plates

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In vibration analysis of sandwich beam/plates, it is often assumed that there is shear deformation only, without extension or compression in the viscoelastic layer. Certainly, this assumption may have limitations, for example, with increase of the core thickness or frequency range of vibration. The purpose of this paper is to consider the normal, as well as shear strain of the core material for modal parameter estimation of the sandwich plates and to investigate how much error will be caused by neglecting the extension or compression in the core material. Natural frequencies and modal loss factors are estimated for a simply supported square plate by taking the normal as well as shear deformation into account for dynamic modeling. Nondimensional characteristic equations are formulated and solved numerically for various ratios of the base layer thickness to plate length, core layer thickness to base layer, constraining layer thickness to base layer, and shear modulus of core material to elastic modulus of base layer. The effects of the various parameters on the modal properties are shown to be intercorrelated to each other and hence difficult to summarize in one phrase. Normal deformation of the core material plays an important role when the thickness ratio of constraining layer to base layer is 0.5 and its Poisson's ratio is smaller than 0.49, and hence need to be included in the dynamic modeling especially for estimation of modal damping when one of the following conditions are met; 1) the ratio of base layer thickness to plate length is greater than 0.02, 2) the thickness ratio of core layer to base layer is greater than 0.01, 3) the wavelength of a mode is less than one third of the plate length, 4) the ratio of shear modulus of core material to elastic modulus of base material is less than 10^{-5}.

1 Introduction

The use of sandwich plates with a viscoelastic layer between two outer elastic layers has been increasing recently for the purpose of noise and vibration control. Since thickness of the core layer is normally small compared with the outer layer, it is often assumed that normal deformation is negligible and shear plays a predominant role. Depending upon the frequency range of interest or ratios of layer thickness, however, this assumption may not necessarily be acceptable. In this paper, effects of the normal as well as shear strain on the modal parameters will be analyzed by two assumptions that the extensional deformation of the inserted layer is included and not. Also the level of errors caused by neglecting the normal strain will be presented for various thickness ratios of the layers.

Kerwin (1959) and Ungar (1962) proposed a shear damping mechanism in plate vibrations with one dimensional formulation. Yu (1960) deduced a flexural theory for sandwich plates and solved for generally forced vibration in case of plane-strain. Wempner and Baylor (1965) derived equations of sandwich plates with weak cores for large deflections. Yin et al. (1967) evaluated constrained layer damping quantitatively based on experiments. Ditaranto and McGraw (1969) determined natural frequencies and modal loss factors of a plate laminated with elastic and viscoelastic layers alternately under simply supported boundary conditions. Mead and Markus (1969) obtained natural frequencies and loss factors for sandwich beams with arbitrary boundary conditions. Yan and Dowell (1972) derived a single equation of motion for the sandwich plates and beams. Problems of multi-layered sandwich plates were solved by Chan and Cheung (1972) using finite strip method. Effects of inertia on transverse, longitudinal and rotary vibrations were included in the analysis of flexural vibrations of asymmetrical sandwich beams and plates (Rao and Nakra, 1974). Durocher and Solecki (1976) analyzed isotropic three-layer plates of symmetrical construction with a fourth-order equation. Poltorak and Nagaya (1985) solved a single equation of motion which had been derived by Yan and Dowell. He and Ma (1988) derived simplified governing equations and obtained an asymptotic solution for the sandwich plate.

Most of the above papers assume that transverse movements of particles in the two outer layers on a line normal to the plate surface remain equal, that is, there cannot occur any extensional deformation in the core layer in the transverse direction. With the increase of viscoelastic layer thickness, however, importance of the normal damping would increase in the core layer. Douglas and Yang (1978) studied the effects of transverse extensional damping in sandwich beams. Sylwan (1987) formulated a theory for combined shear and compressional damping effects of constrained layered beam structures and calculated the loss factor values. Park (1993) also analyzed numerically the effects of both shear and thickness deformations on the damping properties of sandwich beams.

In this paper, in order to investigate the effects of normal and shear deformations of the viscoelastic layer on the modal damping, two coupled sixth-order governing equations are formulated by allowing transverse movements of particles in the outer layers on a line normal to the plate surface. Since analytical solutions can be obtained for simply supported boundary conditions only, the analysis procedure is shown for square sandwich plates with such boundary conditions. By deriving and solving characteristic frequency equations for the two different assumptions that extensional deformation in inserted material is included and not, effects of including the extensional deformation in the core layer in the modeling are obtained for various

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