Abstract:

Polymers are widely used as the matrix in fibre-reinforced composite or as a core in sandwich composite structures, significantly contributing to the inherent material damping, which is advantageous for vibration and noise reduction in engineering structures by limiting the resonance or near-resonance amplitudes of vibration. Experimental investigations demonstrate that for the systems undergoing large amplitude vibrations, damping factor increases with vibration amplitude. For thin viscoelastic composite structures undergoing transverse displacements of the order of their thickness, the consideration of inherent material damping and geometric nonlinearity becomes important for accurate prediction of deflection, frequency response, amplitude-dependent damping and radiated sound pressure response. It is concluded from the literature review that the periodic vibration and sound radiation response characteristics of viscoelastic laminated composite plates, including geometric nonlinearity, have not been investigated. An attempt is made in the thesis to address the problem using the finite element formulation based on equivalent single-layer first-order shear deformation theory incorporating ‘‘zig-zag’’ function accounting for the discontinuity in the slope of in-plane displacements at the layer interfaces, Boltzmann integral viscoelastic constitutive relation and geometric nonlinearity. An integral form of the constitutive relation is converted to the incremental form for the finite element formulation based on the Reissner–Mindlin plate theory incorporating ‘‘zig-zag’’ function and von Karman geometric nonlinearity. The recursive relations are derived to compute the current time-step solution using the previous time-step solution. The non-linear equations of motion are solved in the time domain to obtain the steady-state periodic response using the shooting technique coupled with Newmark time-marching and arc-length continuation algorithms. The implementation of the shooting technique for the Boltzmann integral-based viscoelasticity is done for the first time in this study involving the derivation of a number of additional recursive relations and initial conditions at the beginning of each shooting cycle. The acoustic pressure is evaluated using the time domain Rayleigh integral and elementary radiator approach considering plate vibrations in an infinite baffled plane.

The geometrically non-linear steady-state vibro-acoustic analysis of viscoelastic laminated composite/sandwich plates subjected to uniformly distributed transverse harmonic force is carried out in the time domain. A detailed parametric study is carried out to investigate the effect of boundary condition, lamination scheme, number of layers, aspect ratio, thickness ratio, variation of fibre angle at the center and edge of lamina, relaxation time, and number of Maxwell elements in the viscoelastic model. Additionally, the variation in core-to-face thickness ratio and areal density is also considered for the sandwich composite plates. The influence of these parameters on the non-linear frequency/pressure response, damping factor, steady-state displacement/sound pressure response history, phase-plane plots, displacement/sound pressure frequency spectra, and the A-weighted sound pressure level (dBA) is investigated in detail. The results presented herein, without a priori assumptions of participating modes and harmonics, may also serve as a reference for comparison with approximate analytical solutions.

A significantly greater degree of hardening nonlinearity is predicted for immovable simply supported plates compared to movable simply supported plates. Furthermore, the increase in damping factor (ζ) with vibration amplitude is more pronounced for thin plates than for moderately thick plates. There is a significant contribution of even harmonics in cross-ply $[0^0/90^0]$ laminated antisymmetric thin square plates with non-identical boundary conditions (CSCS) and rectangular thin plates with identical boundary conditions (CCCC/SSSS). The difference in the sound pressure level corresponding to non-linear and linear peak amplitude is more pronounced on the dBA scale compared to the dB scale due to the contributions of higher harmonics. In the case of variable stiffness viscoelastic plates, an edge fibre angle of 90^0 leads to a significant decrease in peak amplitude due to an increase in the damping although overall stiffness decreases. Additionally, the spatial distribution of sound pressure level (in dB) along plane passing through the plate diagonal is highly sensitive to modal contributions producing alternate strong (lobe) and weak (null) sound radiation regions for higher modes excitation.