Multi-layer composite beam modelling and optimization for high speed mechanical applications

ABSTRACT ICCS20

Multi-layer composite beam applications are known and used to obtain functionally graded mechanical components whose properties can be tuned to obtain high performance, such as strength, stiffness, light inertia and damping behaviour. Nevertheless, the technical literature lacks in studies concerning multi-layer dynamical beam modelling making it possible to identify the model parameters of known solutions and to design new solutions being able to overcome the limits associated to such solutions. A current research topic concerns high damping FGM applications in the aerospace field, where standard high stiffness, high strength slender shell components, such as turbine blades, must show a limited vibrational behaviour in operating conditions, i.e. the material used should exhibit normally conflicting characteristics, such as high internal hysteresis and high stiffness as well. In this specific field, some recent applications were explored, mainly based on an experimental approach, and while some of them showed to be effective, the lack of a theoretical model inhibited the study of any possible improvement.

In this paper beam-based mechanical components, to be used in high speed mechanical applications such as in the automotive and in the automation industry field, are considered and investigated from a mainly theoretical point of view. A basic dissipative mechanism is proposed in order to justify the damping behaviour associated to some known multi-layer material composite solutions experimentally shown by some researchers and by our research group in the past. A multi-layer beam modelling, based on the known zig-zag approach, was studied and here proposed, with the specific aim to simulate the dynamical behaviour of known solutions, to make it possible to identify the unknown model parameters associated to the manufacturing technology and then to optimize the multi-layer architecture to obtain the best possible design solution.

A new piecewise cubic function describing the axial displacement of each layer of laminated composite beams, being able to correctly model the shear stress at the different layer interfaces, is proposed. The contribution of this function is added to the classic Timoshenko beam theory component to provide a realistic representation of the deformation states of transverse shear flexible laminated composite beams in the case of plane strain hypothesis. The function is defined in terms of the axial displacements at the layer interfaces, presenting cubic variation across the thickness of every layer of the composite beam and continuity at the layer interfaces, where its amplitude is

supposed to vanish at the top and bottom surfaces of the beam. In addition, the continuity of the transverse shear stress at each layer interface can be imposed in order to obtain a well-conditioned system of equations of motion, but it can also be relaxed to model frictional actions between layers. A procedure making it possible to obtain the value of the axial displacement at each layer interface starting from the axial displacement of the previous layer interface is developed. The profile of the axial displacements along the beam thickness is obtained in the most general form, being not dependent in shape by the boundary conditions and applied external forces. The effect of the thickness and shear modulus of each layer on the profile of the axial displacements along the beam thickness by considering different numbers of layers is studied. Several geometric and material configurations are compared. From the analyses, some optimal configurations concerning heterogeneous materials and layer thicknesses, giving the most relevant deviation of the axial displacement distribution along the depth of the cross-section of the beam with respect to the linear axial displacement distribution given by the Timoshenko beam theory, are outlined. The influence of the heterogeneous axial displacement distribution along the beam thickness on the dynamical behaviour of laminated composite beams is investigated. The free and forced vibrational behaviour of composite beams under different boundary conditions and time-varying transverse loading is obtained and the results are critically discussed.