Abstract

The multi-segmented smart structures are a promising and versatile approach to designing complex systems that can be adapted to various applications. They offer greater flexibility, durability, and efficiency than monolithic structures and have the potential to transform the way of building structures. By breaking down a design into smaller segments, it is possible to make repairs or modifications to individual components without affecting the entire system. Additionally, segmented structures can be optimized for specific applications by adjusting the number, size, and shape of the segments. A variety of materials can be used to construct multi-segmented structures, including metals, composites, and polymers. This concept is extensively used in automobiles, aerospace, robotics, locomotives etc., to reduce the structure weight, material and cost. In this, the segments of different high-strength materials like steel are joined with lighter materials like composites. These segments may be joined along the longitudinal or transverse direction within the system. However, it causes the formation of interfaces at the segment joints and the generation of stress concentration due to sudden changes in the material. It may result in the failure of structures under different loading conditions. So, to tackle the issue of a sudden change in material properties, an idea was proposed to vary the material properties in a gradual manner along the span or thickness. Such advanced materials are known as functionally graded materials (FGMs). Hence, an appropriate method is required to investigate the behaviour of such structures, which can also serve as the benchmark for their optimal design and fabrication. Although numerical methods and commercial finite element packages are available for a variety of structural problems, there is always a need for analytical solutions. The analytical elasticity models can predict the behaviour of segmented structures more accurately as compared to the one or two-dimensional theories or numerical solutions. The extended Kantorovich method is undoubtedly one of the best techniques that offer an analytical solution for complicated problems.

An analytical 2D elasticity solution using the multi-term extended Kantorovich method (EKM) has been presented for the static analysis of multi-segmented dissimilar beams subjected to arbitrary boundary conditions. The beam segments are considered perfectly joined along the span or axial (x) direction. The segments with different material and length combinations are considered. Reissner's type mixed variation principle is applied to derive the weak form of coupled governing equations in which all the stresses and displacements act as primary variables. Further, the EKM is applied to reduce the governing equations into sets of ordinary differential equations (ODEs) along the axial (x) and thickness (z) directions. The system of ODEs along the z and x-direction have constant coefficients, which are solved analytically. Interface continuity and boundary conditions are satisfied in an exact point-wise manner, which ensures the same order of accuracy for all field variables (stresses and displacements). The efficacy and accuracy of the present methodology are verified thoroughly with a 2D finite element solution. Benchmark numerical results are presented for various cases of material combinations under different types of boundary conditions. A significant effect of segment length and thickness on the static behaviour of the beam is observed. This development mimics the axially graded behaviour of the beam and is able to predict results accurately. The developed extended Kantorovich approach is further extended to more complex problems such as in-plane multi-segmented angle-ply flat panels. Benchmark numerical results are presented for single-layered in-plane angle-ply flat panels. The influence of segment material, length and ply-angle variation on the deflections and stresses are studied and discussed comprehensively for arbitrary boundary conditions and configurations. Apart from the above analysis of segmented elastic structures, a piezoelectricity-based analytical solution is also developed for piezoelectric flat laminated panels under arbitrary boundary conditions. The effect of the hard and soft piezoelectric segments on the static behaviour of the panels is investigated. Moreover, a case of linearly graded piezoelectric material is also assumed, which can mimic the axially functionally graded (AFG) behaviour. The presented 2D analytical solution will be helpful in the assessment of various 1D theories and numerical methods. The above analysis is more severe than a homogenous beam and panel. The current research will also be beneficial to model real-life panel structures in which their material properties are piece-wise homogenous. Apart from the analytical and numerical analysis, a fabrication method may be adopted for the experimentation of such structures. In this point of view, multi-segmented metal-ceramic-based axially graded FGM systems of Copper/Silicon Carbide (Cu/SiC) specimens are fabricated, synthesized and characterized considering various volume percentages of ceramic concentrations through the powder metallurgy route. Apart from the characterization of the powders, ceramic particle distribution, microhardness and the effect of ball-milling on the powder is also carried out. Further, the effective elastic properties and modal frequency of the fabricated specimens are obtained using the resonant frequency dynamic analyser (RFDA) technique. A 3D finite element model of the specimen has been modelled in ABAQUS to validate the experimental natural frequencies under different modes. A percentage difference in the experimental and numerical frequencies is presented and discussed for different specimens