THEORETICAL AND EXPERIMENTAL STUDIES OF THERMOELASTIC RESPONSE OF FUNCTIONALLY GRADED BEAMS

by

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Dedicated to

My grandfather Late R. G. Bhattacharjee
and
my family

Certificate

This is to certify that the thesis entitled ***"Theoretical and Experimental Studies of Thermoelastic Response of Functionally Graded Beams"*** *being submitted by Mandira Bhattacharyya to the Indian Institute of Technology, Delhi for the award of the degree of Doctor of Philosophy in Applied Mechanics is a record of original bonafide research work carried out by her under our supervision and guidance. The thesis work, in our opinion, has reached the requisite standard fulfilling the requirements for the degree of Doctor of Philosophy.*

The results contained in this thesis have not been submitted in part or full to any other University or Institute for the award of any degree or diploma.

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Abstract

A unified formulation is presented for coupled efficient zigzag, third order, consistent third order and first order models for hybrid piezoelectric layered functionally graded material (FGM) beams under thermoelectromechanical load. The transverse as well as inplane electric fields are considered. The potential and thermal fields are discretized sublayerwise as piecewise linear which can adequately approximate the actual distributions of these fields across the thickness. The governing equilibrium equations have been derived from a variational principle. The accuracy of the 1D models is assessed in direct comparison with the exact 2D solutions for elastic as well as piezoelectric hybrid layered FGM beams for static response under electrothermomechanical loads, free vibration response and forced vibration response under electromechanical loads. The effects of the inhomogeneity parameter, span-to-thickness ratio and electric boundary conditions are investigated. It is established that the zigzag theory results are, in general, superior to those of other 1D models, even though they have the same number of displacement variables. A two-noded finite-element model is developed based on the zigzag theory for linear dynamic response elastic FGM beams under thermomechanical loading.

Two layered FGM systems, namely aluminium/silicon carbide (Al/SiC) and nickel/alumina (Ni/Al_2O_3) are designed, synthesized and characterized considering 10, 20, 30 and 40 volume percent ceramic concentrations. Two, three and five layer flat beam shaped FGM specimens are fabricated using powder metallurgy route for Al/SiC system and thermal spraying technique for Ni/Al_2O_3 system. Apart from microstructural studies for looking into the ceramic particle distribution and interfacial transition, porosity content and microhardness are also determined. Three bulk properties are evaluated for FGM characterizations, namely effective flexural strength, thermal fatigue behavior and thermal shock resistance. Progressive and appreciable enhancement in FGM performance is observed as the number of layers is increased from two to five keeping the compositions of the extreme layers same. Percent difference between experimental microhardness at layer interfaces and the mean of the microhardness values of the adjacent layers is found

to be consistent with the analytically obtained jump in the inplane stresses at the interfaces, and both are found useful in explaining the failure behavior and performance of the FGMs studied.

The stress to strain transfer ratio for Al/SiC composite system is experimentally determined from the flexural load-deflection behavior of single-layer beams of different compositions. This ratio is used for predicting the elastic modulus of the Al/SiC FGM using a modified rule of mixtures (MROM). The zigzag theory based finite element model in conjunction with the MROM for estimating effective elastic modulus and the Wakashima-Tsukamoto model for the effective coefficient of thermal expansion (CTE) is validated through experiments for static thermomechanical response and free vibration response for Al/SiC and Ni/Al_2O_3 FGM beams. The theoretical predictions for the layered beams with the ceramic content varying from 0 to 40% are compared with the experimental data for the static deflection under simply-supported and cantilever boundary conditions, and for the natural frequencies under cantilever and clamped-clamped boundary conditions. The effect of number of layers on the accuracy of the theoretical model is discussed. The CTE of Al for the temperature range used in this study is determined by measuring the central deflection of simply-supported single-layer Al/SiC samples of three different compositions under thermal loading. The applicability of various models for CTE prediction is tested by comparing the predicted CTE of Al with that reported in literature in the similar temperature range. Two models for thickness discretization with equal thickness and equal change in volume fraction, respectively, are evaluated in terms of magnitude of axial stress and its jump at the interfaces. The effect of inhomogeneity parameter for compositional variation and the number of layers in the FGM on the thermal stress and deflection is studied paving the way for an optimum design of FGM beams under thermal loading.

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