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Buckling of Functionally Graded Plates with Varying In-Plane Loading

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ABSTRACT

Functionally graded materials are materials with a spatial variation of material properties. The FGM plates have significant applications in turbine blades, helicopter blades, compressor blades, aircraft or marine propellers. Many of these plates are subjected to in-plane load due to fluid or air pressure. Hence it is necessary to study their behavior under different types of loads. Study of buckling of functionally graded material (FGM) plates with different boundary conditions under varying in-plane load is therefore an important study. In these days, FGM have many engineering applications because of their high stiffness and strength. The analysis is completed utilizing ANSYS programming. In ANSYS, the SHELL 281 component with six degrees of freedom per node is utilized. Twelve by twelve mesh and twelve layers were chosen for the analysis as per the results obtained in convergence study. Buckling of FGM plates with different in plane loading are studied. The effect of different parameters like width to thickness proportion, aspect ratio, gradient index and boundary conditions on the buckling load of FGM plates with varying in-plane load were studied.

INTRODUCTION

Functionally graded materials are materials with a spatial variation of material properties. The volume fractions of two or more materials may be varied continuously either only along the thickness direction or as a function of the in-plane dimensions. FGMs are usually made from a mixture of metals and ceramic. In this thesis, we consider plates in which the material properties change continuously through the thickness.

These FGM plates are used in various engineering applications and they are often subjected to dynamic loading. FGMs are used by the engineering community mainly in nuclear plants and spacecraft of high temperature applications as FGMs can withstand high temperatures. Presently they are also used in structural walls, body coatings for cars, and in sports products. In the FGMs, interface problems are eliminated by changing the volume fraction of constituent materials smoothly and continuously from surface to surface.

LITERATURE REVIEW

Plenty of studies for vibration, thermal stress and thermal bending of the functionally graded plates are available in the literature. Praveen and Reddy (1998) investigated the nonlinear static and dynamic response of functionally graded ceramic–metal plates in a steady temperature field. The plate was subjected to dynamic transverse loads. They used the finite element method (FEM) based on the first-order shear deformation plate theory (FSDPT).

Reddy (2000) investigated functionally graded plates, based on the third-order shear deformation plate theory. Numerical results of the linear third-order theory and non-linear first-order theory were presented to show the effect of the material distribution on the deflections and stresses. Chung and Chi (2001) studied functionally graded material (FGM) plate of medium thickness subjected to transverse stacking.

Javaheri and Eslami (2002) investigated rectangular functionally graded plates (FGPs) using the variational methodology.

The vibration characteristics and transient response of shear-deformable functionally graded plates and panels in thermal environments was studied by Yang and Shen (2002, 2003). They considered material properties to be temperature-dependent and the effect of temperature rise on the dynamic response was reported. Kang and Leissa (2005) formulated an exact solution for the buckling analysis of rectangular plates having two opposite edges simply supported. These edges were subjected to linearly varying normal stresses.

Abrate (2006) presented free vibration, buckling, and static deflections of functionally graded plates. He showed that natural frequencies of the functionally graded plates were proportional to the homogeneous isotropic plates.

Ebrahimi and Rastgo (2008) investigated the free vibration of smart FGM plates. They studied FGM plates integrated with two uniformly distributed actuator layers made of piezoelectric (PZT4) material on the top and bottom surfaces of the circular FG plate based on the classical plate theory (CPT).

Hadi et al. (2013) presented an elastic analysis of transverse loading acting on the functionally graded beam. They determined the stresses and strains on FG beam by using energy method, and also used power law for varying thickness. This gave the exact solution for stresses and displacements.

THEORY AND FORMULATION

Constitutive Relations

The FGM plate taken for the study is made up of one side metal and the other ceramic. A parameter „n‟ (material property index) shows the material variation along the thickness. The plate is fully ceramic for n = 0, and the plate is fully metal for n = α. Material properties are dependent on the n value and the position in the plate and vary according to the power law. The material property of the FGM changes through the thickness. The numerical model is broken up into a number of layers in order to model the gradual change in properties of the FGM. Each layer is assumed to be isotropic. Material properties are calculated at the mid-point of each of these layers from the mid surface using power law, (Reddy [11]). Although the layered structure does not reflect the gradual change in material property, by using a sufficient number of layers the gradation can be approximated.

Finite element formulation

Finite element software ANSYS 13.0 is used for the formulation of the FGM plate. SHELL 281 is used to model the element. SHELL 281 has eight nodes with six degrees of freedom per node: three translations in x-, y- and z- directions and three rotations. The first-order shear deformation theory is assumed for the modeling in ANSYS 13.0.

ANSYS methodology

Problems that can be solved in ANSYS include static/dynamic structure analysis (both linear and non-linear), heat transfer and fluid problems, as well as acoustic and electro-magnetic problems.

Post-processing

This stage is to view and process the results like the list of nodal displacements, element forces and moments and deflection plots. The present problem has been solved using ANSYS software. The FGM plate was first solved without loading in order to validate the methodology and the results compared to previous results for free vibration and buckling. Also the methodology was tested for a laminated composite plate with different types of edge loading and results compared to a result from a previous paper. The results matched closely in most cases. Then the software was run for studying the FGM plate with different types of in-plane loads.

RESULTS AND DISCUSSIONS

The FGM plate considered here consists of ceramic on top and metal at the bottom. In FGM plates, the material properties change continuously over the thickness by varying the gradient index (n). Those properties are density (ρ), Young‟s modulus (E) and also Poisson‟s (υ) ratio. If n = 0, then the plate is completely ceramic and if n = infinity then the plate is completely metal. Material properties depend on gradient index (n). By using the power law (Reddy[2000]) we can find out the material properties.

By using the MATLAB software, the Young‟s modulus of each layer was calculated. Poisson‟s ratio and density were kept constant. Then a model of FGM plate was developed by using ANSYS. Free vibration of cantilever FGM flat plate will be studied and results obtained and these results compared with previous results. Then the flat FGM plate is modeled and again results will be studied for plate with varying in plane loads.
Figure 4.1 shows the variation of V_f through the plate thickness.

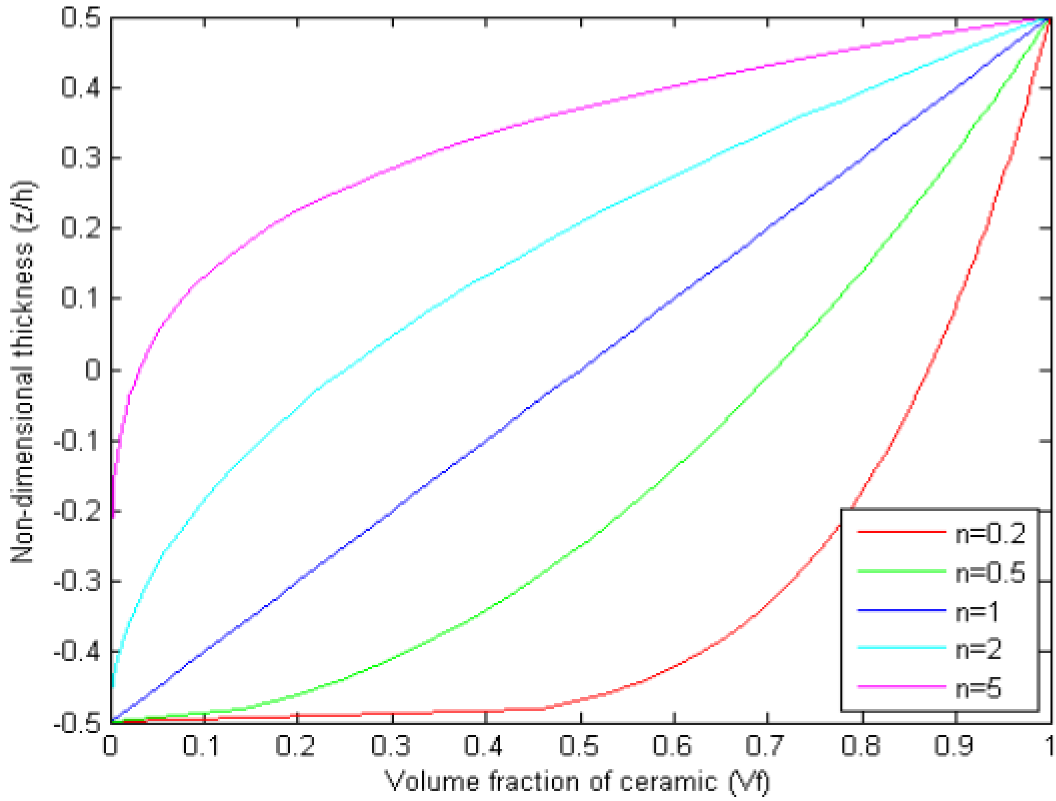

Figure 4.2: Variation of Volume fraction (V_f) through plate thickness

For n=1 the material properties changes linearly, n = 0 plate is total titanium and n= infinite plates is purely aluminum oxide

NUMERICAL RESULTS

As the formulation was validated in ANSYS, the effect of various parameters on the buckling of flat FGM plates with varying in-plane load was studied. Based on the convergence study, a mesh size of 12×12 and 12 number of layers was taken throughout the study. Table 4.4 shows the non-dimensional buckling load of flat FGM plates with different boundary conditions subject to linearly varying load by using different parameters like b/h ratio, aspect ratio(a/b) and gradient index(n).

CONCLUSIONS

The behavior of buckling of functionally graded material (FGM) plate subjected to various types of in-plane loading was studied. The work has been done in ANSYS. The effects of geometrical parameters like side width ratio, aspect ratio (a/b), gradient index and different boundary conditions on buckling parameters of FGM plates has been studied.

From the above study, it is observed that for all boundary conditions, with increasing side width ratio, non-dimensional buckling load increases.

Also for simply supported and cantilever plates, while increasing the aspect ratio and gradient index, the non-dimensional buckling load decreases. In fact for cantilever plates, there seems to be no effect of increase in gradient index for all loading types beyond n =10.

But in plate with all edges clamped, non-dimensional buckling load decreases up to a/b=1 and with further increase in aspect ratio, the buckling load parameter increases.

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