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Analysis of FGM plates using Finite Element Modelling Method

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***Abstract*—Functionally ranked materials have received lots of interest in recent days by their varied and potential applications in region and different industries. The mechanical deformation behavior of shear deformable functionally graded ceramic-metal (FGM) plates. this work deals with the study of vibration and stability analyses of functionally graded (FG) spinning shaft system under thermal atmosphere using 3 nodded beam component supported Timoshenko beam theory (TBT). The effective material properties of functionally graded materials for the plate structures are assumed to be temperature independent and ranked within the plate thickness direction in step with a power law distribution of the amount fractions of the constituents. AN FGM's gradation in material properties permits the designer to tailor material response to satisfy standard. within the present analysis, the mixture of aluminum oxide (Al2O3) and stainless steel (SUS304) is taken into account as FG material wherever metal contain (SUS304) is decreasing towards the outer diameter of shaft. The fabric properties vary continuously from metal (bottom surface) to ceramic (top surface).**

***IndexTerms*—Thermal analysis FGM plates Mathematical modeling Temperature variation Analytical Methods, Numerical methods**

I. INTRODUCTION

Functionally Graded Material (FGM) is combination of a ceramic and a metal. A material in which its structure and composition both varies gradually over volume in order to get certain specific properties of the material hence can perform certain functions. The properties of material depend on the spatial position in the structure of material. The effect of inter-laminar stress developed at the laminated composite interfaces due to sudden change of material properties reduced by continuous grading of material properties. Laminated composites have received a lot of interest in recent days by diversified and potential applications in automotive and aerospace industry due to their strength to weight, stiffness to weight ratio, low fatigue life and toughness and other higher material properties. These are used in buildings, storage tanks, bridges etc. Each layer is laminated in order to get superior material properties. The individual layer has high strength fibres like graphite, glass or silicon carbide and matrix materials like epoxies, polyimides. The main purpose is to increase fracture toughness, increase in strength because ceramics only are brittle in nature. Brittleness is a great disadvantage for any structural application.

It has long been that the laminated composites are being extensively used in aircrafts, spacecrafts, shipbuilding, automotive and various other industries because of their flexibility in design to have desired strength and stiffness. The concept of FGM was proposed in 1984 by materials scientists in the Sendai area as a means of preparing thermal barrier materials. An attempt has been made to classify the various analytical and numerical methods used for the stress, vibration and buckling analyses of FGM plates under one dimensional or three-dimensional variation of temperature with constant/linear/nonlinear temperatures profiles across the thickness [1]. Functionally graded materials (FGMs) are advanced composites that possess smooth spatial variations in the volume fractions of the constituent phases. These variations are additional degrees of freedom in materials design and allow customization of physical properties. The characteristic feature of FGMs is in homogeneity at both micro- and macro scale. The in homogeneity and continuous spatial variations of the physical properties need to be accounted for in theoretical and computational studies so as to produce realistic results regarding behavior of graded structures [2]. The vibration of functionally graded cylindrical shells has been investigated by Lam and Reddy. Lam and Hua considered the influence of boundary conditions on the frequency characteristics of a rotating truncated circular conical shell. In the case of functionally graded plates and shells, the property gradation occurs through the thickness. The property gradation is achieved by either chemically treating a single material to locally alter its properties or combining two or more separate materials with locally prescribed volume fractions. A functionally graded structure is defined as, those in which the volume fractions of two or more materials are varied continuously as a function of position along certain dimension (typically the radius and thickness) of the structure to achieve a require function.

II. CONCEPTUAL IDEA ABOUT FGMS

First FGM concepts have come from Japan in 1984 during a space plane project. There a combination of materials used would serve the purpose of a thermal barrier capable of withstanding a surface temperature of 2000 K and a temperature gradient of 1000 k across a 10 mm section. Recently FGMs concept has become more popular in Europe (Germany). A collaborative research center Transregio (SFB Transregio) is funded since 2006 in order to exploit the potential of grading mono-materials, such as steel, aluminum and polypropylene, by using thermo mechanically coupled manufacturing processes Functionally Graded Materials (FGMs) are those composite materials where the composition or the microstructure is locally varied so that a certain variation of the local material properties is achieved. FGM is also defined as, those in which the volume fraction of two or more materials are achieved continuously as a function of position along certain directions of the structure to achieve a required function (e.g. mixture of ceramic and metal).

It is materially heterogeneous which is defined for those objects with and/or multiple material objects with clear material domain. By grading of material properties in a continuous manner, the effect of inter-laminar stresses developed at the interfaces of the laminated composite due to abrupt change of material properties between neighboring laminas is mitigated. As many thin walled members, i.e., plates and shells used in reactor vessels, turbines and other machine parts are susceptible to failure from buckling, large amplitude deflections, or excessive stresses induced by thermal or combined thermo mechanical loading. Thus, FGMs are primarily used in structures subjected to extreme temperature environment or where high temperature gradients are encountered. Mainly they are manufactured from isotropic components such as metals and ceramics, since role of metal portion is acts as structure support while ceramics provides thermal protection in environments with severe thermal gradients (e.g. reactor vessels, semiconductor industry).In such conditions ceramic provides heat and corrosion resistance, while the metal provides the strength and toughness. Whatever problems arises in using composite materials those problems can be reduced significantly by using FGMs instead of composite materials because FGMs changes the material properties from surface to surface or layer to layer. FGMs are new advanced multifunctional composites where volume fractions of the reinforcements phase(s) vary smoothly. Additionally, FGM allows the certain superior and multiple properties without any mechanically weak interface. This new concept of materials hinges on materials science and mechanics due to integration of the material and structural considerations into the final design of structural component. Moreover, gradual change of properties can be tailored to different applications and service environments.

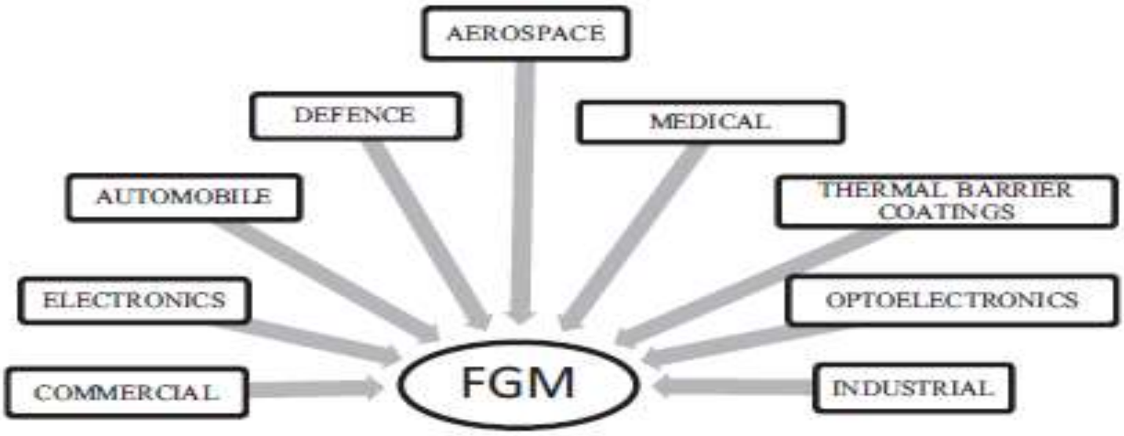


Fig.1Applications of FGM

III. FINITE ELEMENT MODELING FOR FGMS

Solving the engineering problems by conventional analytical methods is either typical or impossible. In these methods mathematical equations are modelled to define the required variables.

The main rule that involved in finite element method is "DEVIDE and ANALYZE". The greatest unique feature, which separates finite element method from other methods, is "it divides the given domain into a set of sub domains, called finite 'elements". Any geometric shape that allows the computation of the solution or its approximation, or provides necessary relations among the values of the solution at selected points called 'nodes' of the sub domain, qualifies as finite element. Division of the domain into elements is called 'mesh'. Approximate solutions of these finite elements give rise to the solution of the given geometry, which is also an approximate solution

The simplest approach is to use homogeneous elements each with different properties, giving a stepwise change in properties in the direction of the material gradient.

Assumptions:

- There are no heat sources within the plate.
- Materials properties for each same ordinate x are homogenous and isotropic.
- Creeps are neglected and perfect bonding.
- Temperature independent material constants.
- Initially stress Free State.
- The width of the plate is assumed to be infinite.

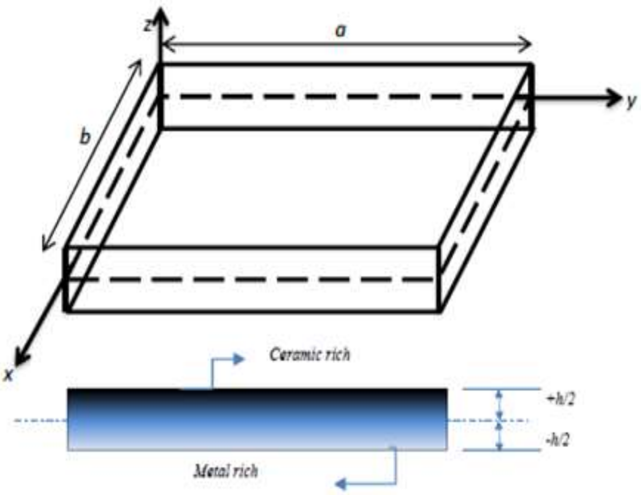


Fig.2 Geometry and dimensions of the FG plate

Element Equations

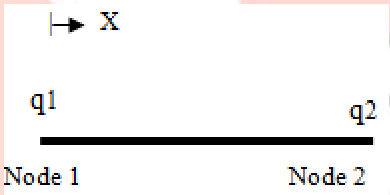
- Direct approach will be used
- 1-D heat flow under steady condition
- Discretization
- Fourier's law:

$$q = -k_x A \frac{dT}{dx}$$

q = heat flux (W)

k_x = thermal conductivity of the material that varies along the thickness direction, x (W/mk^{-1})

A = area normal to the heat flow



$$V_c(x) = \left(\frac{x}{h}\right)^n$$

$$K_x = (K_c - K_m)V_c(x) + K_m$$

K_c & K_m = thermal conductivity of ceramic and metal respectively.

$V_c(x)$ = ceramic volume fraction along the thickness direction and

N= power law index

- Nodal heat flow entering a typical node

$$Q_1^e = \frac{k^e A^e (T_1^e - T_2^e)}{L^e} \qquad Q_2^e = \frac{k^e A^e (T_1^e - T_2^e)}{L^e}$$

- Conservation of energy requires Q_2= -Q_1
- In matrix notation

$$\left(\frac{k^e A^e}{x^e}\right)\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}\begin{Bmatrix} T_1^e \\ T_2^e \end{Bmatrix} = \begin{Bmatrix} Q_1^e \\ Q_2^e \end{Bmatrix}$$

- Or $[K^e]\{T^e\}= \{Q^e\}$

Where $[K^e]$ = element thermal conduction stiffness matrix,
$\{T^e\}$ = element column vector of nodal temperature and
$\{Q^e\}$= element column vector of nodal heat fluxes

FEM: Direct Approach
Step 1: Discretization: element chosen is 1-D, 2 node element
Step 2: Constitutive relations for element stiffness matrix

Type of FGM chosen: P Type Volume fraction equation
Rule of mixtures for effective properties General 1-D heat conduction equation

Step 3: Assembly of element equations
Step 4: Apply boundary conditions
Step 5: Solve for the unknowns the temperature at each node point. Hence the temperature profile for a particular FGM can be simulated

IV. RESULTS

Here we will show results of clamped square and rectangular membrane, using a 10 × 10 Q4 mesh. The following non-dimensional parameters are chosen for the study.

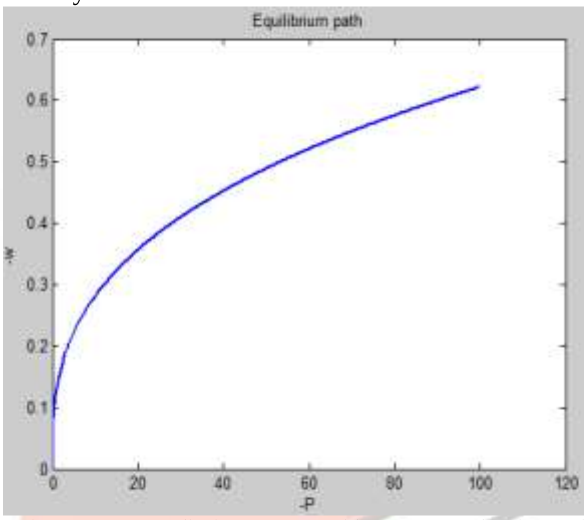


Fig.3 Variation of maximum transverse displacement −w with pressure −P for clammed square membrane

Fig.3 shows the Variation of maximum transverse displacement −w with pressure −P for clammed rectangular membrane with thickness h = 0.001. In the x axis show the pressure and y axis show the displacements.

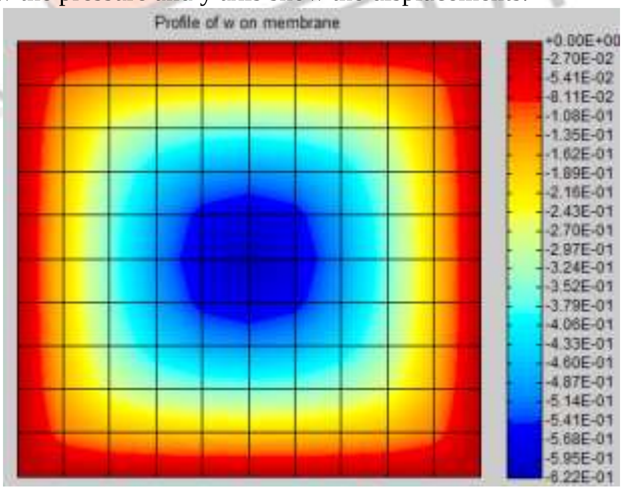


Fig.4 Displacement w for clamped square membrane at pressure P

Fig.4 shows the Displacement w for clamped square membrane at pressure P = −100 with thickness h = 0.01.

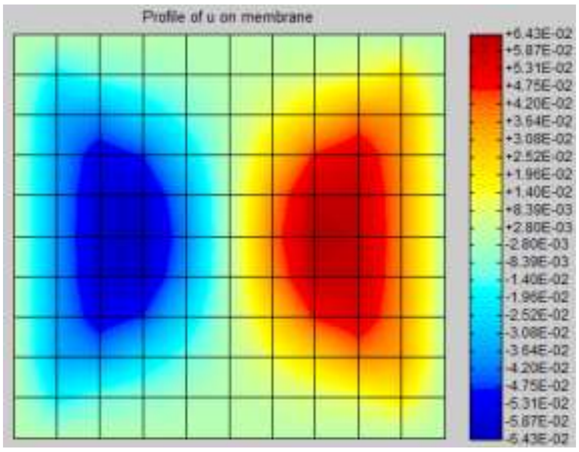


Fig.5 Displacement u for clamped square membrane at pressure P

Fig.5 show the Displacement u for clamped square membrane at pressure P = −100 with thickness h = 0.01.

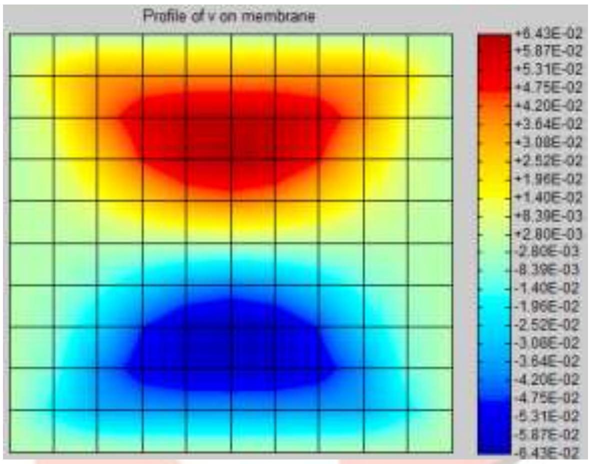


Fig.6 Displacement v for clamped square membrane at pressure P

Fig.6 show the Displacement v for clamped square membrane at pressure P = −100 with thickness h = 0.01.

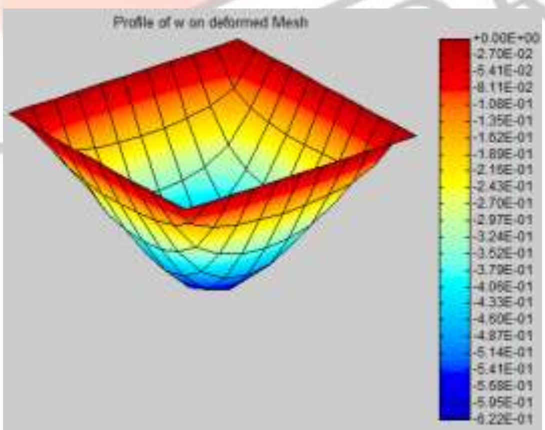


Fig.7 deformed mesh w on membrane

V. Conclusion

The response of FGM plates subject to impact is of interest should FGMs be used as a thermal protection system on an aerospace platform. FGM plates used in such an application must be able to withstand a high-energy impact from a foreign object to avoid deterioration of strength of any substructure the FGM is intended to protect.

This paper provides a strong foundation from which research in the impact response of FGM structures can build. Since almost no treatment of this subject has been available before this work, it was necessary to simplify the FGM impact problem to studying the impact response of FGM plates in low-velocity regimes without a thermal environment other than that of room-temperature.

The overall goal of this study was to provide a unique method by which the impact response of functionally graded plates could be characterized for low-velocity, low- to medium-energy impact loads.

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