STATIC AND DYNAMIC ANALYSIS OF FUNCTIONALLY GRADED FLAT PANELS

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ABSTRACT

Functionally graded materials have received a lot of interest in recent days by their diversified and potential applications in aerospace and other industries. They have high specific mechanical properties and high temperature capabilities which makes them special over all the exiting advanced materials. The present work investigated static and dynamic analysis of functionally graded plate. The material properties vary continuously from metal (bottom surface) to ceramic (top surface). The effective material properties of functionally graded materials for the plate structures are assumed to be temperature independent and graded in the plate thickness direction according to a power law distribution of the volume fractions of the constituents. In present An eight noded isoparametric quadrilateral shell element is used to discretise the present model for both static as well as dynamic analysis . The present model is developed using ANSYS parametric design language code in the ANSYS platform.

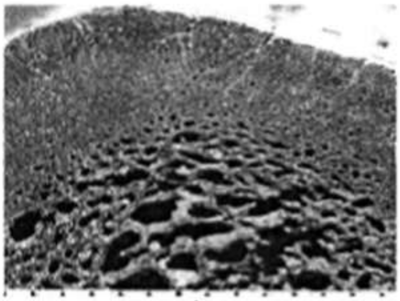
INTRODUCTION

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 made from two or more constituent materials which have different chemical or physical properties and produced a material having different behaviour from the individual. 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. By varying the thickness of laminas desired properties (strength, wear resistance, stiffness) can be achieved.

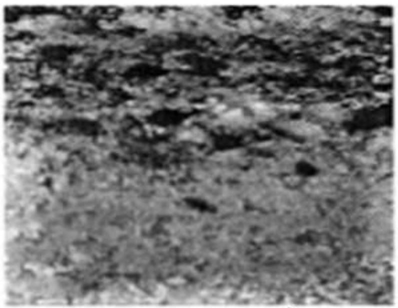
Although these materials have superior properties, their major drawback is the weakness of laminated materials. This is known as delamination phenomenon which leads to the failure of the composite structure. Residual stresses are present due to difference in thermal expansion of the matrix and fibre. It is well known that at high temperature the adhesive being chemically unstable and fails to hold the lamination. Sometimes due to fibre breakdown it also prematurely fails.

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. Generally microstructural heterogeneity or non-uniformity is introduced in functionally graded material. 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. These are manufactured by combining both metals and ceramics for use in high temperature applications. Material properties are varies smoothly and continuously in one or many directions so FGMs are inhomogeneous. FGM serves as a thermal barrier capable of withstanding 2000K surface temperature. Fabrication of FGM can be done by different processing such as layer processing, melt processing, particulate processing etc. FGM has the ability to control shear deformation, corrosion, wear, buckling etc. and also to remove stress concentrations. This can be used safely at high temperature also as furnace liners and thermal shielding element in microelectronics and thermal protection systems for spacecraft, hypersonic and supersonic planes and in combustion chamber also.

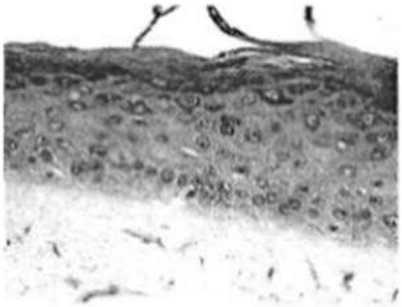
FGMs are being used in several industries and sectors like aerospace, nuclear, defense, automotive, communication, energy etc. As well as they are produced artificially, the primitive forms of FGMs exist in nature. Bones, human skin, bamboo tree can be considered as organic forms of FGM. Figure 1 illustrates several organic and artificial examples that evoke FGM.



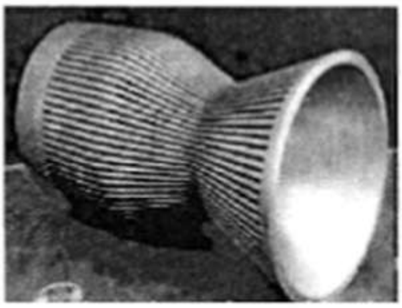
Bone[a]



Thermal coating[d]



Human skin[b]



Rocket casing[e]

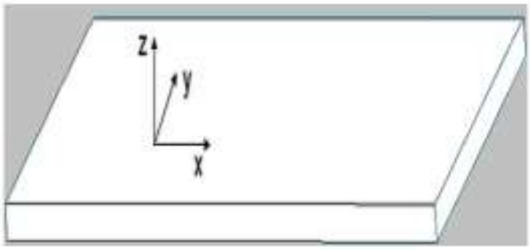
The theoretical concept of producing FGM was proposed in 1984 in Japan (Jha et al. (2013)). Manufacturing and design process of FGM has become the main topic of interest in the last three decades. Manufacturing of FGMs can be discussed under two subtopics which are gradation and consolidation. Gradation is forming the spatially inhomogeneous structure. Gradation processes can be categorized into constitutive, homogenizing and segregating processes. Constitutive processes depend on a stepwise generation of the graded body from pioneer materials or powders. Advances in automation technology in course of the last decades have provided technological and economic viability for constitutive processes. Homogenization is conversion of the sudden transition between two materials into a gradient. Segregating processes start with a macroscopically homogenous material which is transformed into a graded material by material transport caused by an external field (for example gravitational or magnetic field). Homogenizing and segregation processes yield continuous gradients; but such processes have limitations concerning the distribution of materials to be produced.

The consolidation processes, such as drying, sintering or solidification, usually comes after the gradation processes. The processing criterions should be determined in such a way that the gradient is not wrecked or changed in an unrestrained fashion (Kieback et al. (2003)).

As technology progresses at an ever increasing rate, the need for advanced capability materials becomes a priority in the engineering of more complex and higher performance systems. This need can be seen in many fields in which engineers are exploring the applications of these new engineered materials. Aerospace engineers trying to incorporate new and improved capabilities into air and space systems are pushing the envelope for what current materials can physically handle. Functionally Graded Materials (FGMs) are a relatively new (circa 1970's) technology and are being studied for the use in components exposed to harsh temperature gradients.

While laminated composite materials provide the design flexibility to achieve desirable stiffness and strength through the choice of lamination scheme, the anisotropic constitution of laminated composite structures often result in stress concentrations near material and geometric discontinuities that can lead to damage in the form of delamination, matrix cracking, and adhesive bond separation.

FGMs alleviate these problems because they consist of a continuous variation of material properties from one surface to the other. The continuous nature of the variation lessens the stress concentrations which become troublesome in a laminated composite material. Also the smooth transition through the various material properties reduces both thermal and residual stresses. In most cases the material progresses from a metal on one surface to a ceramic or mostly ceramic on the opposite surface, with a smooth transition hroughout the center of the material. Also the material properties can change in any orientation across a material, but the majority of applications to date deal with a material in which the properties change through the thickness of the material or in the Z- Axis of material which is depicted in Figure 1 below.



FGM Orientation

The material transitions from a metal to a ceramic by increasing the percentage of ceramic material present in the metal until the appropriate percentage is reached or a pure ceramic is achieved.

LITERATURE REVIEWS

FG material plates have created revolution in aerospace industry for its thermal properties, multi-functionalities. It also provides opportunities to take the benefits of different material system. Its static and dynamic analysis is necessary to estimate the properties of flat panels. Many researchers reported static and dynamic behaviour of functionally graded plates based on different theories and developed new methods of solutions.

Static and vibration analysis

Talha and Singh [1] investigated the free vibration and static analysis of rectangular FGM plates using higher order shear deformation theory with a special modification in the transverse displacement in conjunction with finite element models. Neves et *al.* [2] studied the static deformations analysis of functionally graded plates by collocation with radial basis functions, according to a sinusoidal shear deformation formulation for plates. Aragh and Hedayati [3] studied the characteristics of free vibration and static response of a 2-D FGM open cylindrical shell. Formulations are done by 2-D generalized differential quadrature method (GDQM). Ferreira *et al.* [4] studied static deformations of functionally graded square plates of different aspect ratios using meshless collocation method, the multiquadric radial basis functions and a third-order shear deformation theory. Reddy[5] studied static and dynamic analysis of FGM plates using third-order shear deformation theory. Navier solutions are obtained for a simply supported square plate. Abrate[6] investigated static, buckling and free vibration deflections of FGM plates by using classical plate theory, FSDT model and HSDT model. Zenkour[7] studied the static behaviour of a rectangular FG plate under simply supported condition and subjected to uniform transverse load. Ferreira *et al.* [8] studied static deformations of simply supported functionally graded plate by using HSDT and multiquadric radial basis functions. Vel and Batra[9] investigated the exact 3-D elasticity solutions of simply supported rectangular FG plates under thermo-mechanical load. The author has assumed power law for material volume fractions. The exact solutions of displacements and stresses are used to find out the accuracy of the solutions. Qian *et al.*[10] investigated plain strain static thermostatic deformations of simply supported thick rectangular FG elastic plate. Displacement and stress are computed and validated from the 3D exact solutions of the problem. Ramirez *et al.*[11] studied static analysis of 3D, elastic, anisotropic FG plates. The author has taken simply supported graphite/epoxy material for analysis. Zenkour [12] further studied the static response of FG plates using shear deformation plate theory using power law for grading. Bhangale and Ganesan[13] investigated static analysis of simply supported FG plates which are exponentially graded in the thickness direction. Aghdam *et al.*[14] studied static analysis foe bending of FG clamped thick plates. The solutions are compared with the solutions of finite element code ANSYS, power law is used for grading the properties in thickness direction. Neves *et al.*[15] investigated the static deformations of FG square plates using radial basis function. Talha and Singh [16] investigated the static and free vibration analysis using C^0 finite element with 13 degrees of freedom per node and formulated by HSDT. Nguyen-Xuan *et al.*[17] studied the static, free vibration and mechanical/thermal buckling problems of FG plates by Reisnner/Mindlin plate theory.

Geometric and material modeling

With the goal of modeling graded compositions, the issue of material modeling becomes as important in the representation of an object as the geometric modeling of its boundary. The Model Space in which the model is defined can now be considered as the combination of the Build Space and the Material Space

Again, the Build Space is simply the three dimensional space in which the object is to be fabricated. The Material Space, however, is spanned by the primary materials in the material system. This concept is analogous to the blending of primary colors (Cyan, Yellow, Magenta, and Black) in an ink-jet printer to produce a wide range of colors and tones for color hard-copy output. To achieve Local Composition Control, an SFF process builds a part by selectively adding varying quantities of different base materials. These materials comprising the material system create a Material Space out of which an FGM is defined. The dimension of the Material Space (dm) is the number of materials out of which the object is to be composed

To define an FGM object, a mapping from the Build Space (X) into the Material Space (M) must be provided. This concept has previously been suggested by Kumar et al. (through the use of atlases) and Jackson et al. Before even exploring how one might maintain a digital representation of the model, it must be understood that the underlying goal of any FGM modeling method is to define a function spanning the material space for all the points in Build Space. This is accomplished by defining the concept of a composition, represented by m, which defines the volume fraction of each of the primary materials.

FGM model processing

As previously stated, an FGM object can be defined as the function m(x), providing a mapping from a Build Space into a Material Space. For the processing of FGM models for fabrication through Local Composition Control, the paradigm of information flow from image processing can be followed.

The process begins with capturing the designer's intent in terms of a digital FGM model. At this point, the model m(x) is maintained within a data structure selected to accurately capture the designer's ideas.

EFFECTIVE MATERIAL PROPERTIES

The effective material properties of the FGM plate are assumed to be varying continuously along their thickness direction as discussed earlier and are obtained by using a simple power-law distribution or exponential law which counts the volume fraction of each constituent.

Exponential law

Exponential law of grading FGM states that for a FGM structure of uniform thickness '*h*', the material properties '*P(z)*' at any point located at '*z*' distance from the mid-plane surface is given by:

$$P(z)=P_t e^{\left(-\lambda\left(1-\frac{2z}{h}\right)\right)} \text{, where, } \quad \lambda=\frac{1}{2}\ln\left(\frac{P_t}{P_b}\right)$$

P (*z*) denotes material property like Young's modulus of elasticity (*E*), shear modulus of elasticity (*G*), Poisson's ratio (□), material density (□) of the FGM structure. P_t and P_b are the material properties at the top ($z=+h/2$) and bottom ($z=-h/2$) surfaces. □ is the material grading indexes which depend on the design requirements.

Power law

The power-law distribution of a panel considered from the mid-plane reference plane can be written as

$$V_f=\left(\frac{z}{h}+\frac{1}{2}\right)^n$$

where, *n* is the power-law index, 0 □ *n* □□□. The variations of volume fraction of the ceramic and metal phase through the non-dimensional thickness coordinate are plotted in Figure for five different values of power-law indices (n = 0.2, 0.5, 1, 2 and 10). The functionally graded material with two constituents and their properties such as, Young's modulus *E* and the mass density *ρ* have been obtained using the following steps.

$$E=(E_c-E_m)\left(\frac{z}{h}+\frac{1}{2}\right)^n+E_m$$

$$\rho=(\rho_c-\rho_m)\left(\frac{z}{h}+\frac{1}{2}\right)^n+\rho_m$$

$$\upsilon=(\upsilon_c-\upsilon_m)\left(\frac{z}{h}+\frac{1}{2}\right)^n+\upsilon_m$$

In the present work, the power- law distribution is used for the continuous gradation of material properties in thickness direction.

INTRODUCTION TO ANSYS

ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements. The software implements equations that govern the behaviour of these elements and solves them all; creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated, or graphical forms. This type of analysis is typically used for the design and optimization of a system far too complex to analyze by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations.

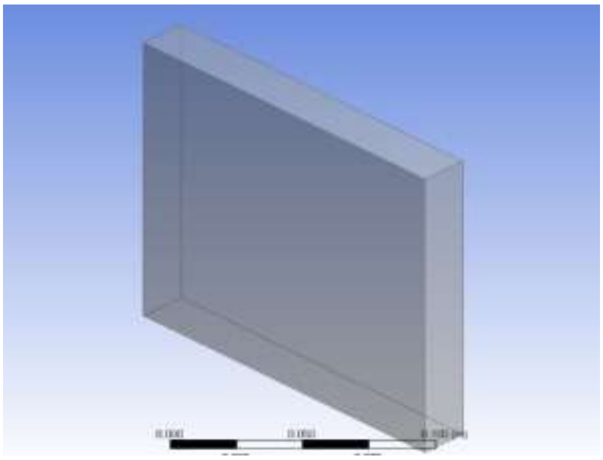
ANSYS is the standard FEA teaching tool within the Mechanical Engineering Department at many colleges. ANSYS is also used in Civil and Electrical Engineering, as well as the Physics and Chemistry departments.

ANSYS provides a cost-effective way to explore the performance of products or processes in a virtual environment. This type of product development is termed virtual prototyping. With virtual prototyping techniques, users can iterate various scenarios to optimize the product long before the manufacturing is started. This enables a reduction in the level of risk, and in the cost of ineffective designs. The multifaceted nature of ANSYS also provides a means to ensure that users are able to see the effect of a design on the whole behaviour of the product, be it electromagnetic, thermal, mechanical etc

Within ANSYS, an acoustic analysis usually involves modelling a fluid medium and the surrounding structure. Characteristics in question include **pressure distribution** in the fluid at different frequencies, pressure gradient, **and particle velocity**, the sound pressure level, as well as, scattering, **diffraction**, transmission, **radiation**, **attenuation**, and **dispersion** of acoustic waves. A coupled acoustic analysis takes the fluid-structure interaction into account. An uncoupled acoustic analysis models only the fluid and ignores any fluid-structure interaction.

The ANSYS program assumes that the fluid is compressible, but allows only relatively small pressure changes with respect to the mean pressure. Also, the fluid is assumed to be non-flowing and in viscid (that is, viscosity causes no dissipative effects). Uniform mean density and mean pressure are assumed, with the pressure solution being the deviation from the mean pressure, not the absolute pressure.

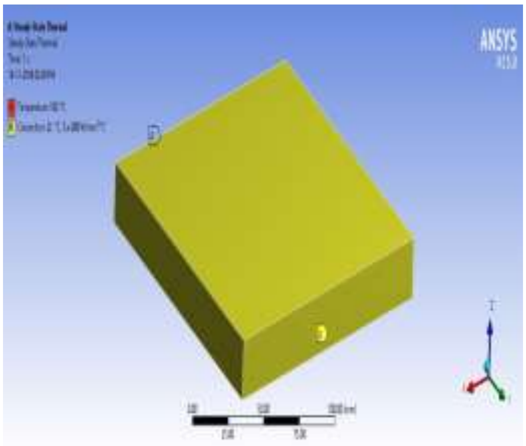
STATIC ANALYSIS AND DYNAMIC ANALYSISFGM plates with different length to thickness ratio, aspect ratio (*a/b*) are analysed in this experiment. The loading conditions are assumed to be static. The element chosen for this analysis is SHELL281, which is a layered version of the 8-node structural shell model. This is suitable for analysing thin to moderately-thick shell structures. This shell element has six degrees of freedom at each node namely three translations and three rotation in the nodal x, y and z directions respectively. The analysis is performed in commercially available software (ANSYS 15.0). The loading conditions are assumed to be static. The FGM plate is modelled in ANSYS 15.0 as shown in the below fig.



The static responses of the FG plates are analysed using ANSYS 15.0 under static surface load for simply supported boundary condition for Aluminium/steel FG flat panel. The computed results are validated and compared with those available in the literature. The analysis is carried out with two different materials

DYNAMIC ANALYSIS

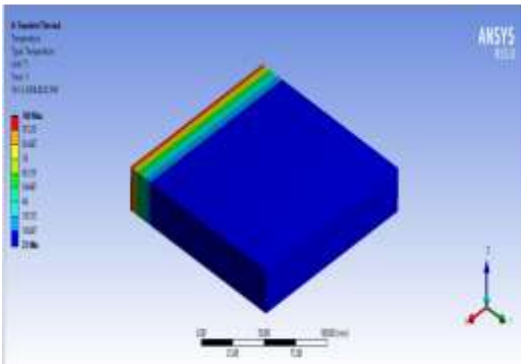
FG model (ANSYS) Rectangular simply supported Aluminium/Steel FG flat panel has been developed in ANSYS15.0 platform. Time dependant step load has been taken for transient dynamic thermal analysis. Step type loading has been taken in to consideration. Below are the boundary conditions



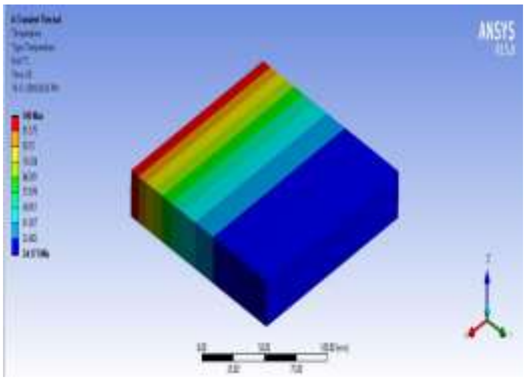
RESULTS:

The analysis is carried out for different materials from time zero second to 60seconds. Dynamic behaviour of FG flat panel can be seen in below figures.

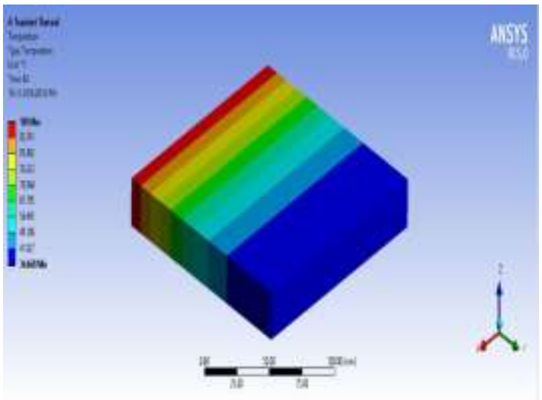
FG aluminium material



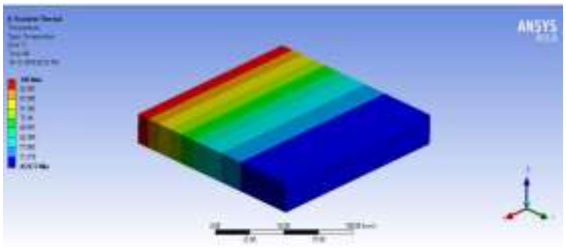
Temperature distribution FG aluminium flat panel with time = 1



When time = 20 seconds



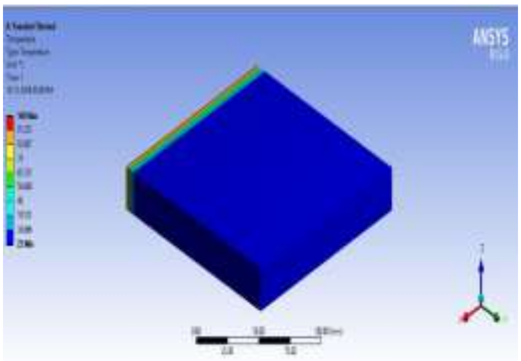
When time = 40 seconds



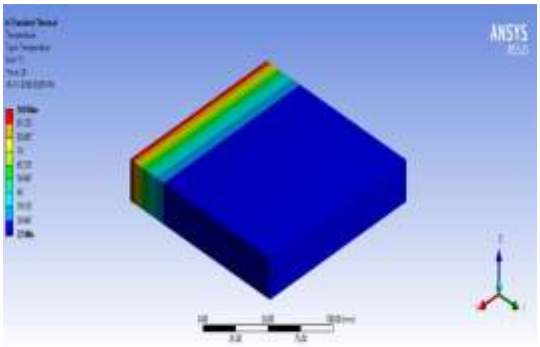
When t = 60 seconds

FG steel material

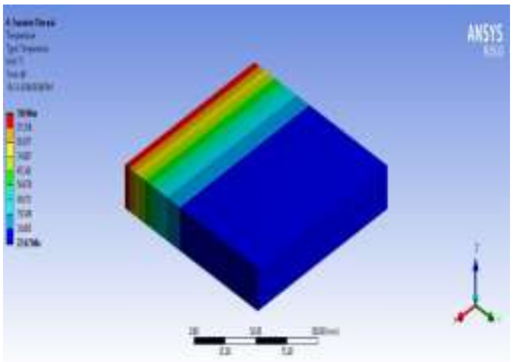
Below are the results for FG steel material with same boundary conditions.



Temperature distribution FG steel flat panel with time = 1

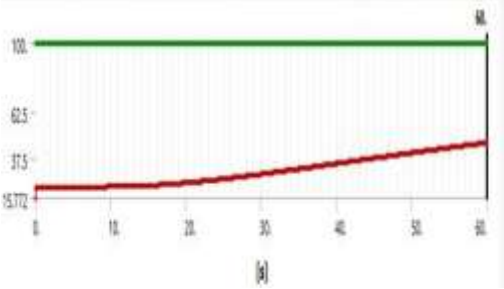


When t = 20 seconds

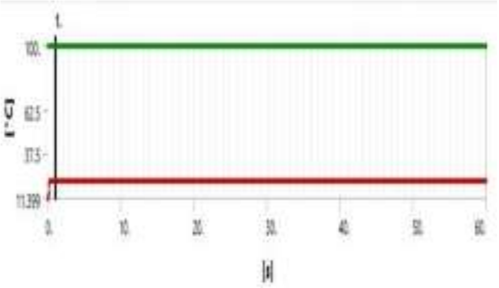


When t = 60 seconds

Temperature distribution



Temperature distribution for aluminium



Temperature distribution for steel

CONCLUSION

In this study, static and dynamic responses of FGM plates are analysed. Boundary conditions have been considered to check the efficacy of ANSYS model. The following points revealed the concluded remarks for thin to thick FGM plates are in the project we determine the maximum and minimum mechanical properties of two different FGM's. Anasys models were created to approximate the actual behavior of the material and to help predict future behaviour of more complex structures. The maximum elastic strain is 5.16 in FG aluminium and 5.7 in FG steel material, FG aluminium deformation is lesser than FG steel material and for better temperature distribution FG steel material is recommended.

Future Scope of work

- Different geometric structures can be modelled such as cylindrical, spherical, conical, hyperboloid etc.
- Temperature dependent material property can be considered.
- Different type of analysis like buckling, post buckling, free vibration, forced vibration etc. can also be performed using the presented model.

REFERENCES

[1] Mohammad Talha, B.N. Singh, Static response and free vibration analysis of FGM plates using higher order shear deformation theory, Applied Mathematical Modelling 34 (2010) 3991–4011

[2] A.M.A. Neves et al. Bending of FGM plates by a sinusoidal plate formulation and collocation with radial basis functions. Mechanics Research Communications 38 (2011) 368– 371.

[3] B. Sobhani Aragh, H. Hedayati. Static response and free vibration of two-dimensional functionally graded metal/ceramic open cylindrical shells under various boundary conditions. Acta Mech 223,(2012) 309–330

[4] A.J.M. Ferreira, R.C. Batra, C.M.C. Roque, L.F. Qian, P.A.L.S. Martins. Static analysis of functionally graded plates using third-order shear deformation theory and a meshless method. Composite Structures 69 (2005) 449–457

[5] J N Reddy. Mechanics of laminated composite: Plates and shells-Theory and analysis. Second edition. CRC press.2003

[6] Abrate S., Free vibration, buckling, and static deflections of functionally graded plates. Compos Sci Technol 2006;66:2383–94.

[7] A.M. Zenkour, Generalised shear deformation theory for bending analysis of functionally graded plates, Appl. Math. Model. 30 (2006) 67–84.

[8] A.J.M. Ferreira, R.C. Batra, C.M.C. Roque, L.F. Qian, P.A.L.S. Martins, Static analysis of functionally graded plates using third order shear deformation theory and a meshless method, Compos. Struct. 69 (2005) 449–457.

[9] Vel SS, Batra RC. Exact solutions for thermoelastic deformations of functionally graded thick rectangular plates. AIAA J 2002; 40(7):1421–33.

[10] Qian LF, Batra RC, Chen LM. Static and dynamic deformations of thick

functionally graded elastic plate by using higher-order shear and normal deformable plate theory and meshless local Petrov–Galerkin method.Composites Part B 2004;35:685–97.

[11] Ramirez F, Heyliger PR, Pan E. Static analysis of functionally graded elastic anisotropic plates using a discrete layer approach. Composites Part B 2006; 37:10–20

[12] Zenkour AM. Benchmark trigonometric and 3-D elasticity solutions for an exponentially graded thick rectangular plate. Arch Appl Mech 2007; 77:197–214.

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