

Higher Order Normal Shear Deformation Theory for Static FG Rectangular Plates

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Abstract - In this paper, static response for simply supported rectangular functionally graded plate which is subjected transverse and sinusoidal load in is studied. The generalized shear deformation theory obtained by author in recent year. Material properties of rectangular plate are supposed to be varying in its thickness direction by using power law. The results are compared and validated with literature available. Modeling is based on HONST & finite element tool ABAQUS.

Key Words: Functionally graded material, HONST, Uniform loading, sinusoidal loading etc.

1.INTRODUCTION

In recent years FG materials have gained advantages and attention for the use of materials in various engineering applications. FG materials are considered as very useful material in structural engineering in the field of spacecraft industries and power generation industries. FG materials are new materials; in which properties of materials are vary smoothly along from one face to the other face. By applying the many possibilities inherent in the FGM concept, it is anticipated that materials will be improved and new function for them created.

In simplest FG materials two different material ingredients change gradually from one face to the other face. The most commonly used FG materials are Metal, Ceramic etc. The ceramic in an FGM acts as thermal barrier effects and protects the metal from corrosion and oxidation, and the FGM is toughened and strengthened by the metallic composition. A mixture of ceramic and metal with a continuously varying volume fraction can be easily manufactured. This eliminates interface problems of composite materials and thus the stress distributions are smooth.

Several researchers has done the research work in this field and they introduced various theories. Sankar (1) presented an elasticity solution for a functionally graded beam subjected to transverse loads. Chakraborty et al. (7) developed new beam element to study the thermoelastic behavior of functionally graded beam structures. Zenkur (4) discussed two dimensional solutions for bending analysis of simply supported functionally graded ceramic metal sandwich plates. Zenkur (5) presented the static response for a simply supported functionally graded rectangular plate

subjected to a transverse uniform load. The generalized shear deformation theory obtained by the author in other recent papers is used. This theory is simplified by enforcing traction-free boundary conditions at the plate faces. The equilibrium equations of a functionally graded plate are given based on a generalized shear deformation plate theory. The numerical illustrations concern bending response of functionally graded rectangular plates with two constituent materials. The influences played by transversal shear deformation, plate aspect ratio, side-to-thickness ratio, and volume fraction distributions are studied. The results are verified with the known results in the literature.

Bhangale et al. (6) studied buckling and vibration behavior of a functionally graded material (FGM) sandwich beam having constrained viscoelastic layer (VEL) is studied in thermal environment by using finite element formulation. The FGM sandwich beam is assumed to be clamped on both edges. The material properties of FGM are functionally graded in thickness direction according to volume fraction power law distribution. Temperature dependent material properties of FGM stiff layer and shear modulus of viscoelastic layer are considered to carry out buckling and vibration analysis.

Kadoli (9) studied displacement field based on higher order shear deformation theory is implemented to study the static behavior of functionally graded metal-ceramic (FGM) beams under ambient temperature. Using the principle of stationary potential energy, the finite element form of static equilibrium equation for FGM beam is presented. Numerical results on the transverse deflection, axial and shear stresses in a moderately thick FGM beam under uniform distributed load for clamped-clamped and simply supported boundary conditions are discussed in depth. The effect of power law exponent for various combination of metal-ceramic FGM beam on the deflection and stresses are also commented. The studies reveal that, depending on whether the loading is on the ceramic rich face or metal rich face of the beam, the static deflection and the static stresses in the beam do not remain the same. Sina (16) developed new beam theory different from the traditional first-order shear deformation beam theory is used to analyze free vibration of functionally graded beams. HenniAbdelaziz (11) performed a new displacement based high order shear deformation theory for static response of functionally graded sandwich plates. Unlike other theory, number of unknown functions involved is only four, as against five in case of other shear

deformation theories. The theory presented is variationally consistent, has strong similarities with classical plate theory in many aspects. In this theory governing equations are derived from principle of virtual work. The closed form solution of simply supported rectangular plate subjected to sinusoidal loading has been obtained by using Navier method and validation of present theory is performed by comparing some of the present results with the classical theory.

Sobhy (15) described the vibration and buckling behavior of exponentially graded material (EGM) sandwich plate resting on elastic foundations under various boundary conditions. Swaminathan et al. (13) presented a comprehensive review of the various methods employed to study the static, dynamic and stability behavior of Functionally Graded Material (FGM) plates. Both analytical and numerical methods are considered. The review is carried out with an emphasis to present stress, vibration and buckling characteristics of FGM plates predicted using different theories proposed by several researchers without considering the detailed mathematical implication of various methodologies. The main objective of this paper is to serve the interests of researchers and engineers already involved in the analysis and design of FGM structures.

The FGM plate is made of an isotropic material with material properties varying in the thickness direction only. To make the study reasonably, displacements are given for different homogenization schemes and exponents in the power law that describes through-the-thickness variation of the constituents.

1.1 Mathematical Model

Consider a solid rectangular plate of length a , width b and thickness h made up of FG materials as shown in above figure 1.

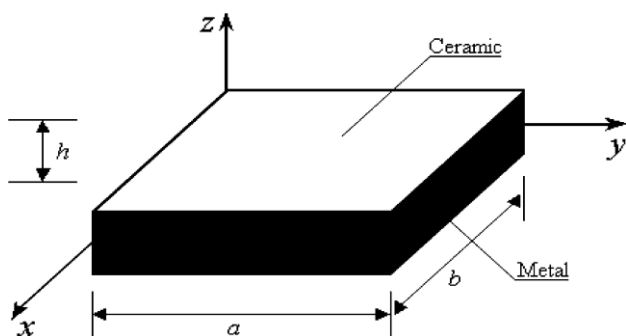


Figure 1. Geometry of rectangular plate

1.2 Calculation of Material Properties

The materials properties of rectangular plate such as Young's Modulus is assumed to be the function of volume fraction constituents. The rectangular Cartesian planform co-

ordinates x and y are introduced in the deformation analysis of the present plate. The considered plate is bounded by the co-ordinate planes $x = 0, a$ and $y = 0, b$. The reference surface is the middle surface of the plate defined by $z = 0$, and z denotes the thickness co-ordinate measured from the undeformed middle surface. The functional relationship between E and z for ceramic and metal FGM plate is assumed as Other font types may be used if needed for special purposes.

$$E(z) = E_c + E_m \times V$$

$$\text{Where } V = \left(\frac{2z + h}{2h} \right)^K$$

Where E_c = Young's Modulus for ceramic and E_m = Young's Modulus for metal respectively, K is the volume fraction exponent which has values greater than or equals to zero. The value of K equals to zero represents the plate is fully ceramic. The above power law will helps for the mixture of materials. The variation of material along the thickness of the plate is shown in above figure no2.

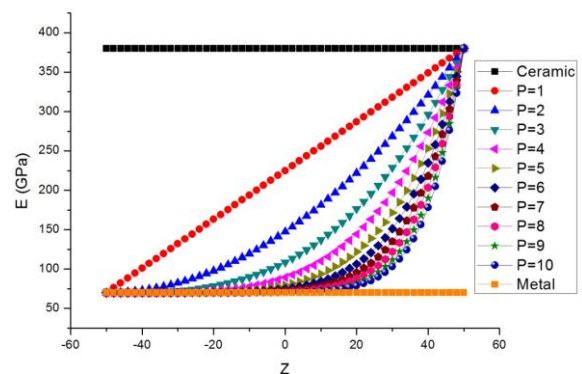


Figure 2. Variation in Material in FGM Plate

2. Formulation of HONST

2.1 Equations of equilibriums are

The following differential equations of equilibrium are obtained from the classical theory of elasticity in Cartesian coordinate system (x, y and z)

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z} + B_x = 0$$

$$\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \sigma_y}{\partial y} + \frac{\partial \tau_{yz}}{\partial z} + B_y = 0 \tag{1}$$

$$\frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \sigma_z}{\partial z} + B_z = 0$$

where B_x , B_y and B_z are the body forces along x, y and z directions respectively.

2.1 Strain-displacement relations

From linear theory of elasticity, the general strain-displacement relationships for small displacements can be stated as under.

$$\begin{Bmatrix} \epsilon_x \\ \epsilon_y \\ \epsilon_z \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{xz} \end{Bmatrix} = \left\{ \frac{\partial u}{\partial x}, \frac{\partial v}{\partial y}, \frac{\partial w}{\partial z}, \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}, \frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}, \frac{\partial u}{\partial z} + \frac{\partial w}{\partial x} \right\}^T \quad (2)$$

2.2 Constitutive relations

Principal material coordinate system (1-2-3) is used for the stress-strain relationship of fiber-reinforced composites. The axis 1 is aligned with the fiber direction, the axis 2 is perpendicular to the fibers but in the plane of the layer, and axis 3 is perpendicular to the fibers as well as to plane of layer. The stress strain relationship in 1-2-3 coordinate system is as per the following form.

$$\begin{aligned} \epsilon_1 &= \frac{\sigma_1}{E_1} - \nu_{21} \frac{\sigma_2}{E_2} - \nu_{31} \frac{\sigma_3}{E_3}, \\ \epsilon_2 &= -\nu_{12} \frac{\sigma_1}{E_1} + \frac{\sigma_2}{E_2} - \nu_{32} \frac{\sigma_3}{E_3}, \\ \epsilon_3 &= -\nu_{13} \frac{\sigma_1}{E_1} - \nu_{23} \frac{\sigma_2}{E_2} + \frac{\sigma_3}{E_3}, \\ \gamma_{12} &= \frac{\tau_{12}}{G_{12}}, \gamma_{23} = \frac{\tau_{23}}{G_{23}}, \gamma_{31} = \frac{\tau_{31}}{G_{13}} \end{aligned} \quad (3)$$

The above relationship for L^{th} orthotropic elastic layer can be written in a matrix form as

$$\begin{Bmatrix} \epsilon_1 \\ \epsilon_2 \\ \epsilon_3 \\ \gamma_{12} \\ \gamma_{23} \\ \gamma_{13} \end{Bmatrix}^L = \begin{bmatrix} \frac{1}{E_1} & -\frac{\nu_{21}}{E_2} & -\frac{\nu_{31}}{E_3} & 0 & 0 & 0 \\ -\frac{\nu_{12}}{E_1} & \frac{1}{E_2} & -\frac{\nu_{32}}{E_3} & 0 & 0 & 0 \\ -\frac{\nu_{13}}{E_1} & -\frac{\nu_{23}}{E_2} & \frac{1}{E_3} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{12}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{23}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{13}} \end{bmatrix} \begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{12} \\ \tau_{23} \\ \tau_{13} \end{Bmatrix}^L \quad (4)$$

Using Maxwell-Betti reciprocal theorem, there are only 9 independent elastic properties with following relationships.

$$\frac{\nu_{21}}{E_2} = \frac{\nu_{12}}{E_1}, \frac{\nu_{31}}{E_3} = \frac{\nu_{13}}{E_1}, \frac{\nu_{32}}{E_3} = \frac{\nu_{23}}{E_2} \quad (5)$$

The 3D stress-strain constitutive relationship with stiffness matrix $[C]$ for L^{th} lamina w. r. t. 1.2.3 can be written as:

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{12} \\ \tau_{23} \\ \tau_{13} \end{Bmatrix}^L = \begin{bmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ C_{12} & C_{22} & C_{23} & 0 & 0 & 0 \\ C_{13} & C_{23} & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{66} \end{bmatrix}^L \begin{Bmatrix} \epsilon_1 \\ \epsilon_2 \\ \epsilon_3 \\ \gamma_{12} \\ \gamma_{23} \\ \gamma_{13} \end{Bmatrix}^L \quad (6)$$

In which this equation can be written as -

$$\begin{aligned} C_{11} &= \frac{E_1(1-\nu_{23}\nu_{32})}{\Delta}; C_{12} = \frac{E_1(\nu_{21} + \nu_{31}\nu_{23})}{\Delta}; C_{13} = \frac{E_1(\nu_{31} + \nu_{21}\nu_{32})}{\Delta}; \\ C_{22} &= \frac{E_2(1-\nu_{13}\nu_{31})}{\Delta}; C_{23} = \frac{E_2(\nu_{32} + \nu_{12}\nu_{31})}{\Delta}; C_{33} = \frac{E_3(1-\nu_{12}\nu_{21})}{\Delta}; \\ C_{44} &= G_{12}; C_{55} = G_{23}; C_{66} = G_{13}. \end{aligned}$$

and $\Delta = (1 - \nu_{12}\nu_{21} - \nu_{23}\nu_{32} - \nu_{31}\nu_{13} - 2\nu_{12}\nu_{23}\nu_{31})$.

Substituting,

$$E_1 = E_2 = E_3 = E; \nu_{12} = \nu_{23} = \nu_{13} = \nu; G_{12} = G_{23} = G_{13} = G = \frac{E}{2(1+\nu)},$$

following elastic constants are defined for isotropic layer.

$$\begin{aligned} C_{11} = C_{22} = C_{33} &= \frac{(1-\nu)E}{(1+\nu)(1-2\nu)} = (\lambda + 2G); \\ C_{12} = C_{13} = C_{23} &= \frac{\nu E}{(1+\nu)(1-2\nu)} = \lambda; \\ C_{44} = C_{55} = C_{66} &= \frac{E}{2(1+\nu)} = G. \end{aligned} \quad (7)$$

where, λ and G are Lamé's constants.

In the laminate coordinate system (x-y-z) the stress strain relationship for L^{th} lamina can be written as

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{xy} \\ \tau_{yz} \\ \tau_{xz} \end{Bmatrix}^L = \begin{bmatrix} Q_{11} & Q_{12} & Q_{13} & Q_{14} & 0 & 0 \\ Q_{12} & Q_{22} & Q_{23} & Q_{24} & 0 & 0 \\ Q_{13} & Q_{23} & Q_{33} & Q_{34} & 0 & 0 \\ Q_{14} & Q_{24} & Q_{34} & Q_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & Q_{55} & Q_{56} \\ 0 & 0 & 0 & 0 & Q_{56} & Q_{66} \end{bmatrix}^L \begin{Bmatrix} \epsilon_x \\ \epsilon_y \\ \epsilon_z \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{xz} \end{Bmatrix}^L \quad (8)$$

where $(\sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{yz}, \tau_{xz})$ are the stresses and $(\epsilon_x, \epsilon_y, \epsilon_z, \gamma_{xy}, \gamma_{yz}, \gamma_{xz})$ are the strains with respect to laminate coordinate system (x-y-z). Q_{ij} are transformed elastic constants or stiffness matrix and defined as per the following.

$$\begin{aligned}
 Q_{11} &= C_{11}c^4 + 2(C_{12} + 2C_{44})s^2c^2 + C_{22}s^4; Q_{12} = C_{12}(c^4 + s^4) + (C_{11} + C_{22} - 4C_{44})s^2c^2; \\
 Q_{13} &= C_{13}c^2 + C_{23}s^2; Q_{14} = (C_{11} - C_{12} - 2C_{44})sc^3 + (C_{12} - C_{22} + 2C_{44})cs^3; \\
 Q_{22} &= C_{11}s^4 + C_{22}c^4 + 2(C_{12} + 4C_{44})s^2c^2; Q_{23} = C_{13}s^2 + C_{23}c^2; \\
 Q_{24} &= (C_{11} - C_{12} - 2C_{44})s^3c + (C_{12} - C_{22} + 2C_{44})c^3s; Q_{33} = C_{33}; \\
 Q_{34} &= (C_{31} - C_{32})sc; Q_{44} = (C_{11} - 2C_{12} + C_{22} - 2C_{44})c^2s^2 + C_{44}(c^4 + s^4); \\
 Q_{55} &= C_{55}c^2 + C_{66}s^2; Q_{56} = (C_{66} - C_{55})cs; Q_{66} = C_{55}s^2 + C_{66}c^2.
 \end{aligned} \tag{9}$$

and $Q_{ij} = Q_{ji}$, $i, j = 1$ to 6, where, $c = \cos(\alpha)$ and $s = \sin(\alpha)$ is the angle made by fiber direction to x-axis.

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{xy} \\ \tau_{yz} \\ \tau_{xz} \end{Bmatrix}^L = \begin{bmatrix} Q_{11} & Q_{12} & Q_{13} & 0 & 0 & 0 \\ Q_{12} & Q_{22} & Q_{23} & 0 & 0 & 0 \\ Q_{13} & Q_{23} & Q_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & Q_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & Q_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & Q_{66} \end{bmatrix}^L \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{xz} \end{Bmatrix} \tag{10}$$

2.3 Displacement Fields

In order to approximate the 3D elasticity problem to a 2D plate problem, the displacement components $u(x, y, z)$, $v(x, y, z)$ and $w(x, y, z)$ at any point in the plate space are expanded in a Taylor series in terms of thickness coordinate z , viz.,

$$\begin{aligned}
 u(x, y, z) &= u(x, y, 0) + z \left(\frac{\partial u}{\partial z} \right)_0 + \frac{1}{2!} z^2 \left(\frac{\partial^2 u}{\partial z^2} \right)_0 + \frac{1}{3!} z^3 \left(\frac{\partial^3 u}{\partial z^3} \right)_0 + \dots + \infty \\
 v(x, y, z) &= v(x, y, 0) + z \left(\frac{\partial v}{\partial z} \right)_0 + \frac{1}{2!} z^2 \left(\frac{\partial^2 v}{\partial z^2} \right)_0 + \frac{1}{3!} z^3 \left(\frac{\partial^3 v}{\partial z^3} \right)_0 + \dots + \infty \tag{11} \\
 w(x, y, z) &= w(x, y, 0) + z \left(\frac{\partial w}{\partial z} \right)_0 + \frac{1}{2!} z^2 \left(\frac{\partial^2 w}{\partial z^2} \right)_0 + \frac{1}{3!} z^3 \left(\frac{\partial^3 w}{\partial z^3} \right)_0 + \dots + \infty
 \end{aligned}$$

2.4 Displacement Model

$$\begin{aligned}
 u(x, z) &= u_0(x) + z\theta_x(x) + z^2 u_0^*(x) + z^3 \theta_x^*(x) \\
 w(x, z) &= w_0(x) + z\theta_z(x) + z^2 w_0^*(x) + z^3 \theta_z^*(x)
 \end{aligned} \tag{12}$$

2.5 Governing Equations

Using the principle of minimum potential energy, which derives the equation of equilibrium. In analytical form it can be written as,

$$\delta(U + V) = 0 \tag{13}$$

where U is the total strain energy due to deformation, V is the potential of the external loads and $U+V= \pi$ is the total potential energy and δ is the variational symbol. Substituting the appropriate energy expressions in the above equation, the final expression can be written as,

$$\left[\int_{-h/2}^{+h/2} \int_l (\sigma_x \delta \varepsilon_x + \sigma_z \delta \varepsilon_z + \tau_{xz} \delta \gamma_{xz}) dx dz - \int_l q_0^+ \delta w^+ dx \right] = 0 \tag{14}$$

where, $w^+ = w_0 + (h/2)\theta_z + (h^2/4)w_0^* + (h^3/8)\theta_z^*$ is the transverse displacement at top surface of the plate. q_0^+ is the transverse load applied at top of the plate. Integrating the above equation by parts and collecting the coefficients of $\delta u_0, \delta w_0, \delta \theta_x, \delta \theta_z, \delta u_0^*, \delta w_0^*, \delta \theta_x^*, \delta \theta_z^*$, the following equations of equilibrium are obtained.

$$\delta u_0: \frac{\partial N_x}{\partial x} = 0, \delta w_0: \frac{\partial Q_x}{\partial x} + q_0^+ = 0, \delta \theta_x: \frac{\partial M_x}{\partial x} - Q_x = 0, \delta \theta_z: \frac{\partial S_x}{\partial x} - N_z + \frac{h}{2}(q_z^+) = 0$$

$$\begin{aligned}
 \delta \theta_x^*: \frac{\partial M_x^*}{\partial x} - 3Q_x^* &= 0, \\
 \delta u_0^*: \frac{\partial N_x^*}{\partial x} - 2S_x &= 0, \\
 \delta w_0^*: \frac{\partial Q_x^*}{\partial x} - 2M_z^* + \left(\frac{h^2}{4}\right)q_0^+ &= 0 \\
 \delta \theta_z^*: \frac{\partial S_x^*}{\partial x} - 3N_z^* + \left(\frac{h^3}{8}\right)q_0^+ &= 0
 \end{aligned} \tag{15}$$

Where the stress resultants in terms are defined by

$$\begin{aligned}
 M_x &= \sum_{l=1}^n \int_{Z_L}^{Z_{L+1}} \sigma_x z dz, \quad M_x^* = \sum_{l=1}^n \int_{Z_L}^{Z_{L+1}} \sigma_x z^3 dz, \\
 M_z &= \sum_{l=1}^n \int_{Z_L}^{Z_{L+1}} \sigma_z z dz, \\
 Q_x &= \sum_{l=1}^n \int_{Z_L}^{Z_{L+1}} \tau_{xz} dz, \quad Q_x^* = \sum_{l=1}^n \int_{Z_L}^{Z_{L+1}} \tau_{xz} z^2 dz, \\
 S_x &= \sum_{l=1}^n \int_{Z_L}^{Z_{L+1}} \tau_{xz} z dz, \quad S_x^* = \sum_{l=1}^n \int_{Z_L}^{Z_{L+1}} \tau_{xz} z^3 dz, \\
 N_x &= \sum_{l=1}^n \int_{Z_L}^{Z_{L+1}} \sigma_x dz, \quad N_x^* = \sum_{l=1}^n \int_{Z_L}^{Z_{L+1}} \sigma_x z^2 dz, \\
 N_z &= \sum_{l=1}^n \int_{h_l}^{Z_{L+1}} \sigma_z dz, \quad N_z^* = \sum_{l=1}^n \int_{Z_L}^{Z_{L+1}} \sigma_z z^2 dz.
 \end{aligned} \tag{16}$$

3. Results and Discussions

In this paper FGM simply supported rectangular plate is studied subjected uniform and sinusoidal loading. Dimensions of the plate are $a=1000, b=1000$ and $h=100$ is considered and calculated by using aspect ratio $a/h=10$.

Now, a functionally graded material consisting of aluminum and alumina is considered. Young's modulus for aluminum is 70GPa while for alumina is 380GPa. Note that, Poisson's ratio is selected constant for both and equal to 0.3. The non-dimensional displacement parameters are calculated by using the following relations -

$$\bar{W} = \frac{10h^3 E_c W}{a^4 q_0} \left(\frac{a}{2}, \frac{b}{2} \right) \tag{17}$$

Above table shows comparison between results for plates subjected to uniform or sinusoidal distributed loads, respectively. As it is well known, the uniform load distribution always overpredicts the displacements. As the plate becomes more and more metallic, the difference increases for deflection w . In above table no.1 the non dimensionless displacements of FGM simply supported rectangular plates subjected to uniform loading and non dimensionless displacements of FGM simply supported rectangular plates subjected to uniform loading are given –

Table No. 1 Non-Dimensional transverse displacement for S-S FGM Plate under uniformly distributed loading and Sinusoidal loading.

K	Loading	Lit.(5)	Present Values
Ceramic	UL	0.4665	0.4636
	SL	0.2960	0.2926
1	UL	0.9287	0.9382
	SL	0.5889	0.5920
2	UL	1.1940	1.1973
	SL	0.7573	0.7558
3	UL	1.3200	1.3235
	SL	0.8377	0.8356
4	UL	1.389	1.3927
	SL	0.8819	0.8793
5	UL	1.4356	1.4383
	SL	0.9118	0.9085
6	UL	1.4727	1.4728
	SL	0.9356	0.9306
7	UL	1.5049	1.5017
	SL	0.9562	0.9317
8	UL	1.5343	1.5276
	SL	0.9750	0.9652
9	UL	1.5617	1.5511
	SL	0.9925	0.9800
10	UL	1.5876	1.57244
	SL	1.0089	0.9937
Metal	UL	2.5327	2.54448
	SL	1.6070	1.6404

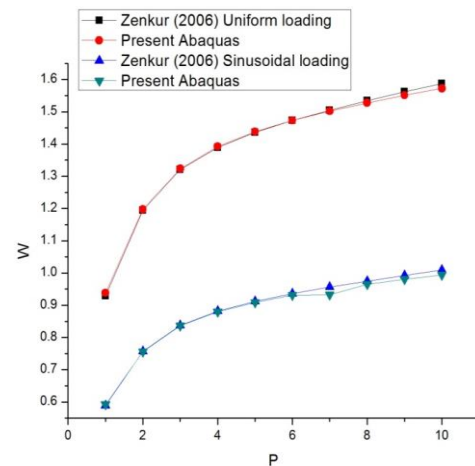


Figure 3. Comparison between Lit. (5) & Present Results for Non-Dimensional transverse displacement S/S FGM Plate under uniformly distributed loading & Sinusoidal loading.

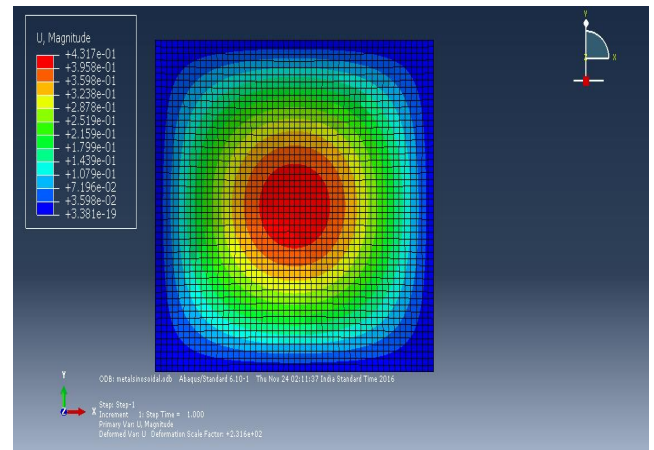


Figure 4. Non-Dimensional transverse displacement for S-S FGM Plate under uniformly Sinusoidal loading for metal plate.

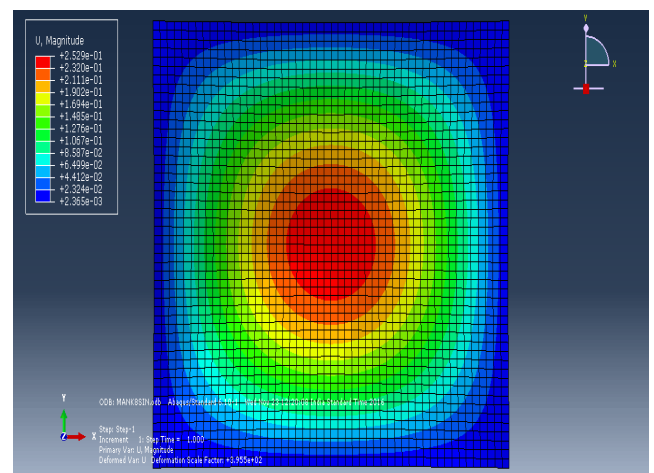


Figure 5. Non-Dimensional transverse displacement for S-S FGM Plate under uniformly Sinusoidal loading for P=8 plate.

Conclusion –

The static response of FGM plate is studied using this HONST. This HONST results shows good validation for the results available in the literature. The displacement response of rectangular plate under uniform and sinusoidal loading is studied. Non dimensional displacements for FGM rectangular plate are computed. From the results it is seen that non dimensional vertical displacement of FGM plate goes on increasing for both uniform loading and sinusoidal loading as per the power law distribution. Thus it shows that the gradients in Material properties plays very important role.

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