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Thermo Mechanical Analysis of Functionally Graded Material Plates

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***Abstract* - In this thesis, the thermal responses, stresses and deformations, frequencies due are investigated analytically for functionally graded material plates and compared with that of Structural Steel and Aluminum. Mathematical correlations are done to determine the material properties of functionally graded material with metal Aluminum using Ceramic as interface zone for each layer up to 10 layers. FGM's are considered for volume fractions of K=2 and K=4. Thermal, Static, Modal and Random vibration analyses are performed on the plates for Structural Steel and Aluminum using Solid Element and for FGM material k = 2, and k = 4 using Shell Element. Analysis is done in Ansys.**

Index Terms* - Functionally *Graded Material Plates, Thermal, Static, Modal and Random Vibration analysis.

I INTRODUCTION:

In Materials science **Functionally Graded Material** (**FGM**) may be characterized by the variation in composition and structure gradually over volume, resulting in corresponding changes in the properties of the material. The materials can be designed for specific function and applications. Various approaches based on the bulk (particulate processing), perform processing, layer processing and melt processing are used to fabricate the functionally graded materials.

II LITERATURE REVIEW:

The following works are done by some authors on functionally graded material plate.

The work done by Natarajana [1], In this paper, a cell based smoothed finite element method with discrete shear gap technique is employed to study the static bending, free vibration, mechanical and thermal buckling behaviour of functionally graded material (FGM) plates. The plate kinematics is based on the first order shear deformation theory and the shear locking is suppressed by the discrete shear gap method In the work done by Swarup Sahoo[2], This analytical work deals with prediction of the stresses developed in a Functionally Graded Timoshenko Beam that has been reinforced with Carbon Nanotubes (CNTs), which is subjected to thermal and mechanical loads. High temperatures have been applied to the upper and lower surfaces of the beam with a certain temperature difference between the two layers for the formation of a temperature gradient.

The work done by Natarajana [1], In this paper, a cell based smoothed finite element method with discrete shear gap technique is employed to study the static bending, free vibration, mechanical and thermal buckling behaviour of functionally graded material (FGM) plates. The plate kinematics is based on the first order shear deformation theory and the shear locking is suppressed by the discrete shear gap method In the work done by Swarup Sahoo[2], This analytical work deals with prediction of the stresses developed in a Functionally Graded Timoshenko Beam that has been reinforced with Carbon Nanotubes (CNTs), which is subjected to thermal and mechanical loads. High temperatures have been applied to the upper and lower surfaces of the beam with a certain temperature difference between the two layers for the formation of a temperature gradient. In the work done by Manish Bhandar[3], Most structural components used in the field of engineering can be classified as beams, plates, or shells for analysis purposes. In the present study the power law, sigmoid and exponential distribution is considered for the volume fraction distributions of the functionally graded plates. The work includes parametric studies performed by varying volume fraction distributions and boundary conditions. Also static analysis of functionally gradient material plate is carried out by sigmoid law and verified with the published results. In the work done by Shabna M.S[4], In this study, flat rectangular plates without cut-out which can be assumed as prefect plates and plates with a central rectangular cut-out that is considered as imperfect plates which are made up of steel, aluminium and invar materials are analysed. Finally comparison has been done between the results obtained from numerical analysis and ANSYS results for isotropic rectangular plate without cut-out. In the work done by S Natarajana[5], In this paper, the bending and the free flexural vibration behaviour of sandwich functionally graded material (FGM) plates are investigated using QUAD-8 shear flexible element developed based on higher order structural theory. This theory accounts for the realistic variation of the displacements through the thickness.

III OBJECTIVE OF THE PROJECT

This paper aims at the evaluation of the thermal responses, stresses and deformations, frequencies due are investigated analytically for functionally graded material plates and compared with that of Structural Steel and Aluminum. Mathematical correlations are done to determine the material properties of functionally graded material with metal Aluminum using Ceramic as interface zone for each layer up to 10 layers. FGM's are considered for volume fractions of K=2 and K=4. Thermal, Static, Modal and Random vibration analyses are performed on the plates for Structural Steel and Aluminum using Solid Element and for FGM material k = 2, and k = 4 using Shell Element. Analysis is done in Ansys.

IV SOFTWARE:

MODELING OF FUNCTIONALLY GRADED PLATE IN CREO 2.0:

For modeling of plates, the reference is taken from Mervin Ealiyas Mathews, Shabna M.S, Thermal-Static Structural Analysis of Isotropic Rectangular Plates [4] as specified in References chapter.

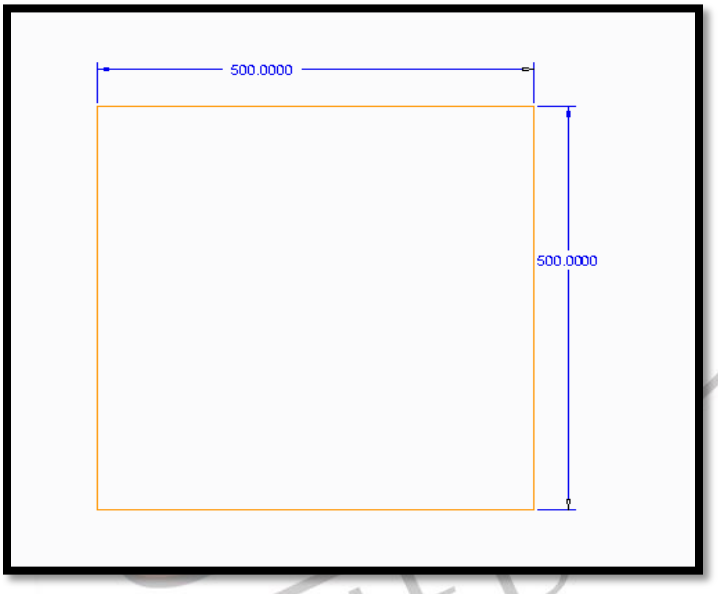


Fig4.1 - 2D Sketch

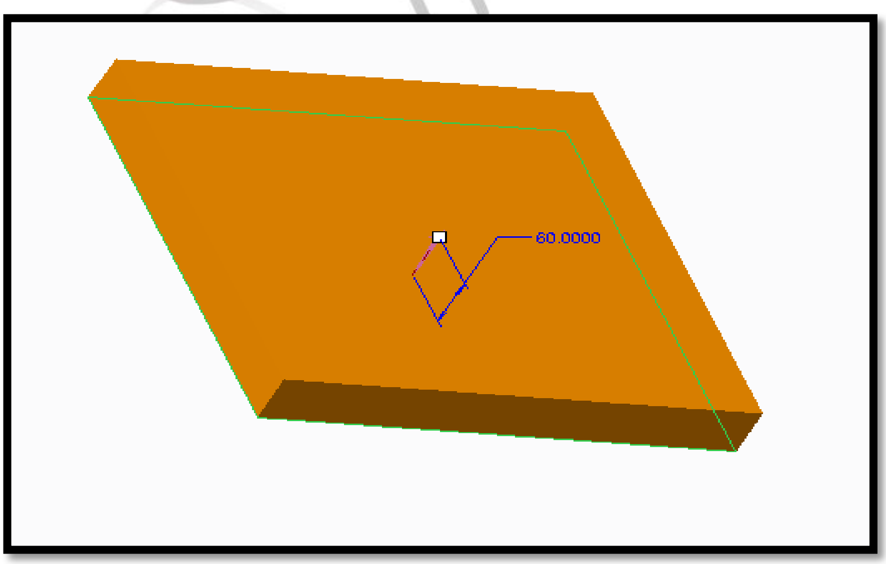


Fig4.1.a – Extrude to create plate

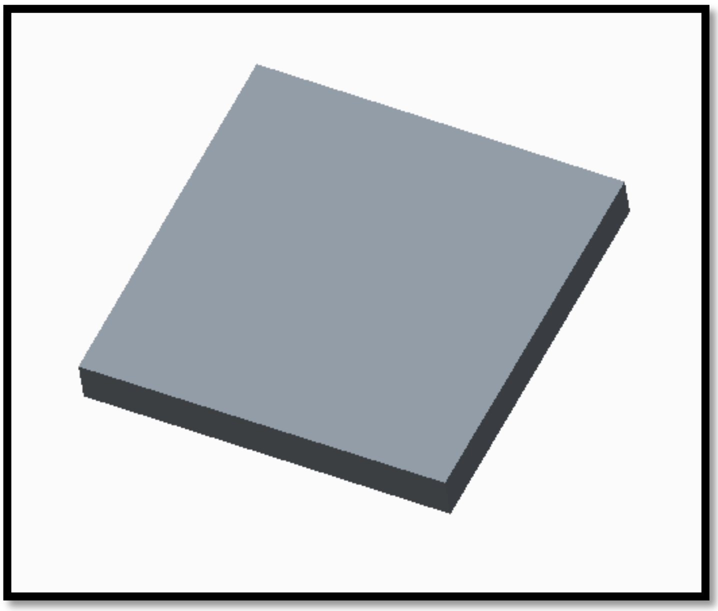


Figure: Final model

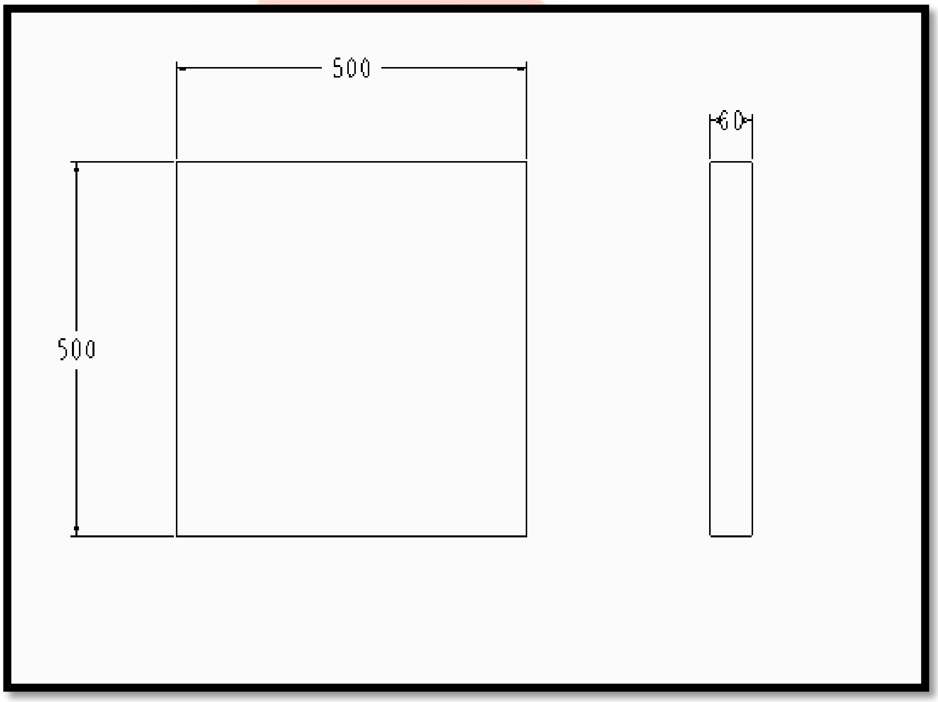


Fig4.1.c - 2D drafting of plate

1. Theoretical calculations of Young's Modulus, Density and Thermal Conductivity for FGM plate

5.1.1 Young's Modulus

Material properties

Top material: ceramic (E_t=380000MPa)

Bottom material: Aluminium (E_b=68000 MPa)

2. **Analysis of functionally graded material plate**

STRUCTURAL ANALYSIS OF PLATE FOR FUNCTIONALLY GRADED MATERIAL USING SHELL ELEMENT

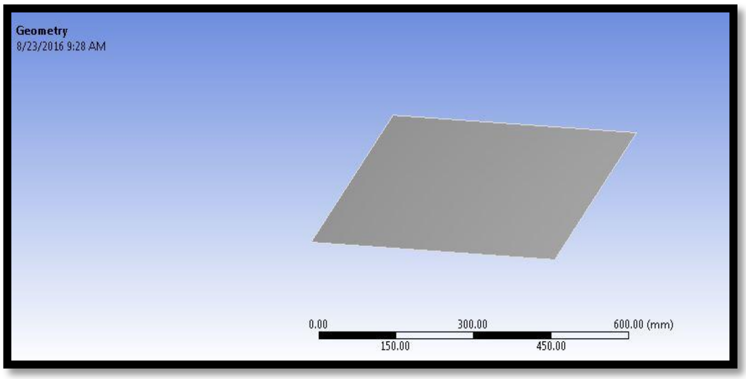
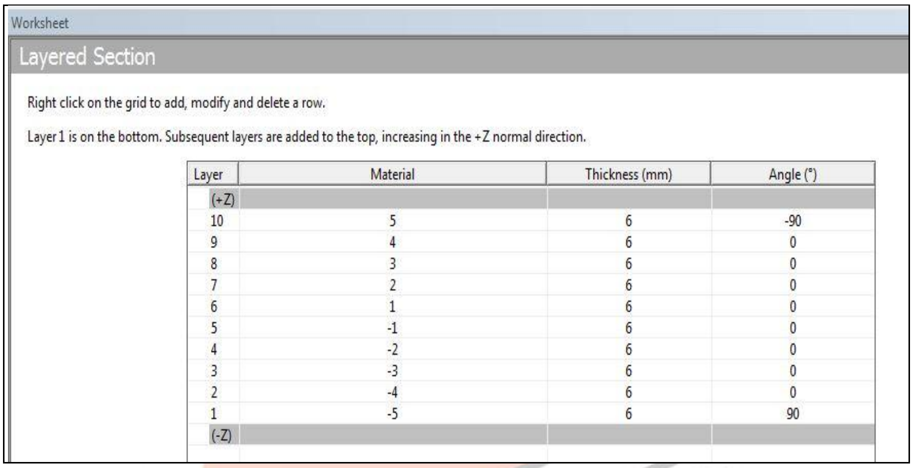


Figure: Imported Model from Creo 2.0



Layered Section

Right click on the grid to add, modify and delete a row.

Layer 1 is on the bottom. Subsequent layers are added to the top, increasing in the +Z normal direction.

Layer	Material	Thickness (mm)	Angle (°)
(+Z)			
10	5	6	-90
9	4	6	0
8	3	6	0
7	2	6	0
6	1	6	0
5	-1	6	0
4	-2	6	0
3	-3	6	0
2	-4	6	0
1	-5	6	90
(-Z)			

Fig – Thickness values in worksheet

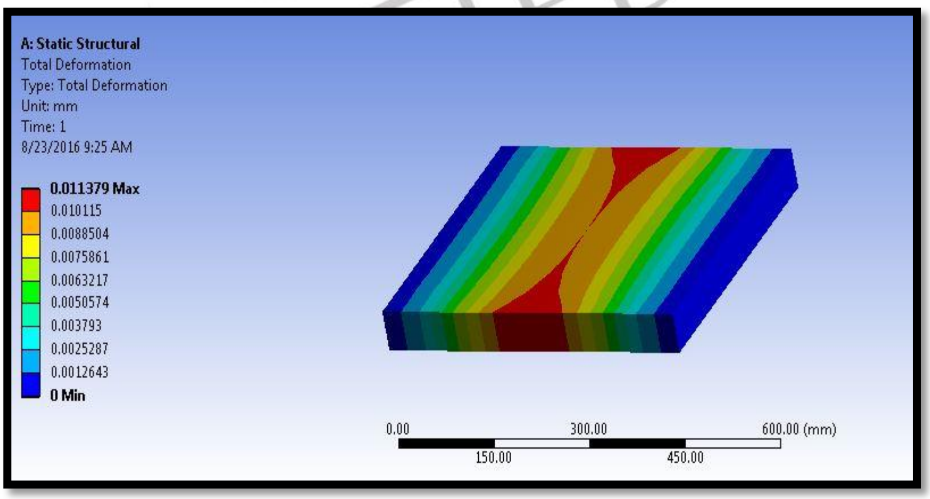
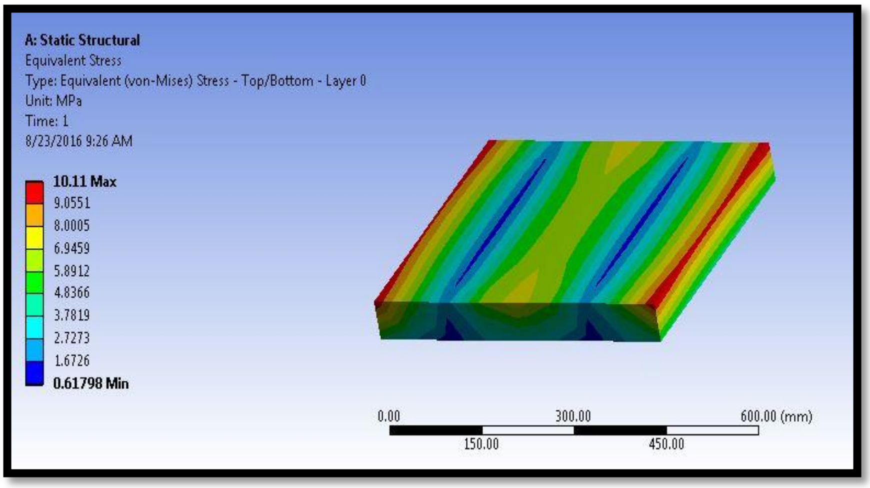
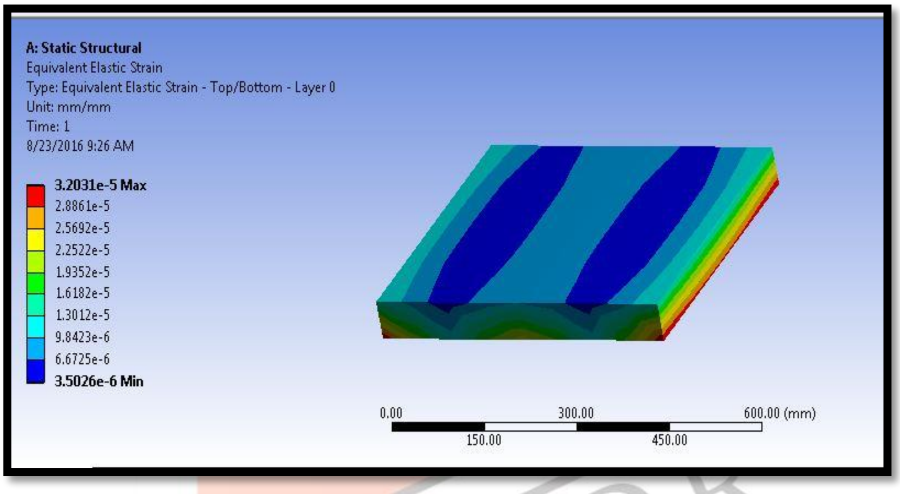


Fig – Total Deformation for FGM plate



A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress - Top/Bottom - Layer 0
Unit: MPa
Time: 1
8/23/2016 9:26 AM

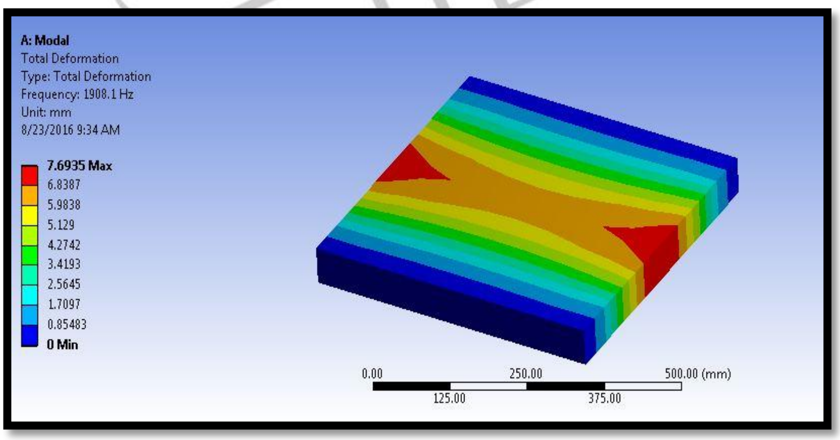
Fig – Equivalent stress for FGM plate



A: Static Structural
Equivalent Elastic Strain
Type: Equivalent Elastic Strain - Top/Bottom - Layer 0
Unit: mm/mm
Time: 1
8/23/2016 9:26 AM

Fig – Equivalent strain for FGM plate

3. MODAL ANALYSIS FOR PLATE USING FGM



A: Modal
Total Deformation
Type: Total Deformation
Frequency: 1908.1 Hz
Unit: mm
8/23/2016 9:34 AM

Fig – Total Deformation at Mode1 for FGM plate

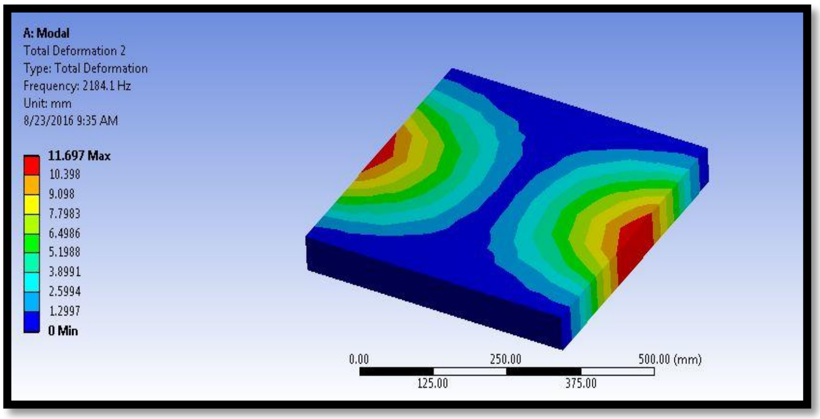


Fig – Total Deformation at Mode2 for FGM plate

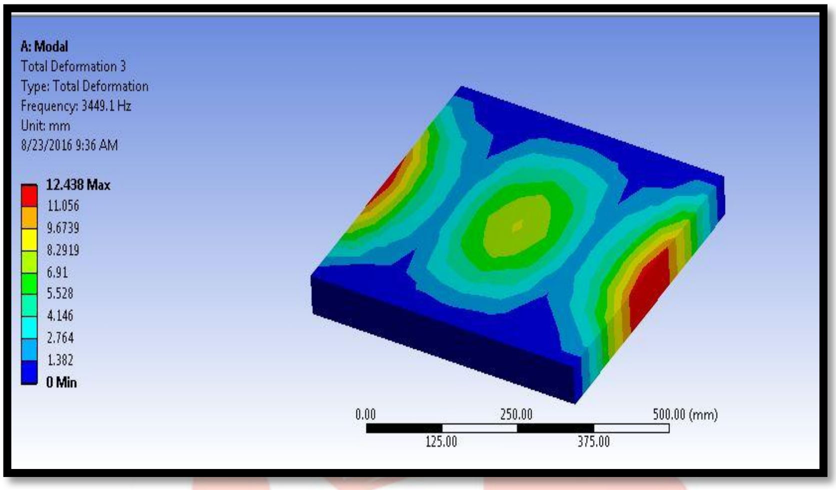


Fig – Total Deformation at Mode3 for FGM plate

4. RANDOM VIBRATION ALANALYSIS FOR PLATE

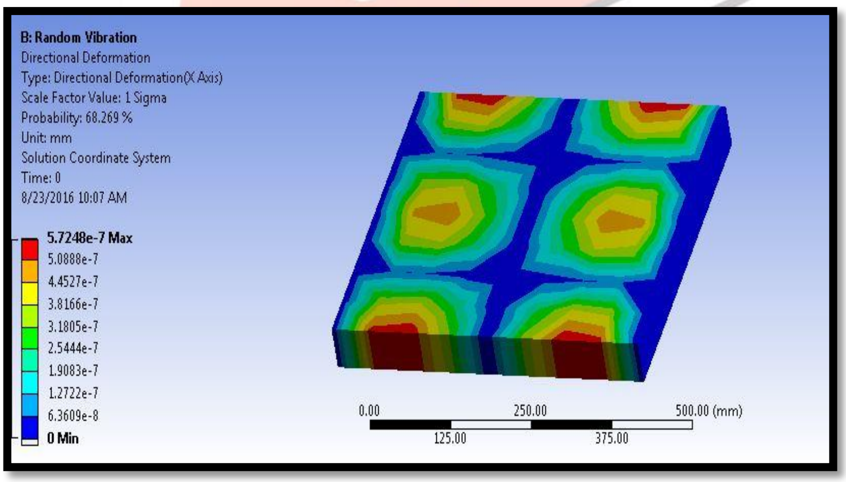


Fig – Directional Deformation for FGM plate

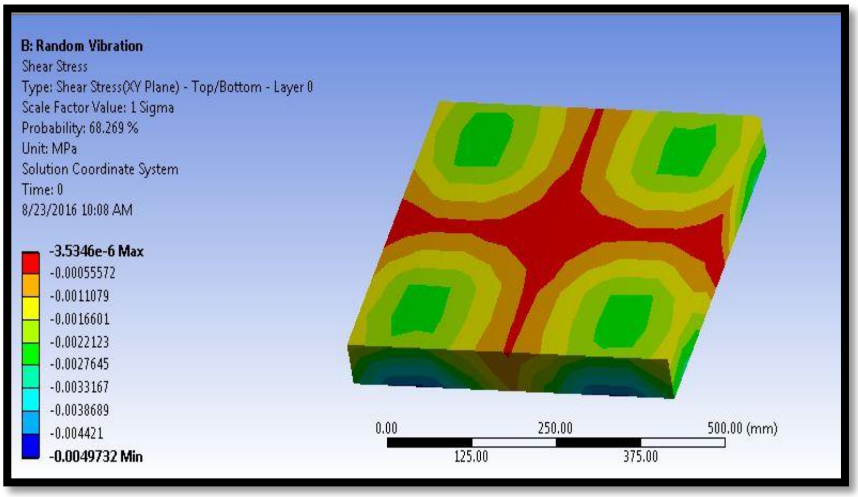


Fig – Shear stress for FGM plate

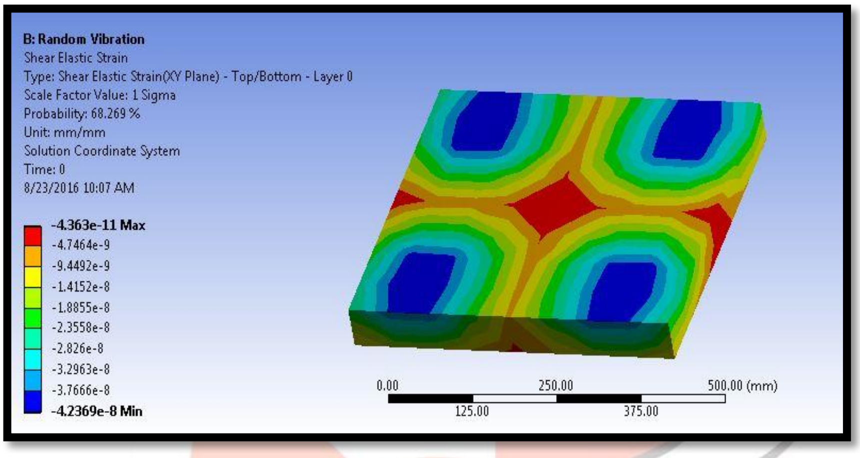


Fig – Shear strain for FGM plate

5. THERMAL ANALYSIS FOR PLATES

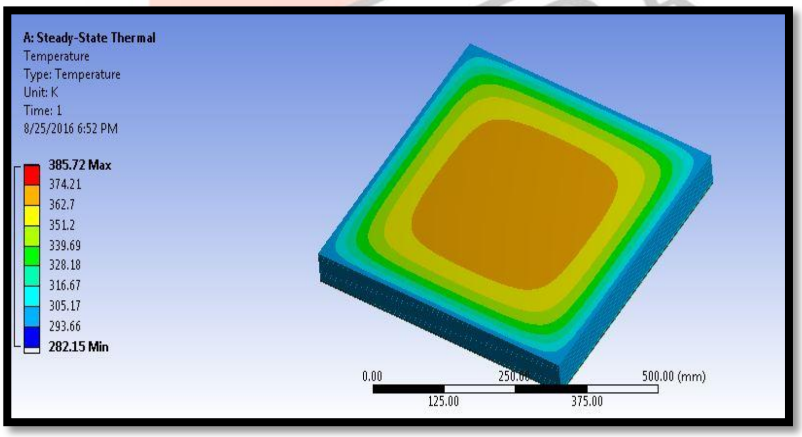


Fig – Temperature Distribution for FGM plate

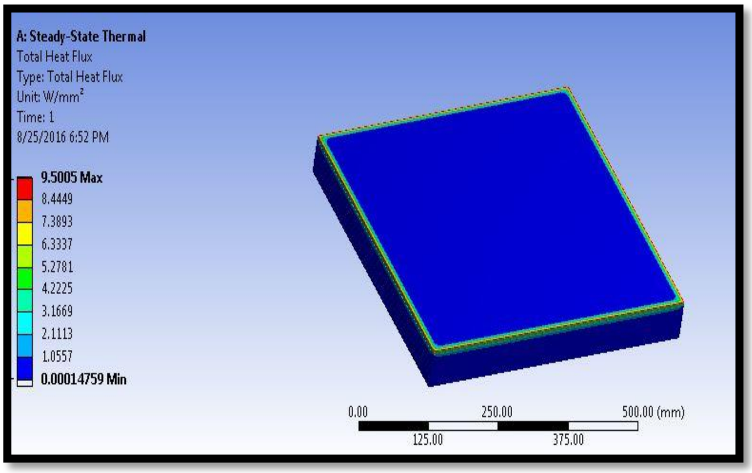


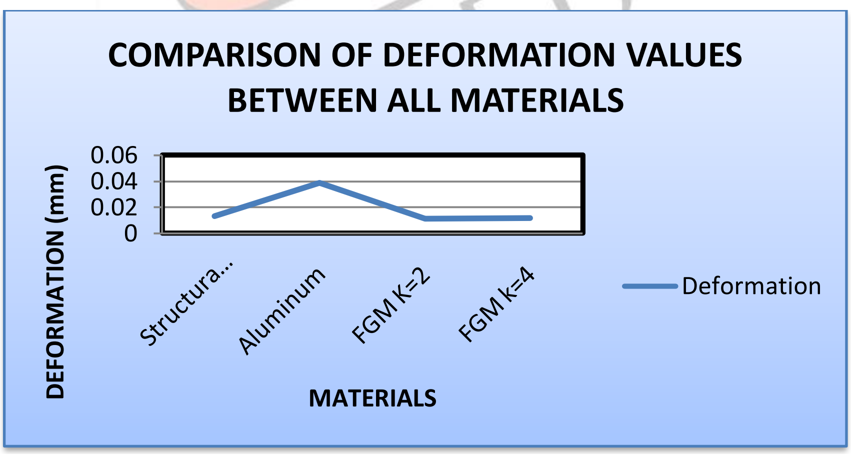
Figure:Heat Flux for FGM plate

V RESULTS

STRUCTURAL ANALYSIS

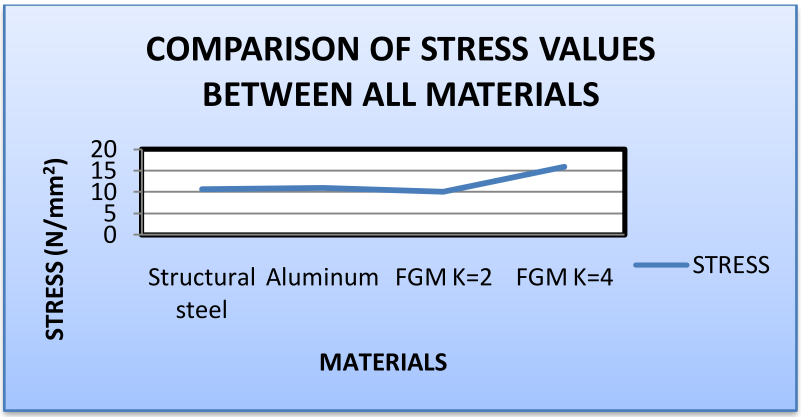
Table: Static analysis results of plate

Material		Deformation(mm)	Strain	Stress (Mpa)
Structural steel		0.013187	5.3522e-5	10.704
Aluminum		0.038755	0.00016155	10.985
FGM	**K=2**	0.011379	3.2031e-5	10.11
	K=4	0.012042	3.8413e-5	15.906



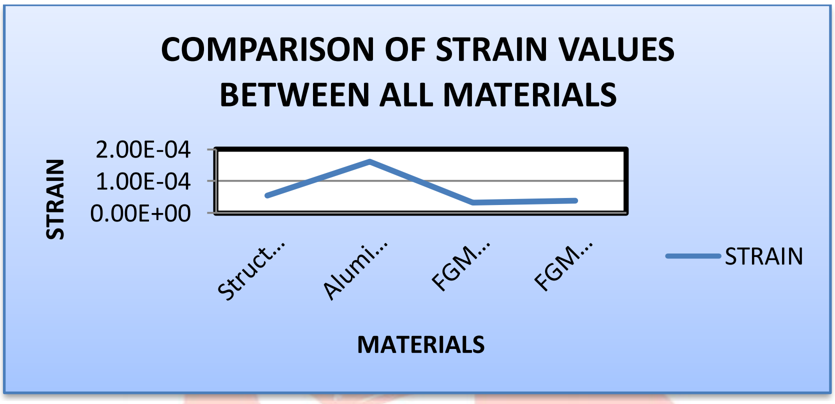
Graph: Comparison of Deformation values between all materials

By observing the result and graph for deformation values, the values are less when FGM is used than Steel and Aluminum. The deformation is increasing from k=2 to k=4.



Graph – Comparison of Stress values between all materials

By observing the result and graph for stress values, the values are more when FGM is used than Steel and Aluminum. The stress is increasing from k=2 to k=4.



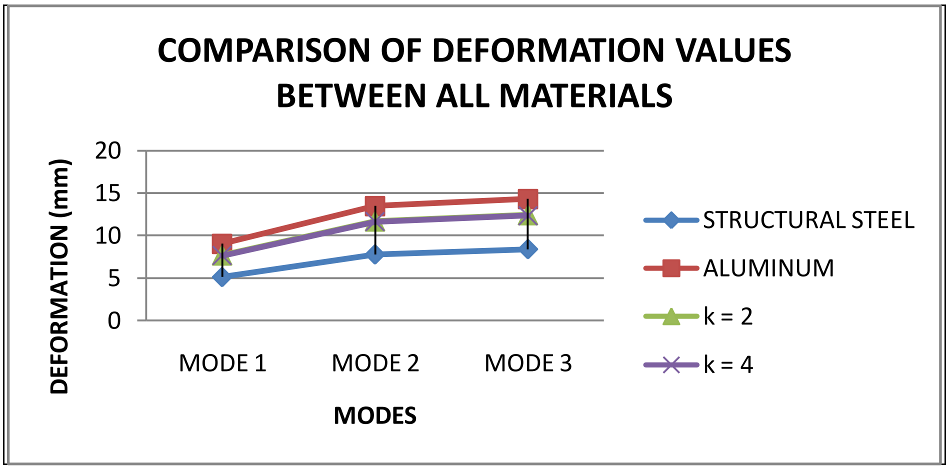
Graph – Comparison of Strain values between all materials

By observing the result and graph for strain values, the values are less when FGM is used than Steel and Aluminum. The deformation is increasing from k=2 to k=4.

MODAL ANALYSIS

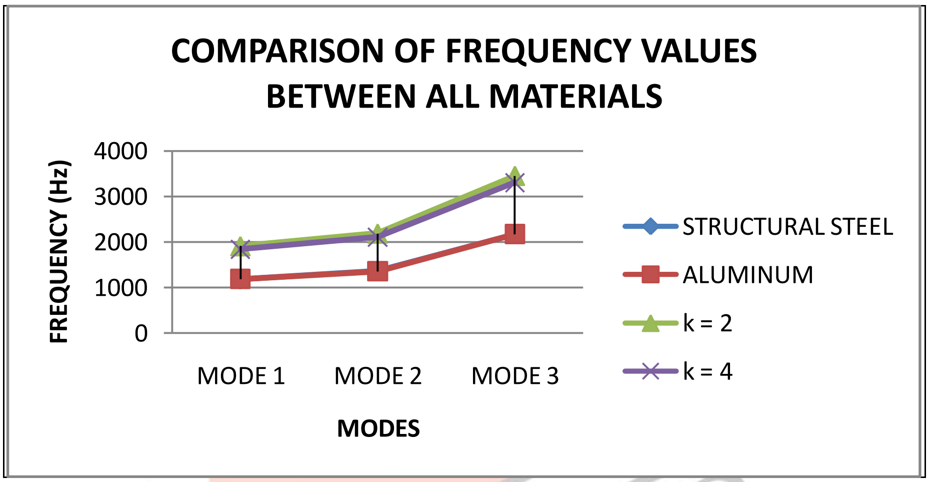
Table – Modal analysis results of plate

MATERIAL		MODE 1		MODE 2		MODE 3	
		Deformation (mm)	Frequency (Hz)	Deformation (mm)	Frequency (Hz)	Deformation (mm)	Frequency (Hz)
Structural steel		5.1542	1179.8	7.7911	1364.5	8.4108	2172.5
Aluminum		9.0672	1188.3	13.466	1358.6	14.309	2171.4
FGM	K=2	7.6935	1908.1	11.697	2184.1	12.438	3449.1
	K=4	7.6682	1845.2	11.642	2107.2	12.36	3304.4



Graph – Comparison of Deformation values between all materials

By observing the result and graph for deformation values, the values are less when FGM is used than Aluminum but the deformation values are less for Steel material.



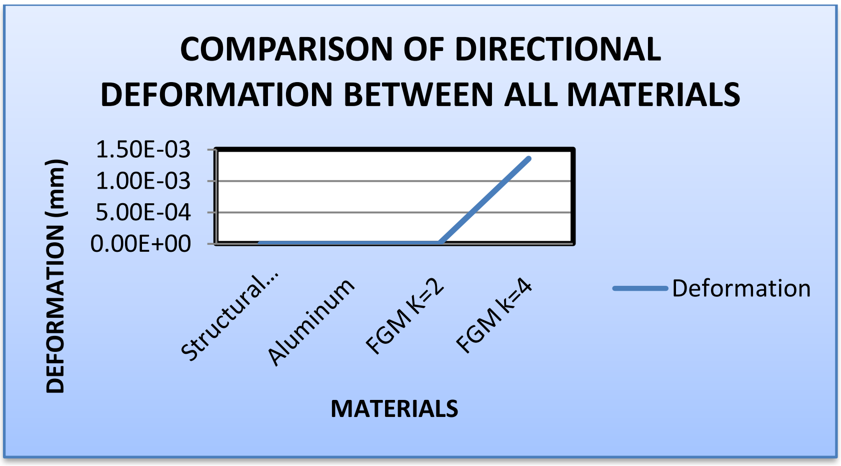
Graph – Comparison of Frequency values between all materials

By observing the result and graph for frequency values, the values are more when FGM is used than Steel and Aluminium. So the vibrations will increase when FGM is used for plates.

RANDOM VIBRATION ALANALYSIS

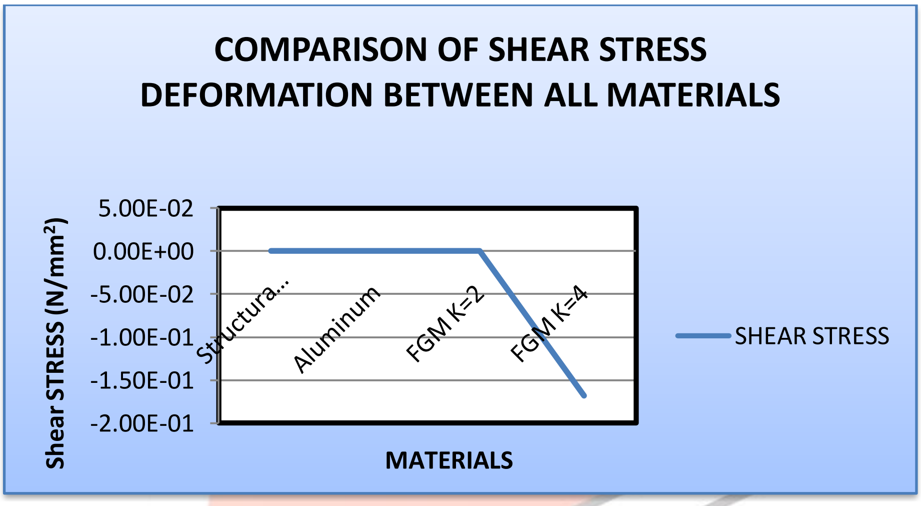
Table: Random vibration analysis results of plate

Material		Directional Deformation(mm)	Shear Stress (Mpa)	Shear Strain
Structural steel		7.965e-8	6.1031e-5	7.934e-10
Aluminum		2.2361e-8	6.0767e-6	2.4307e-10
FGM	**K=2**	5.7248e-7	-3.5346e-6	-4.363e-11
	K=4	0.0013577	-0.16789	-1.1034e-6



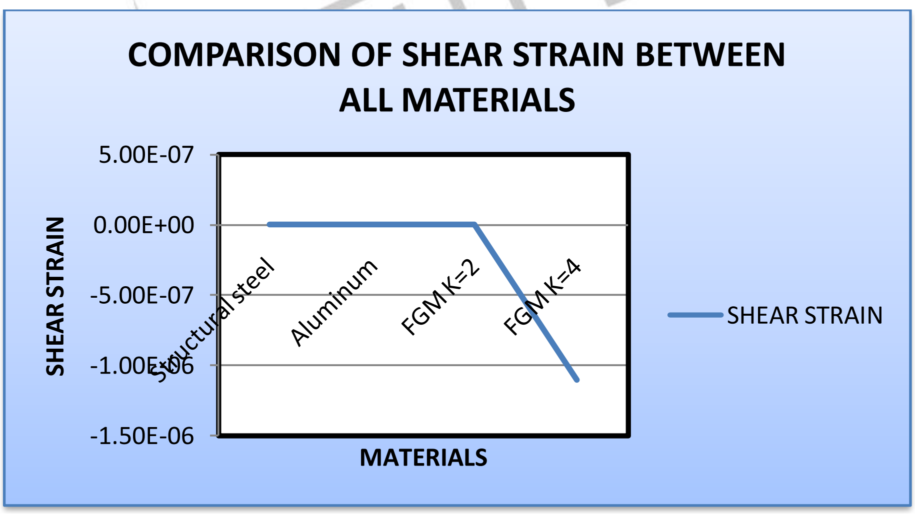
Graph – Comparison of Directional Deformation values between all materials

By observing the result and graph for directional deformation values, the values are less when FGM is used than Steel and Aluminum. The deformation is increasing from k=2 to k=4.



Graph – Comparison of Shear Stress Deformation values between all materials

By observing the result and graph for shear values values, the values are less when FGM is used than Steel and Aluminum. The stress is decreasing from k=2 to k=4. The negative value for shear stress for FGM material specifies that the stress is negative since it points in a negative direction on a negative plane.



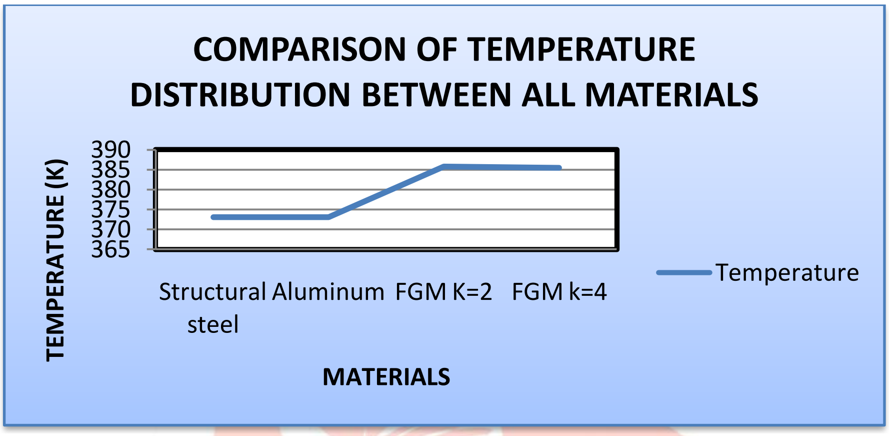
Graph – Comparison of Shear Strain values between all materials

By observing the result and graph for strain values, the values are less when FGM is used than Steel and Aluminum. The deformation is decreasing from k=2 to k=4.

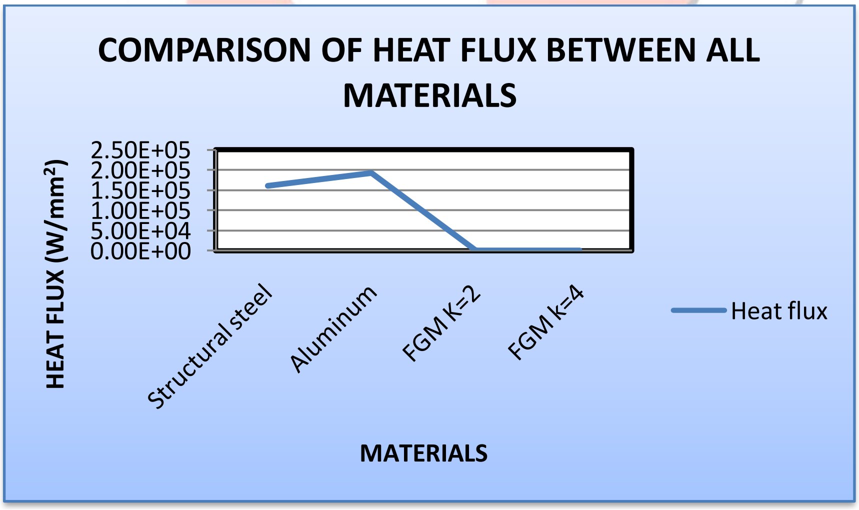
THERMAL ALANALYSIS

Table: Thermal analysis results of plate

Material		Temperature	Heat flux (W/mm^2)
Structural steel		373.15	1.6043e5
Aluminum		373.15	1.9189e5
FGM	**K=2**	385.72	9.5005
	K=4	385.43	10.651



Graph: Comparison of Temperature Distribution values between all materials



Graph: Comparison of Heat Flux values between all materials

By observing the result and graph for heat flux values, the values are less when FGM is used than Steel and Aluminum. The values displayed for FGM are for each layer.

VI CONCLUSION:

By observing the structural analysis results, for deformation values, the values are less when FGM is used than Steel and Aluminum. The deformation is increasing from k=2 to k=4. By observing the result and graph for stress values, the values are more when FGM is used than Steel and Aluminum. The stress is increasing from k=2 to k=4. By observing the result and graph for strain values, the values are less when FGM is used than Steel and Aluminum. The deformation is increasing from k=2 to k=4. By observing the modal analysis results, for deformation values, the values are less when FGM is used than Aluminum but the deformation values are less for Steel material. By observing the result and graph for frequency values, the values are more when FGM is used than Steel and Aluminum. So the vibrations will increase when FGM is used for plates. By observing the result

Random Vibration analysis, for directional deformation values, the values are less when FGM is used than Steel and Aluminum. The deformation is increasing from k=2 to k=4. By observing the result and graph for shear values , the values are less when FGM is used than Steel and Aluminum. The stress is decreasing from k=2 to k=4. The negative value for shear stress for FGM material specifies that the stress is negative since it points in a negative direction on a negative plane. By observing the result and graph for strain values, the values are less when FGM is used than Steel and Aluminum. The deformation is decreasing from k=2 to k=4. By observing the thermal analysis, for heat flux values, the values are less when FGM is used than Steel and Aluminum. The values displayed for FGM are for each layer.

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