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ANALYTICAL INVESTIGATION OF FUNCTIONALLY GRADED MATERIAL PLATE UNDER MECHANICAL LOAD SUBJECTED TO VARIOUS BOUNDARY CONDITIONS

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Abstract - *Functionally graded material (FGMs) are the new trend of novel composite materials in an engineering applications like aerospace, bio materials and energy, structures etc, whose properties are varied easily in the spatial direction microscopically to improve the overall structural performance. These materials offer great result in extreme temperature environments in most general structures, regardless of their use; will going to be subjected to dynamic loads during their operational life.*

In this article, determining of the buckling behavior of the simply supported fgm plates by using first order and second order of shear deformation theories. The FGM plate manufactured from Aluminum alloy and Ceramic as interface zone for every layer up to 10 layers of the plate. A theoretical calculation was done to determine the material properties for every layer.

Buckling analysis was done in ANSYS. The load is applied on the FGM plates were 0.001 MPa, 0.01 MPa, 0.1 MPa and 0.2 MPa. The resultant deformation of 0.00873 mm is very less at 0.001MPa and it is gradually increasing when the load is amplified on the FGM plate. The stress at 3.3846 MPa which is very less when the load is 0.001 MPa applied and it reaches 338.46 MPa at 0.1 MPa load which is nearby elastic limit. If the load is extended, then this material is losing the elastic nature . The Buckling load factor was found by using ANSYS.

***Key Words*: Functionally graded materials (FGM's), Aluminium metal alloy, ceramic, ANSYS.**

1. Introduction

FGM's, eliminates the quick interfaces existing in composite substance which is where failure is initiated. It replaces this sharp interface with a gradient interface which produces soft transition from one substance to other .One unique characteristics of FGM is the ability to tailor a material for specific application.

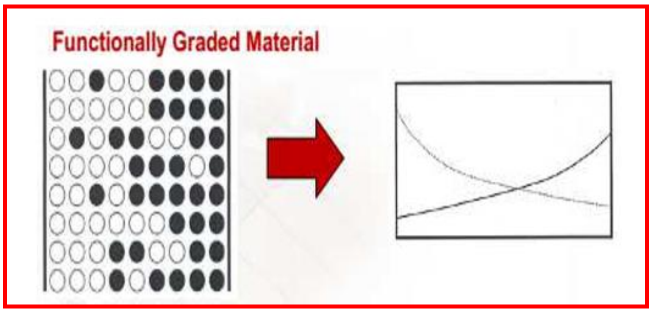


Fig-1.1: Functionally Graded Materials.

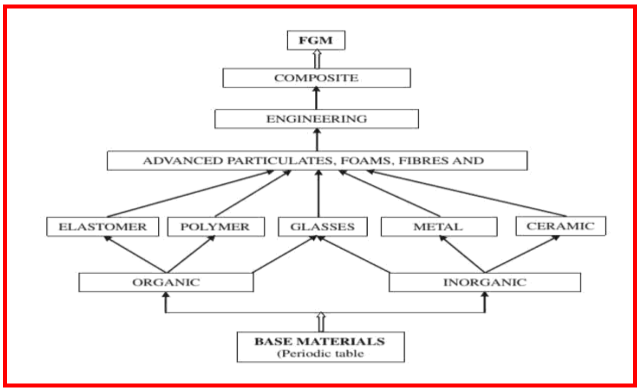


Fig-1.2: Representation of recent material Hierarchy

In the development of materials fgm have played an essential role. The scientific available of base materials into different inorganic & organic compounds has made the path for developing the highly developed polymers, engineering alloys, structures, ceramics, etc. The structure of development of modern material is illustrated in Fig. 1.2. These materials possess various advantages that create them fitting in potential applications. It includes a potential decline of in-plane and through the thickness transverse stresses, improved thermal, toughness properties etc.

FGMs have nice potential in applications wherever the in operation conditions are severe, as well as space vehicle heat shields, device tubes, medical specialty implants, flywheels, and plasma facings for fusion reactors, etc. numerous combos of the usually incompatible functions will be enforced to make new materials for region, chemical plants, atomic energy. Typical applications of FGMs ar as follows:

One of the foremost vital characteristics of functionally hierarchic material is that the ability to inhibit crack propagation. This property makes it helpful in defense application as a penetration resistant materials used for armor plates and bullet-proof vests.

2. Literature Review

Mohammad Abedi and GH. Rahim [1] introduced analytical solutions for stress distribution around circular cutout in orthotropic Functionally hierarchic material Composite (FGC) plate. By victimization the idea of advanced variable functions, stress distributions around circular cutout of orthotropic FGC plate underneath plane stress conditions has been obtained. Variations of mechanical properties through the thickness are thought of.

D.K. Jha, Tarun Kant, R.K. Singh [2] tried to choose out and spotlight the themes which might be most applicable to FGMs and systems and appraise adviser magazine guides which might be related to FGM subjects. a significant appraise of the aforementioned analysis with within the place of thermo-elastic and vibration analyses of functionally hierarchic (FG) plates with a stress at the present works announce thanks to the actual fact that 1998. The review meted out here, cares with deformation, stress, vibration and stability issues of FG plates.

Victor Birman and Larry w. byrd [3] they cover blending of particulate FGM, heat switch problems, strain, balance and dynamic analyses, testing, production and layout, programs, and fracture. The very important regions whereby additionally studies is needed for a a success implementation of FGM in layout ar mentioned with within the conclusions.

Fernando Ramirez, Paul R. Heyliger, Associate in Nursingd Brian Pan [4] offered an approximate declare the static analysis of three dimensional, eolotropic, elastic plates composed of functionally hierarchic substances (FGM). the solution is nonheritable with the help of victimization the usage of a distinct layer plan in combination with the Ritz approach, whereby the plate is split into Associate in Nursing whimsical vary of undiversified and/or FGM layers. 2 styles of functionally hierarchic substances are taken into consideration: Associate in Nursing exponential variant of the mechanical residences by the thickness of the plate, and mechanical residences as a feature of the fiber orientation, that varies quadratically by the laminate thickness. The approach became established with the help of victimization fixing the trouble actually supported FGM plate, that terrific settlement with the precise answer became nonheritable. undiversified, graded, and bi-layer plates tested with the intention to seem at ability edges of the usage of FGM.

J.N.Reddy offered theoretical formula, Navier's [5]answers of sq. plates, and finite detail fashions whole} totally at the third- order shear deformation plate plan for the analysis of by-thickness functionally hierarchic plates.

Pathak H [6] they cover blending of particulate FGM, heat switch problems, strain, balance and dynamic analyses, testing, production and layout, programs, and fracture. The very important regions whereby additionally studies is needed for a success implementation of FGM in layout ar mentioned with within the conclusions.

Dharmendra S. Sharma[7] conducted stress general functions to verify the strain concentration around elliptical, circular, and triangular cuts in laminated composites infinite plate subjected to whimsical line loading at time ar obtained victimization victimization advanced variable technique.

3. Problem Statement

Pure metals find little use in engineering applications. Alloys of quite dissimilar metals are tough to combine. Composite materials endure delamination under high load applications. Hence FGMs are proposed in 1980s. FGM are non- homogeneous and it is difficult to evaluate characteristics analytically. An important numerical tool ANSYS is used to evaluate mechanical characteristics of FGM.

From the literature review it is observed that very few works is carried out on analysis of FGM plates using higher order shear deformation theory and so far, there is limited literature available for static analysis and Also, there is limited result available in the literature for static analysis of FGM skew plates. Hence in the present paper, an attempt has been made to develop a finite element model based on higher order shear deformation theory that requires evaluating the static mode and random vibrational analysis of a FGM.

4. OBJECTIVES

The objectives of the current work are:

a) To estimate the mechanical properties (young's modulus and density of the material) of the FGM plate by standard first and second order differential formulas.
b) To estimate the strength, focused on analyzing stresses and deflections in materials under the load. information of stresses and deflections permits for the safe design of structures that are capable of supporting their anticipated loads.
c) To estimate under different loading conditions of the FGM plate of different layer orientation by using simulation tool as ANSYS (Static, random vibrational and buckling analysis).
d) To analyze Shear stress, the resultant shear is of huge importance in nature, being intimately related to the down slope movement. Shear strain measures deformation differs from a rigid deformation.
e) To analyze Shear strain, It is an angular change at some points in a shape in this regard the shear stress and

shear strain is estimated form the random vibrational analysis.

5. Design and Analysis Of FGM Plate

5.1 Modelling Of FGM Plate

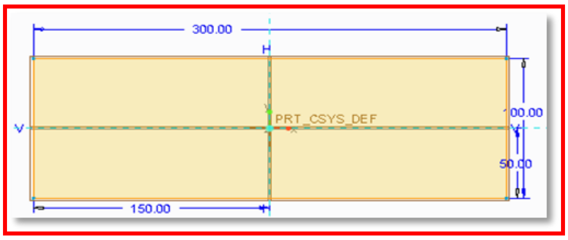


Fig-5.1: Sketch

This sketch is developed by using 3D part modelling software system. Then it is changed into surface feature by fill option.

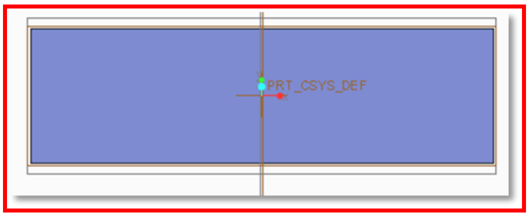


Fig-5.2: Fill

5.2 Theoretical calculations

Material Properties:

Materials	Density (g/cc)	Young's modulus (GPa)	Poisson ration	Ultimate compressive strength (MPa)	Ultimate tensile strength (MPa)
Al alloy 6061	2.7	68	0.3	262	310
Ceramic (aluminum oxide (al2o3) 99.9%.	3.9	380	0.22	3000	300

Plate dimensions: 100x300mm (ASTM/ASME Plate dimensions: 100x300 mm (ASTM/ASME B209 ratio of 1:10)

Loads: 0.001, 0.01, 0.1 and 0.2MPa

FOR YOUNGS MODULUS:

1) For k=2; z=1

$E(Z)=(Et-Eb)(z/h+1/2)^K+Eb$

2)For k=2;z=-1

$E(Z)=(Et-Eb)(z/h+1/2)^K+Eb$

FOR DENSITIES:

1)For k=2;z=1

$\rho(Z)=(\rho t-\rho b)(z/h+1/2)^K+\rho b$

For Young's Modulus

Material properties

Top material: ceramic ($E_{T=}$380000MPa)

Bottom material: Aluminium (E_b=68000 MPa)

Z= layer number

H=thickness of the plate

K=number of materials

1) For k=2; z=1

$E(Z_1) = (Et-Eb)(z/h+1/2)^K+Eb$

$= (380000-68000)(1/5+1/2)^2+68000$

$=(312000)\ (0.49)+68000$

$= 152880+68000$

$E(Z_1) =220880$

Therefore, remaining calculated based on above process.

Z	Young's modulus E (Mpa)	Density (Kg/mm³)
+5	770000	0.000005536375
+4	595280	0.000004830159
+3	445520	0.000004164936
+2	320720	0.000003720391
+1	220880	0.000003307739
-1	96080	0.000002812399
-2	71120	0.000002711511
-3	71120	0.000002711511
-4	96080	0.000002812399
-5	146000	0.000002383625

5.3 STRUCTURAL ANALYSIS OF PLATE

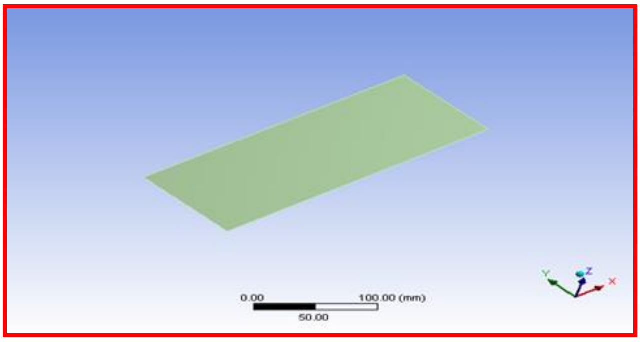
Static analysis: The plate of IGES model is imported and added the substance properties. The various load are applied on the plate then estimated the deformation, stress and strain.

Buckling analysis: The load feature is estimated in buckling analysis, the input data which is reflect on from static analysis.

Random vibrational analysis: The shear stress, shear strain and deformation was find in vibration analysis, input stresses are considering from static analysis.

For Load = 0.001 MPa

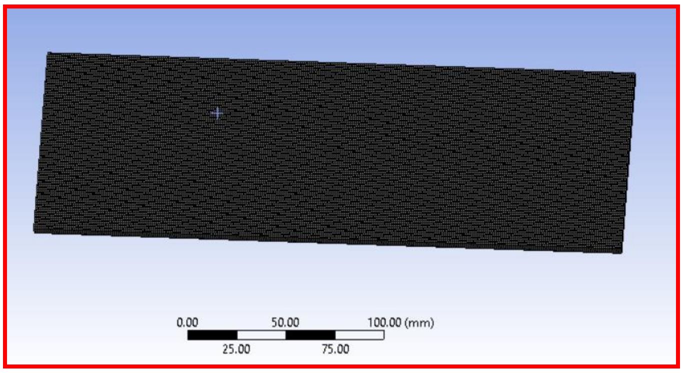
Imported model



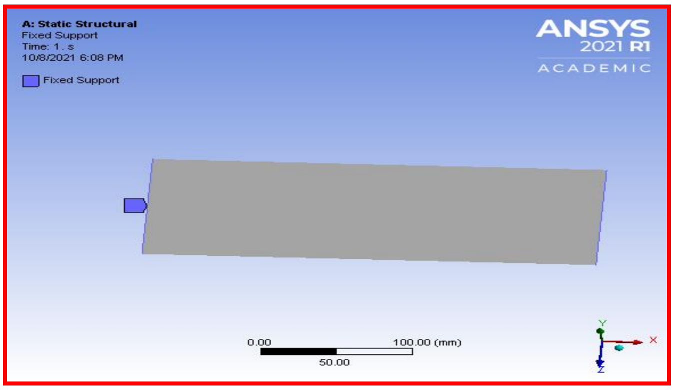
Layer Section

Layer	Material	Thickness (mm)	Angle (°)
(+Z)			
10	+5	0.5	0
9	+4	0.5	45
8	+3	0.5	0
7	+2	0.5	45
6	+1	0.5	0
5	-1	0.5	45
4	-2	0.5	0
3	-3	0.5	45
2	-4	0.5	0
1	-5	0.5	45
(-Z)			

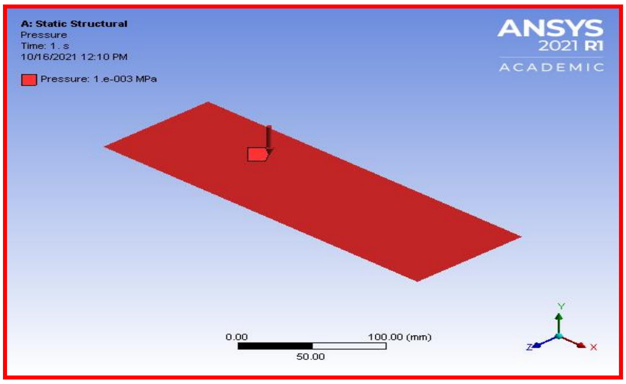
Meshed model



Fixed support



Pressure



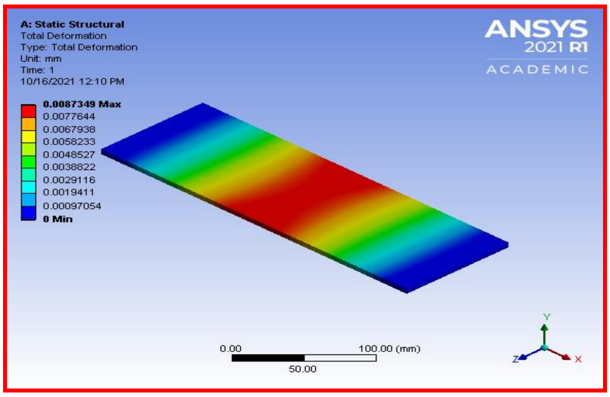


Fig 5.3.1: Deformation

From above figure, it is stated that deformation of the FGM Plate. Both left and right side of the plate is fixed and the load is applied on the surface of the plate. The maximum deformation (mm) is 0.0087349 mm at center of the plate and minimum is 0mm at fixed end because of the fixed support.

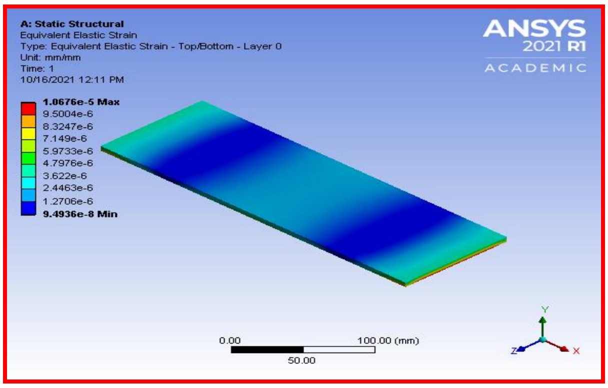


Fig 5.3.2: strain

The strain is defined as change in length to original length. In the above figure, the maximum strain is 1.0676e-5 and minimum is 9.4936e-8 which is observed as near by the fixed supports.

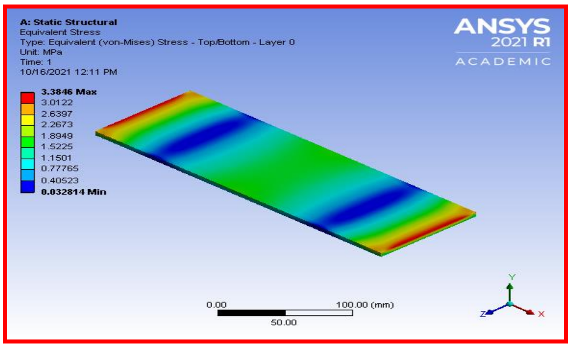


Fig 5.3.3: Stress

The load (0.001MPa) is applied on the area of surface plate is called as stress. The maximum stress is 3.3846MPa is at ends of the plate and minimum 0.032814MPa at nearby ends of the plate.

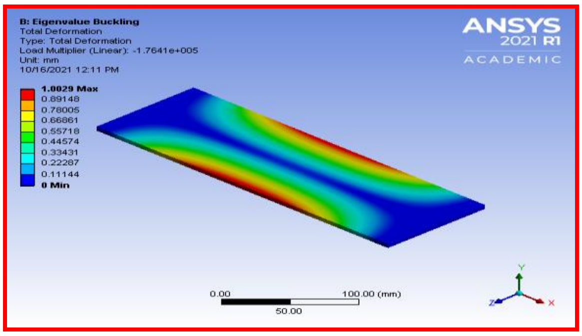


Fig 5.3.4: Eigenvalue buckling –deformation

In structural engineering, buckling is such as the bowing of a column under compression or the wrinkling of a plate under shear. The load multiple factor is 1.7641e+5 and maximum deformation is 1.0029mm at edges of the FGM Plate and minimum is 0mm.

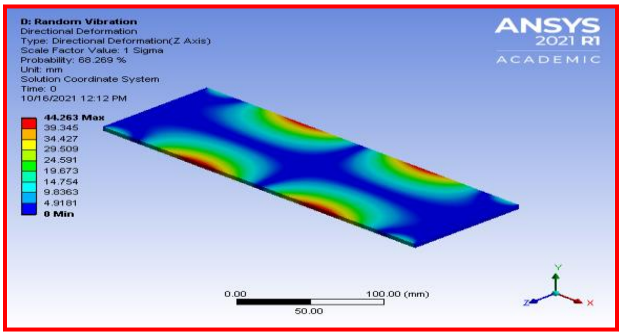


Fig5.3.5: Directional deformation

The above figure is representing the deformation of FGM Plate, the maximum is 44.263mm at edges of the plate and minimum deformation is 0mm at midsection of the plate.

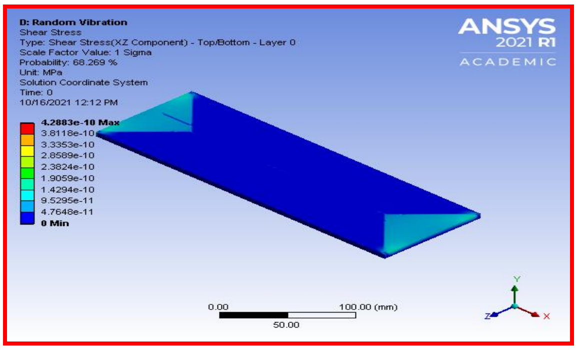


Fig 5.3.6: shear stress

The above figure is representing the shear stress of FGM Plate, the maximum is 4.2883e-10 MPa at fixed ends of the plate and if we observe the plate maximum area is indicated as blue color represents minimum so, and the shear stress is 0 covers the entire plate.

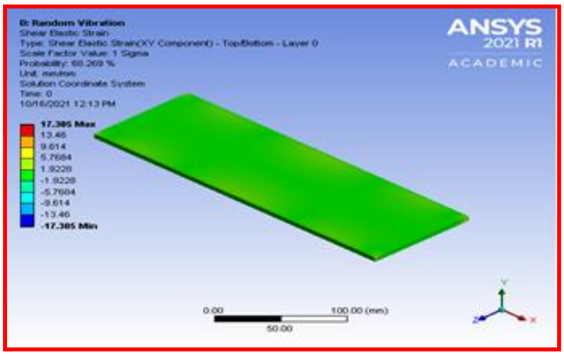


Fig 5.3.7: Shear strain

The above figure is representing the shear strain of FGM Plate, the maximum is 17.305 at corners of the plate and if we observe the plate entire is indicated as green color so, the shear strain is 1.9228 covers the entire plate.

6. Results and discussions

Analysis Results:

a) Here, minimum deformation (0.00873mm) is for minimum loading (0.001MPa) conditions and maximum deformation (1.747mm) is for maximum load (0.2MPa).

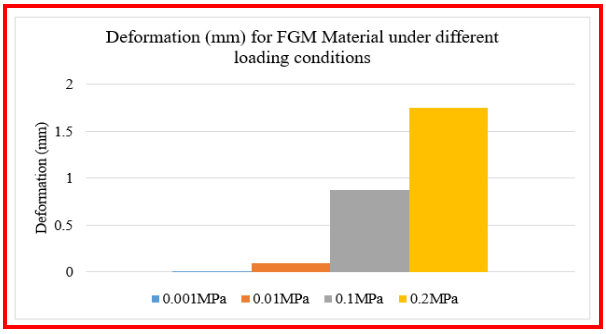
b) If the load is increases on the object, then the strain is gradually increases. Here, minimum strain (1.06e-5) is for minimum loading (0.001MPa) conditions and maximum (0.002135) is for maximum load (0.2MPa).

c) Minimum stress (3.3846 MPa) is for minimum loading (0.001MPa) conditions and maximum (676.92 MPa) is for maximum load (0.2MPa).

d) The buckling load factor of FGM Plate under different loading conditions. Here, minimum load factor (882.06) is for maximum loading (0.2MPa) conditions and maximum load factor (1.76e+5) is for minimum load (0.001MPa).

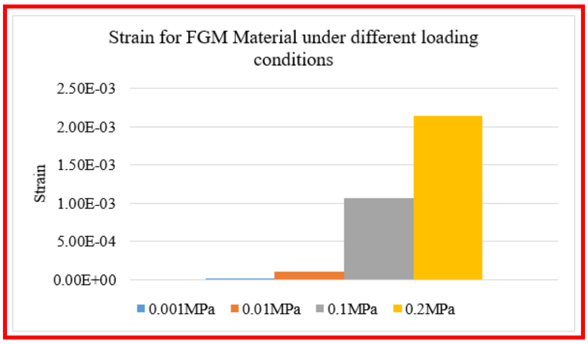
e) The directional deformation of FGM Plate under different loading conditions. If the load is increases on the object, then the deformation is gradually increases. Here, minimum deformation (44.263 mm) is for minimum loading (0.001MPa) conditions and maximum deformation (63.787 mm) is for maximum load (0.2MPa).
f) Strain (17.305) is for minimum loading (0.001MPa) conditions and maximum (24.94) is for maximum load (0.2MPa).
g) Shear stress (4.288e-10 MPa) is for minimum loading (0.001MPa) conditions and maximum (6.1799e-10 MPa) is for maximum load (0.2MPa).

	0.001MPa	*0.01MPa*	*0.1MPa*	*0.2MPa*
Deformation (mm)	0.00873	0.0873	0.873	1.747
Strain	1.06e-5	0.000106	0.001067	0.002135
Stress (MPa)	3.3846	33.846	338.46	676.92
Buckling load multiplier	1.76e+5	17641	1764.1	882.06
Directional deformation (mm)	44.263	45.147	53.979	63.787
Shear stress (MPa)	4.288e-10	4.3739e-10	5.229e-10	6.1799e-10
Shear strain	17.305	17.651	21.104	24.94



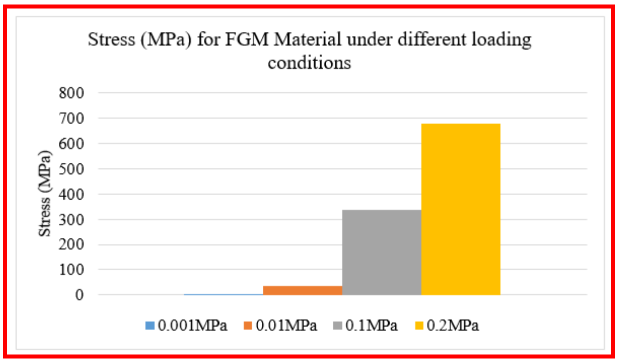
Graph.1: Deformation v/s Load

The above graph represents the deformation of FGM Plate under different loading conditions. If the load is increases on the object, then the deformation is gradually increases. Here, minimum deformation (0.00873mm) is for minimum loading (0.001MPa) conditions and maximum deformation (1.747mm) is for maximum load (0.2MPa).



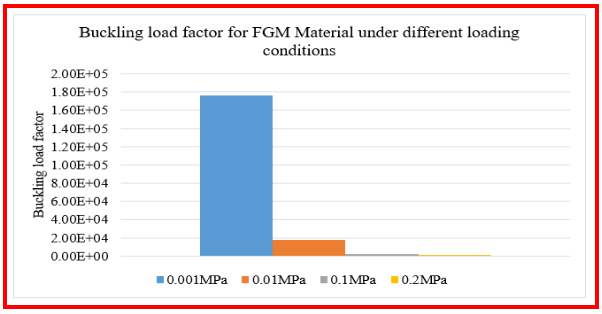
Graph.2: Strain v/s Load

The above graph represents the strain of FGM Plate under different loading conditions. If the load is increases on the object, then the strain is gradually increases. Here, minimum strain (1.06e-5) is for minimum loading (0.001MPa) conditions and maximum (0.002135) is for maximum load (0.2MPa).



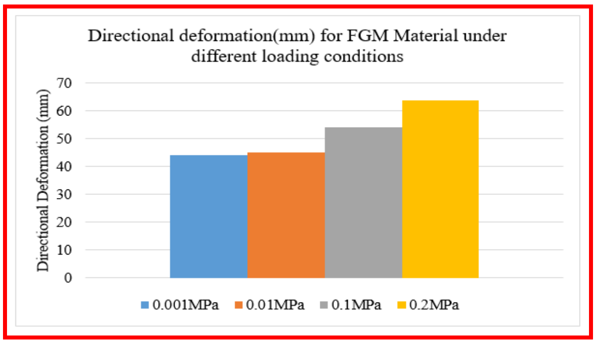
Graph.3: Stress v/s load

The above graph represents the stress of FGM Plate under different loading conditions. If the load is increases on the object, then the stress is gradually increases. Here, minimum stress (3.3846 MPa) is for minimum loading (0.001MPa) conditions and maximum (676.92 MPa) is for maximum load (0.2MPa).



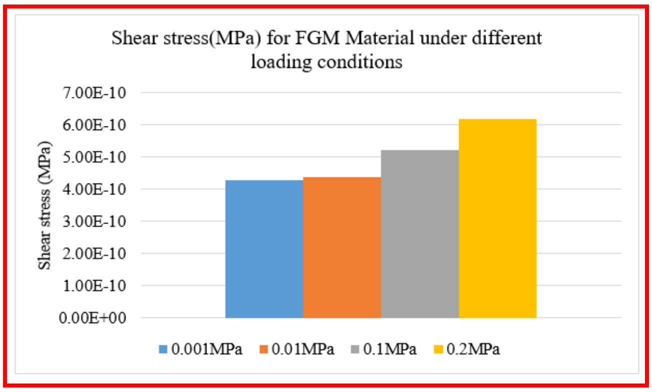
Graph.4: Buckling load factor

The above graph represents the buckling load factor of FGM Plate under different loading conditions. Here, minimum load factor (882.06) is for maximum loading (0.2MPa) conditions and maximum load factor (1.76e+5) is for minimum load (0.001MPa).



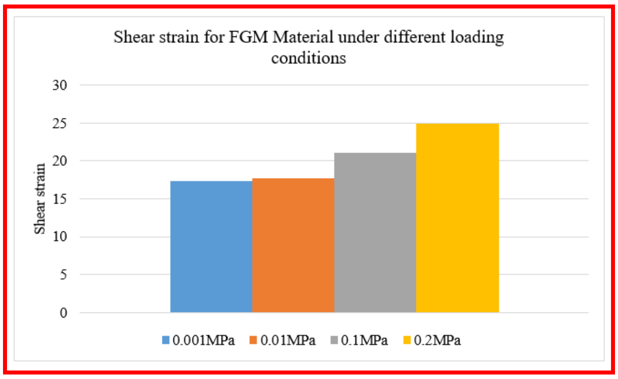
Graph.5: Directional deformation

The above graph represents the deformation of FGM Plate under different loading conditions. If the load is increases on the object, then the deformation is gradually increases. Here, minimum deformation (44.263 mm) is for minimum loading (0.001MPa) conditions and maximum deformation (63.787 mm) is for maximum load (0.2MPa).



Graph.6: Shear stress

The above graph represents the shear stress of FGM Plate under different loading conditions. If the load is increases on the object, then the stress is gradually increases. Here, minimum shear stress (4.288e-10 MPa) is for minimum loading (0.001MPa) conditions and maximum (6.1799e-10 MPa) is for maximum load (0.2MPa).



Graph.7: Shear strain

The above graph represents the shear strain of FGM Plate under different loading conditions. If the load is increases on the object, then the strain is gradually increases. Here, minimum strain (17.305) is for minimum loading (0.001MPa) conditions and maximum (24.94) is for maximum load (0.2MPa).

6.3 Comparison of simulation results with published results in the literature:

The validation revision is conducted to the following aspects buckling of types A & B FGM fgm plates. For mechanical buckling, the FGM plates are made from aluminum (Al) and ceramic are compared the results with ahar Hassaine Daouadji and Manoj Sharma.

The deformation is obtained 0.873mm in this present study, 0.858mm deformation is observed at ahar Hassaine Daouadji work which is represented in his research paper. In manoj sharma's work, the non-dimensional was plotted for various a/b ration which represents the range is 1E-4 to 1E-1 which is near results obtain in current work i.e., 1.06e-5 to 0.002135.

7. Conclusions

The deformation (0.00873mm) is very less at 0.001MPa and it is gradually increasing when the load is increased on the FGM plate.

The stress (3.3846MPa) which is very less when the load is 0.001MPa applied and it reaches 338.46 MPa at 0.1MPa load which is nearby elastic limit. If the load is extended, then this material is losing the elastic nature of the material. The shear stress and strain also very less to this kind of FGM plate which is observed in results table.

Linear Buckling (LBA) is a common Buckling Analysis. The buckling load factor of FGM Plate under different loading conditions. Here, minimum load factor (882.06) is for maximum loading (0.2MPa) conditions and maximum load factor (1.76e+5) is for minimum load (0.001MPa). In structural engineering, as the bowing of a column under compression or the wrinkling of a plate under shear.

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