FINITE ELEMENT ANALYSIS OF SINGLE DRY CLUTCH WITH FUNCTIONAL GRADED ALUMINUM MATRIX COMPOSITE AND SILICON CARBIDE REINFORCED

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ABSTRACT**:** *Functionally Graded Materials (FGMs) is a promising material in many structural applications due to their specific advantages over metallic materials and conventional composite materials. Functionally graded aluminum matrix composite (FGAMC) with silicon carbide has been used in the clutch as a friction material since it has an acceptable friction coefficient and high wear resistance. Clutches are designed to fit most of the current clutches in the market and studied under common working conditions of clutches in different applications. The FGM material is represented as layered solid parts, each layer with different properties, the properties are calculated using rule-of-mixture and power-law of Voight. The behavior of the FGAMC clutch plate is studied against natural vibration, forced vibration, and static analysis with Finite Element Method, by* ***ANSYS****. To evaluate the result, the FGAMC clutch is compared with two materials E-glass and Aluminum Matrix composite with 20% Silicon Carbide particles, the FGAMC also has Silicon carbide as the second material. Analysis reveals an increase in strain for the FGAMC over the traditional AMC. Adding to that a significant decrease in deformation at thickness direction and for stresses, in most analysis, it was the least. The drawbacks of the material are a rise in the mass resulting in low natural frequency, but the deformation is low. The obtained results combined with FE simulation will be used to exactly predict the properties grading function. The conclusion of the project will help for spreading the use of FGM in automobile engineering.*

Keywords: Functionally graded material, Aluminum matrix composite, Deformations, Stresses, and Strain.

1. INTRODUCTION:

Few decays ago iron and steel were the most prevailing material in the auto industry, but present work on eco-friendly and control unnecessary weight. Aluminum matrix composite is the most suitable material to resolve such types of problems [1]. MMC materials have advantages overcast iron because of superb properties like lower density, better resistance to correction, lower thermal expansion, higher thermal conductivity [2]. Clutch is one of the most important mechanical parts in many types of equipment just like automobiles with manual transmission systems, washing machines, and many rotating tools. Clutches are used to transmit power and motion. As it transmits the rotation movement from a driving shaft, connected to a power source (combust engine or motor) to a driven shaft. In automobiles, the clutch is designed to transmit the torque and motion from the flywheel connected to the engine, to the gearbox while maintaining the same velocity, but the main idea of it is to allow connection and disconnection between those two parts without the need of stopping the power source (engine). It transmits the motion in automobiles by friction contact, as the friction disc of the clutch will be pressurized by a spring (mostly diaphragm spring) towards the flywheel, the friction lining will connect to the flywheel and start to rotate with the flywheel, transmitting the motion and torque. Therefore, friction materials in clutches are been under focus in many types of research to develop new materials or studying using of existing ones to achieve the highest efficiency in transmission of power and motion, while maintaining long working life. The friction lining materials should have also beside high friction coefficient, withstanding high temperatures and wear resistance other essential properties such, developing friction force between the lining surface and flywheel, the ability to hold and transmit the load, keeping between surfaces pressure low as possible. Adding to that the material should be able to dissipate and withstand the heat generated from the friction [3]. Now-a- days attractive area of research for the researcher is to introduce advanced metal-matrix micro-and nano-composite (MMCs) which can improve their reliability, efficiency, lightweight also with the following properties. Not only high specific strength but also specific stiffness. Low thermal expansion and coefficient of friction. Not allowed low thermal conductivity [4]. Many materials have been used as friction lining in clutches. But the most common ones are E glass epoxy with a competitively low cost. The type of glass fiber is E-class which is famous for its high quality, it has high strength and even high chemical resistance, but the low modulus of elasticity and the high density is considered as a disadvantage because they result in weight increase [5]. AMCs have an excellent combination of properties e.g. lightweight, and high performance that's why AMCs have been used in automobile, aerospace defense, and many numerous fields [6]. Aluminum matrix composites (AMCs), especially Aluminum matrix composite enforced by silicon carbide, with high strength to weight ratio, (in this study Al+20% Sic will be used). AMCs reinforced by SiC have a lower coefficient of thermal expansion and higher elasticity modulus than the unenforced aluminum matrix alloy [7]. As the improvement in the reinforced cause of the Sic partials in the material resulting in higher hardness. Effect of SiC content on wearing behavior of the aluminum alloy. By changing the SiC particles in 10,15, and 25% and sliding speeds of 0.25, 1.72, 3.35, and 5.23 m/s for the same sliding distance of 5000m. so result showed that SiC content increase the wear rate and temperature decrease [8]. Artificial Functionally graded materials are only imitating the ones found in nature, such as bones and Mollusk shells. Mollusk shell, for instance, is made of one material calcium carbonate(caco3), and it is not considered as a structural material, but to withstand external stresses and hydraulic pressure (under deep water) the shells by combining different microstructure formed a graded structure that achieves uniform strength. And has flexible deformation ability in microstructures boundaries by making these areas softer [9]. Nevertheless, there are many types of functionally graded materials, all of which share the changing of materials from metal to ceramic mostly, and to simplify analysis the change is dependent on one direction. The property of the material changes in this direction, we can say the FGMs properties are different in different locations. This character is the reason which let to develop FGMs materials. A new sector of research is concentrating now on functionally graded metal matrix composites (FGMMCs). Essentially, producing metal matrix composites by means of functionally graded materials, to enhance the properties of materials to be used in components used in multifunction and various conditions with a multiphasic nature. FGM produces in many ways. They can be processed by powder stacking (by normal gravity, under pressure-induced flow, or under centrifugal forces), vapor depositing, centrifugal casting, or solid freeform fabrication [10]. Many pieces of research have been done in the usage of Aluminum matrix composites as friction material of the clutch. S.Dhanasekaran, S.Sunilraj, G.Ramya, and S.Ravishankar in their work [11], found that A356 aluminum alloy when reinforced by Sic and Al_2O_3particles and produced by stir casting, the tensile, hardness, and yield strength compared to alloy. An increase of 16% in tensile when 20% of Sic was reinforced and the yield increased 50%. 10% ofAl_2O_3 increased the tensile by 19% and the yield is nearly the same as of 20% Sic reinforced (50%). [12] studied the effects of different percentages and sizes of SiC particles, also investigated the effects of the different conditions in processing, their criteria of instigation were tensile, hardness, and wear rate. They found that the SiC particles in the outer part of the cast tubes reach their maximum and then gradually decreased towards the inner diameter. Large particles and high rotation speed increase the concentration of reinforced particles in the outer part. Hardness measurement revealing on FGMs outer zone has the highest hardness in all tests, compared to the inner zone. The smallest particles cases have the highest hardness in all tests. The increase of SiC weight results in a rise of hardness in the outer zone and tensile rises too. With up to 10% SiC the tensile strength increase linearly. [13] claimed that mechanical properties of surface and bulk can be attained when processing Aluminum matrix composite reinforced by 20% Sic particles processed as functionally graded material, by centrifugal casting. The outcome of this process resulted in a material which examined to evaluate it wear and friction properties by sliding it on a cast iron pin disk. Comparing to the homogenous Aluminum matrix composite, the new material has a lower friction coefficient (from .60 for the homogenous AMC to .50 for the FGAMC). Also a less wear coefficient for the functionally graded matrix composite (10-6 mm3N-1M-1) meaning higher wear resistance. Friction and wear properties of aluminum Matrix composites are based on the effect of the reinforced particles works as load-bearing elements in addition to the formation of protective attached iron-rich trilayers, refiled by the characterization of worn surfaces. Here we compare the wearing behavior of (Al MMC) with conventional grey cast iron under identical conditions. The Al MMC was fabricated by A356 aluminum alloy and 25% silicon carbide, both have been tested at various sliding velocities, loads, and sliding distances. Al MMC has a 25% friction coefficient more than cast iron. The effect of aluminum oxide and silicate oxide in the presence of 8%pumice is an increment of 11.08-28.39% on hardness and tensile strength [14]. In this research work different friction materials (E-glass epoxy, Aluminum Matrix composite (20% Sic reinforced and Functionally graded Aluminum matric composite (with Sic)) is tested as a friction lining of single clutch plate working in usual automobiles conditions. To give a comparison result of the possibility of using FGAMCs in friction clutches.

2. DESIGNING THE FRICTION PLATE:

There are many aspects to be considered while designing the plate including but not limited; clutch moving parts, to have minimum inertia load, should have low weight as possible. The clutch must not be in need of external force to maintain the connection of the friction surface. Adding to that is the capability of discharge heat from contacted surfaces [15].

There are two cases to be considered one of them in the design. When uniform pressure is found and when uniform axial wear is found. In this piece of work, the latter will be considered, as it is the actual condition that the plate work at for the longest time of plate life. The uniform pressure is found only for a very small time when the plate is new and changes to uniform axial wear after wear starts in the lining.

$T \equiv\ transmitted\ torque\ F_a$

$\equiv$ Force axially acting on the

friction surface

$p \equiv\ axial\ pressure\ holding\ surfaces\ in\ contact$

$Ri, Ro \equiv\ the\ inner\ and\ outer\ radius.$

$R \equiv the\ main\ radius\ of\ the\ fractioning\ face$

$\mu_L \equiv\ friction\ coefficient\ of\ the\ lining\ material$

Considering the clutch plate as a ring. In uniform wear the design is done based on the following equations:

Force axially acting on the friction surface(F_a):

$$F_a = Pressure\ *\ Area$$

$$F = p * \pi * [R_o^2 - R_i^2]$$

Total Friction torque acting on the friction surface(T):

$$T = n * \mu_L * F * R$$

$$R = (R_o + Ri)/2$$

And $n =$ $number\ of\ acting\ surfaces$ ($2\ surfaces\ in\ most\ single-clutch\ plates,\ and\ is\ considered\ in\ this\ case$).

2.1. DESIGN SPECIFICATIONS:

Many medium-weight and heavy vehicles and equipment have clutch plates with outer diameters of $300mm$ [16].

Therefore, the outer diameter in this study will be taken as $300\,mm$, while the inner diameter will be fixed at $150\,mm$. Frictional material thickness is taken as 4 mm for each side as most commercial clutches.

To find the pressure needed on the clutch plate, most vehicles the engines run at $1250\,r.p.m$, as initial speed. And the engine output power is assumed $110\ KW$. The torque will be:

$$T = \frac{60 * 110 * 10^3}{2 * \pi * 1250} = 840.34\ N - m$$
$$= 840.34\ *\ 10^3 N - mm.$$

To calculate the needed pressure on the clutch plate for the different materials

$$T = n * \mu_L * W * R$$
$$R = (R_o + Ri)/2 = \ 112.5\ mm$$
$$F_a = Pressure\ *\ Area$$
$$F_a = p * \pi * [R_o^2 - R_i^2]$$

Then:

$$F_a = \frac{T}{n * \mu_L * R}$$
$$p = T/(n * \mu_L * Area * R)$$

For E-glass epoxy, the pressure should be (friction coefficient taken on normal load 50N, it ranges from .42 to .5 [17]. The later will be considered in this study:

$$\mu_L = .5$$

$$\therefore F_a = 7470N$$

$$\therefore\ p = .141 N/mm^2$$

For Aluminum matrix composites 20% Sic reinforced [18]:

$$\mu_L = .6$$

$$\therefore F_a = 6224.7N$$

$$\therefore\ p = .117 N/mm^2$$

For the functionally graded aluminum matrix composite:

$$\mu_L = .54\ [as\ the\ average\ of\ the\ total\ material]$$

$$\therefore F_a = 6916.4$$

$$\therefore\ p = .131\ N/mm^2$$

It can be seen that the new material has average working pressure more than the traditional AMC by 10.7% and lower than E-glass by 20.5%.

3. MODELING:

E-GLASS EPOXY AND ALUMINUM MATRIX COMPOSITE 20% SIC REINFORCED:

The clutch plate is designed and represented by 3D geometry with ***SolidWorks*** software contains three parts. Two friction lining sides and a structural support disc. With 4 mm as lining thickness for each side (8.5 mm in total thickness). Figure 1 shows the 3D model of the clutch plate. To carry the analysis on the clutch plate, firstly the analysis method used is the Finite Element Method, which is a numerical method rely on dividing the structure into small elements connected by nodes and analyses those elements, and then reassembly them to give a reaction of the complete structure based on the reactions of each element in the nodes. To perform this analysis by this method ***ANSYS 2020R2*** is used.

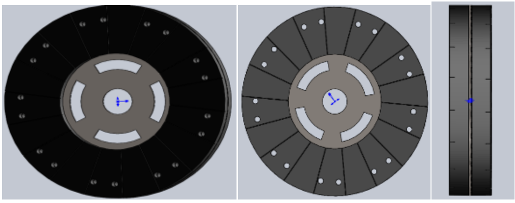


Figure (1) the Developed 3D Model in SolidWorks

The representation geometry is imported from ***SolidWorks*** to the ***ANSYS***. In all models, elements sizes are settled at 2 mm for each. Achieve 122171 elements connected by 322237 nodes for the E-glass Epoxy and Aluminum Matrix Composite 20% Sic reinforced. Figure (2) shows the clutch plate meshed in ***ANSYS***.

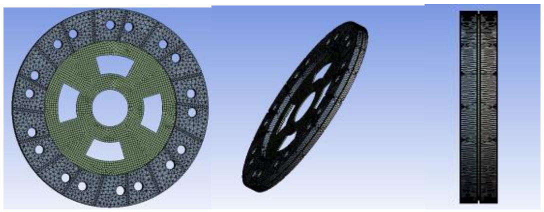


Figure (2) meshed clutch plate for E-glass Epoxy and Al-Sic.

3.1 FUNCTIONALLY GRADED ALUMINUM MATRIX COMPOSITE:

As FGMs mechanical properties change in a certain direction. Normal one solid part may not be sufficient to represent and modeling them. There are several methods to predict the behavior of FGMs and to model, the simplest one, and used here, is the linear rule of mixture method (Voight estimate) for two materials [19].

$$\beta_{fgm} = V_{material1} * \beta_{material1} + V_{material2} * \beta_{material2}$$

Where $\beta$is the property of the material and V the volume fracture of the material in the new FGM.

$$V_{material1} + V_{material2} *= 1$$

To determine the properties of the new FGM It is assumed that its properties change with respect to only one direction. Therefore, we can consider the property is a function in location (x) (Rehman et al, 2012):

$$\beta_{fgm} = \beta_{fgm}(x)$$

And this function can be solved with power-low assumptions based on the Voight model to get:

$$\beta_{fgm}(x) = [1 - V_{material2}(x)] * \beta_{material1} + V_{material2}(x) * \beta_{material2}$$

where $V_{material2}(x)$ refers to the volume fraction of the material 2 and is changing in power form:

$$V_{material2}(x) = (\frac{x}{L})^{\kappa}$$

where L is the length of graded direction, and κ is the given graded parameter (in this study assumed by $\kappa = 1\ which\ means\ the\ change\ linearly$), substituting the previous two equations we can get:

$$\beta_{fgm}(x) = \left[1 - (\frac{x}{L})^{\kappa}\right] * \beta_{material1} + (\frac{x}{L})^{\kappa} * \beta_{material2}$$

And this is the equation used in modeling the FGAMC.

The FGAMC consider is changing in the thickness direction. One of the methods of modeling FGMs is representing them as small layers forming together one complete part, each layer with different proportions of the materials forming the FGMs. To get as much as accurate results, each side of the friction lining was divided into 16 layers, by step thickness .25 mm. the two materials used to produce the FGAMC properties are in the following table.

Table (1) showing the two materials' properties

Material 1			Material 2	
Aluminum alloy Properties			Sic Silicon Carbide, SiC Ceramic Properties	
Density	2770	kg/m3	3100	kg/m3
thermal Expansion	2.30E-05	1/c	4.00E-05	1/c
young modulus	7.10E+10	pa	4.10E+11	Pa
Poisson's ratio	0.33	-	0.14	-
Bulk Modulus	6.96E+10	pa	2.20E+11	Pa
Shear Modulus	2.67E+10	pa	4.15E+10	Pa
Tensile yield strength	2.80E+08	pa	9.33E+08	Pa
compression yield strength	2.80E+08	pa	3.90E+09	Pa
Specific heat	923.5	j/kgc	750	J/Kg•°K
Hardness(Vickers)	799000000	pa	27458620000	Pa
Friction Coefficient against Steel[11,10]	.47		.6	
Fracture Toughness	28500000	Pa/m^0.5	67000000	Pa/m^0.5
Conductivity	160	W/m•°K	120	W/m•°K

By applying the above method, the new material has different properties in the different 16 layers, table (3) shows the properties in the 16 layers. In ***SolidWorks*** to represent the New material, the 3D model was established with 16 parts to form each side and with the structural support disc. The 3D model is imported to ***ANYSY*** to carry out analyses. It also meshes with a 2 mm element in size. Also, here the model has 3 parts, one for the support disc and 2 for the two-side friction material including 32 solid bodies, 16 layers for each. The number of elements is 649564 attached in 2401471 nodes. The figure below shows the model of the new material and after meshed.

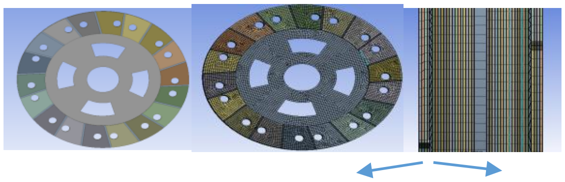


Figure (3) meshed clutch plate for FGAMCs with a gradual change in the thickness direction.

4. Vibration Analyses:

The first and most important property difference is in the mass of the clutch plate. The plate made of E-glass is lower by 26.5% (equivalent to 1.0783 Kg) than FGAMCs, which is highest with 1.4676 kg. for the AMC is lower by 5.7% than the FGAMC plate with.

4.1 Free Vibration analyses:

The 3 models are studied under free vibration conditions with fixed support implemented in the center of the clutch plate. Results are shown below.

From the three tables, it can be seen that the FGAMC has a lower first natural frequency than the others, but for the important natural frequency range, where the deformation is in the Y Direction, the FGAMC has a lower natural frequency,23.74 Hz, with a deformation less in magnitude than the AMC by 2.6%, while the AMC is 27.153mm at 24.38. E-glass is having the highest first natural frequency with the highest deformation by 13.6% than FGAMC at 27.59 Hz. The same thing happens in the second natural frequency. The figure below shows the deformation at different natural frequencies. Figure (5) shows the modal shapes which are identical to the three models in appearance.

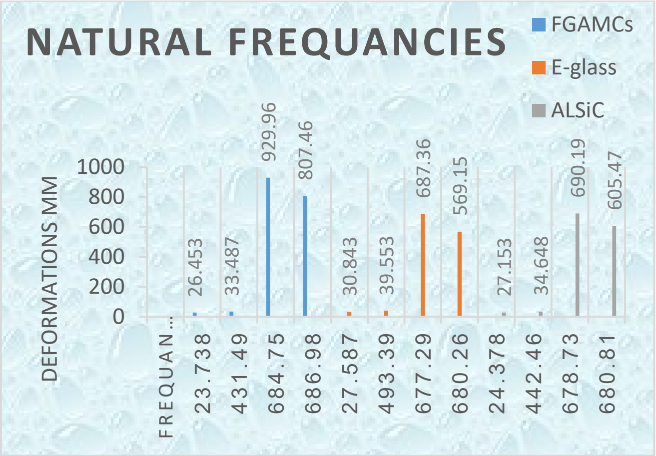


Figure (4) Deformations at different frequencies for the 3 Models.

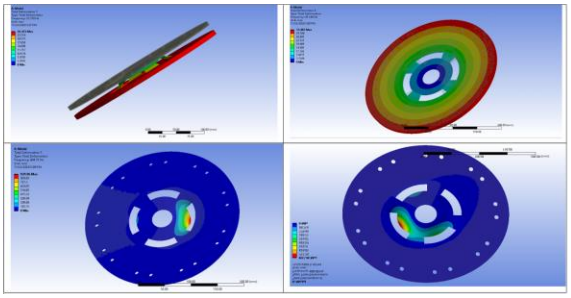


Figure (5) Modal Shapes of First 4 Natural Frequencies.

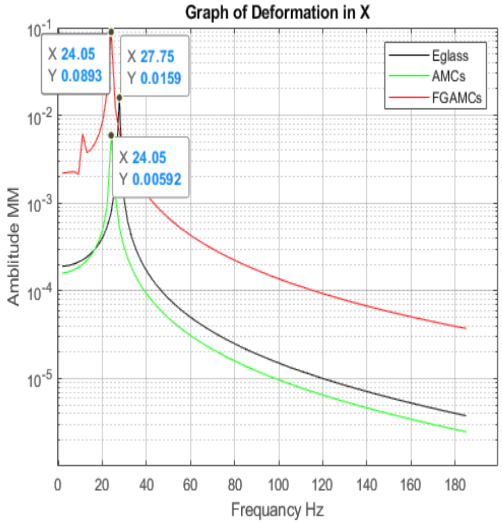


Figure (6) Deformation in X Direction

4.2 Forced Vibration Analysis:

The analysis is conducted under the condition of the clutch plate is under working pressure for each material type, which is calculated in the Design step, $.141 N/mm^2$ for Clutch made of E-glass, $.117 N/mm^2$ for aluminum matrix composites with 20% Silicon Carbide particles, and lastly $.131 N/mm^2$ for the functionally Graded Aluminum matrix composite with Silicon Carbide. The graphs below show the result of the analysis while the range of frequencies is from 0 to 180 Hz (equivalent to 0 r.pm. to 11000 r.pm) as it is the common vibration range developed by automobiles and other equipment engines.

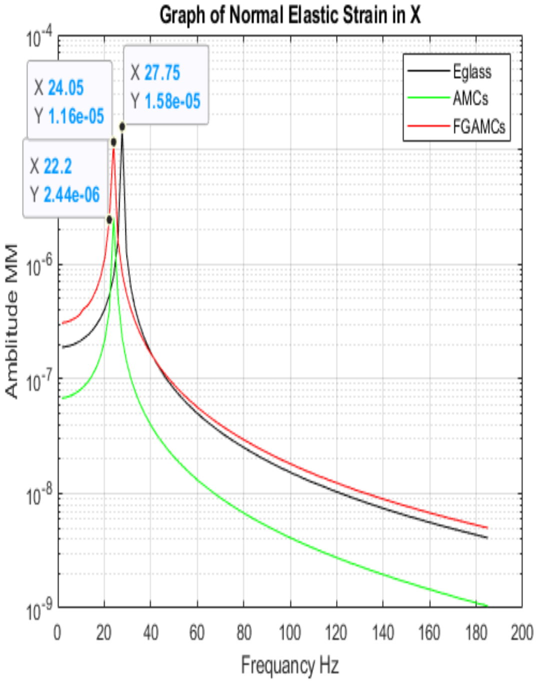


Figure (7) Normal Elastic Strain in X Direction

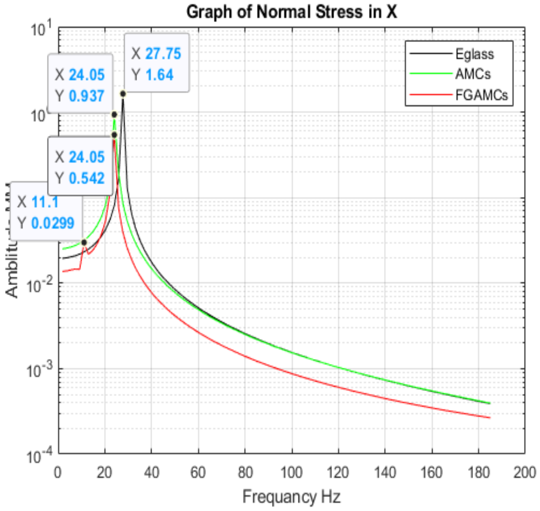


Figure (8) Normal Stress in X Direction

In X direction the deformation of the FGAMC is the highest by 93.4 and 82.2 % than AMC and E-glass at peaks respectively. While in the same direction the strain is higher than the AMC by 79% and less than E-glass plates with 60% at peaks. In terms of stresses in X direction, the FGAMC is the lowest, it is from AMC and E-glass by 72.9% and 202.6% respectively

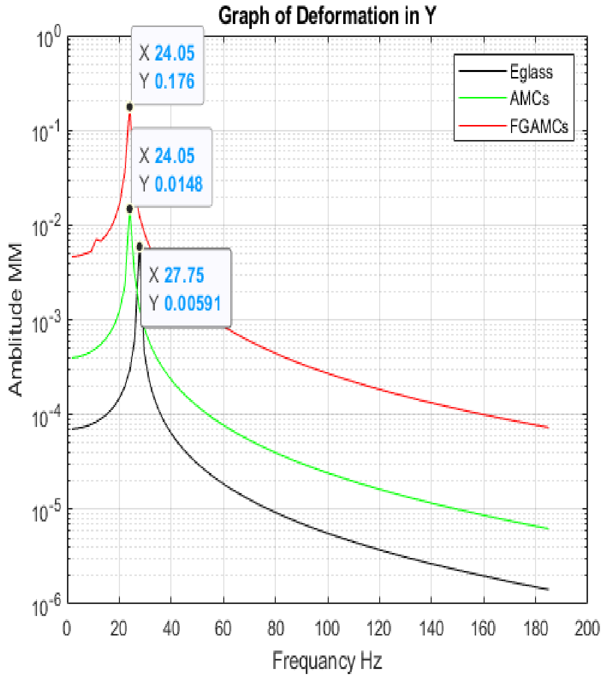


Figure (9) Deformation in Y Direction

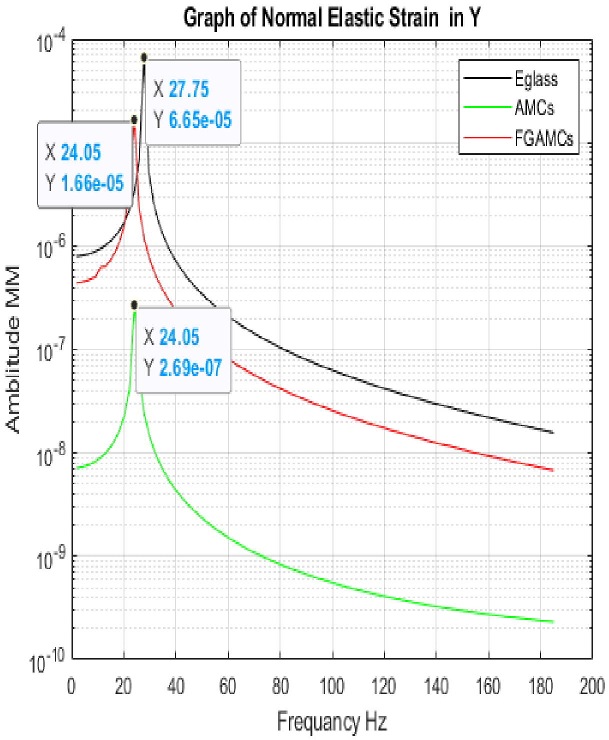


Figure (10) Normal Elastic Strain in Y Direction

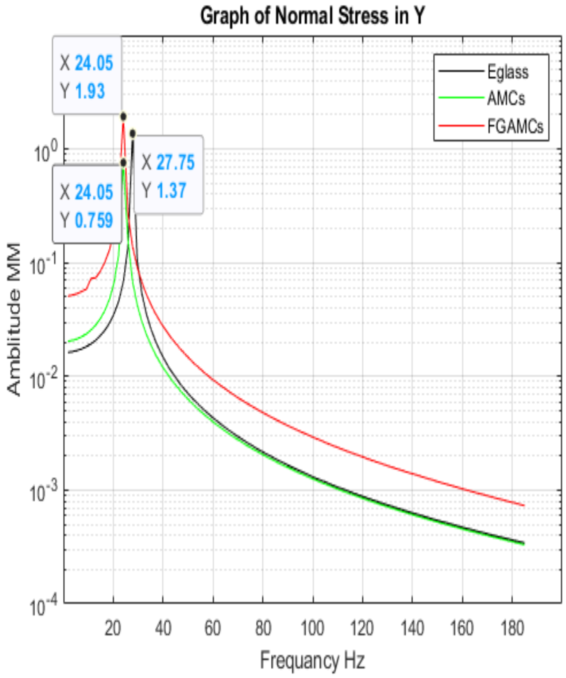


Figure (11) Normal Stresses in Y Direction

In Y direction the deformation of the FGAMC clutch plate is the highest, 91.5% higher than AMC and 96.5% than E-glass. Regarding strain, is between the AMC and E-glass plates. But for stresses, FGAMC is having the highest stresses and AMC is the lowest by 60.7% lower than FGAMC and E-glass is lower by 29%.

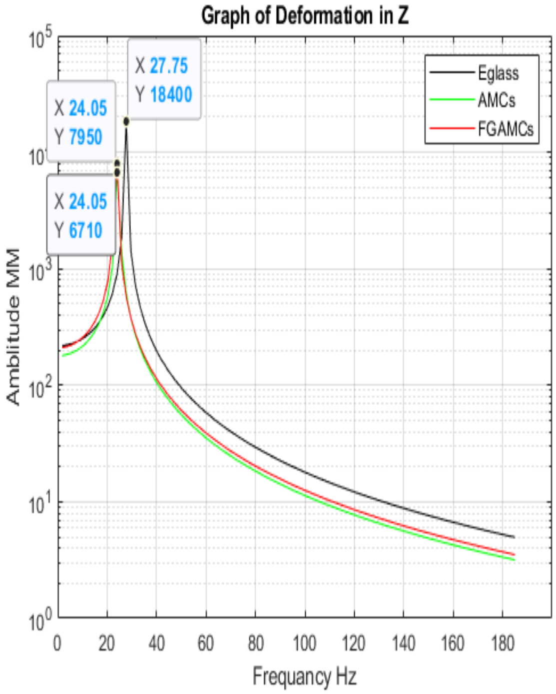


Figure (12) Deformation in Z Direction

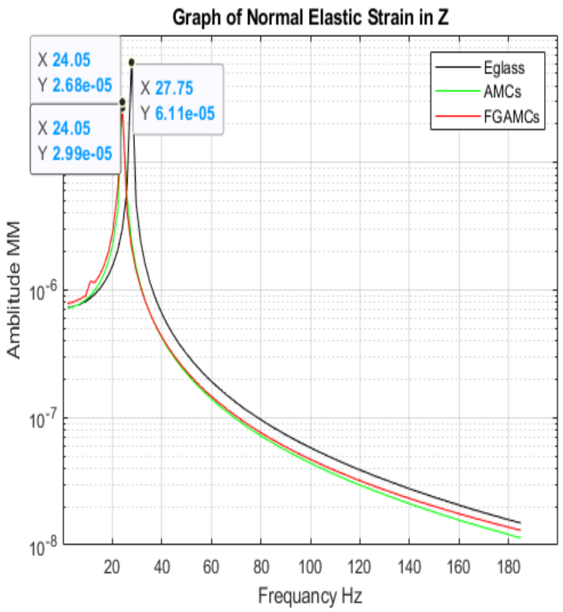


Figure (13) Normal Elastic Strain in Z Direction

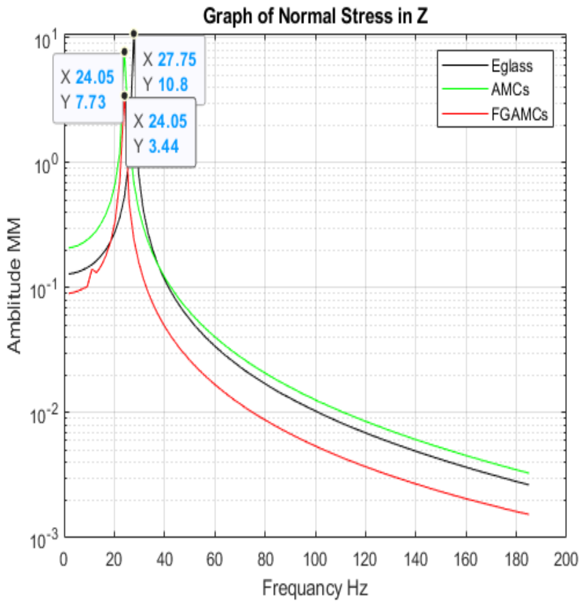


Figure (14) Normal Stresses in Z Direction

In Z direction, which is the direction of applied pressure, FGAMC has nearly identical curves to the AMC in deformation and strain, but for stress, the FGAMC is the lowest. As AMC and E-glass stress equals approximately 2 times and 3 times respectively the stress of FGAMC.

5. STATIC ANALYSIS:

The clutch plate was studied against the pressure when the flywheel is revolving with 1250 $R.P.M$. and the pressure is assigned for each material as in the Design part. The graphs show the different deformations of all of the plates with different assigned materials.

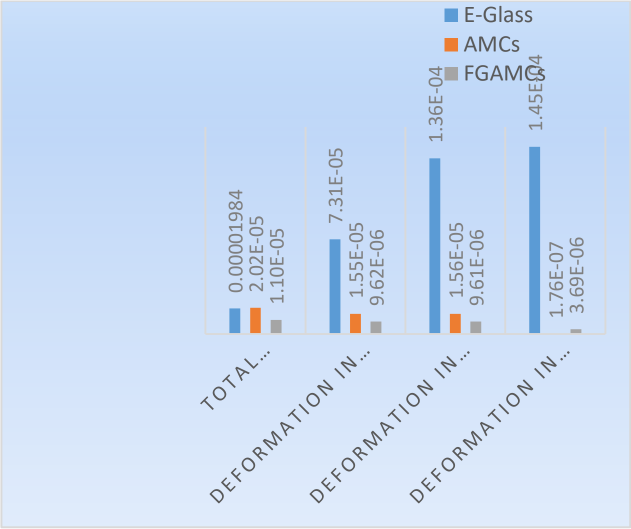


Figure (15) shows deformations under static analysis

The first bar chart shows the total deformation and the deformation at X, Y, and Z directions respectively. FGAMC has the lowest deformations except in the Z direction, where AMC is the lowest. In total deformation, FGAMC is lower by 45% and 44% from AMC and E-glass respectively. In X-direction, FGAMC is lower by 38% than AMC and even lower by 86.7% from the E-glass. In the Y direction, it is the same scenario lower by 38.4% and 93% from AMC and E-glass. In Z-direction AMC is the lowest, nearly 95% from the FGAMC. E-glass is higher than FGAMC with 97.5%.

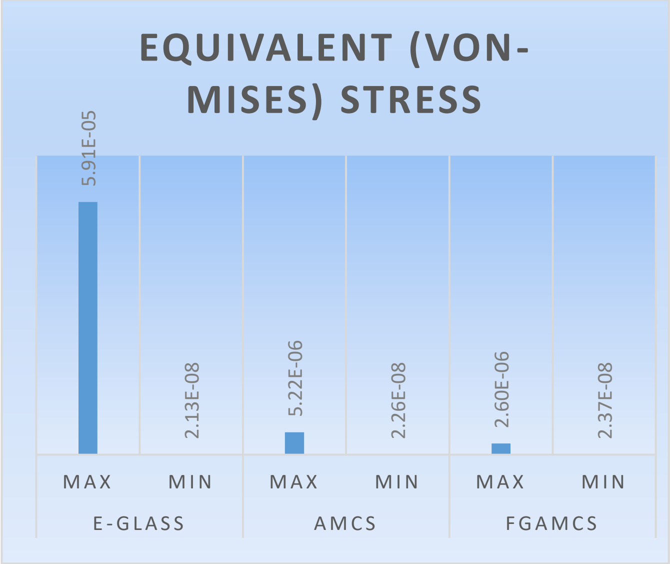


Figure (16) shows stresses under static analysis

The second bar chart shows the equivalent stresses maximum and minimum on each model, and the FGAMCs plate is having the lowest value of stress. For the maximum stresses, it is nearly half of the traditional AMC (50% less than AMC). While it is 95 times E-glass.

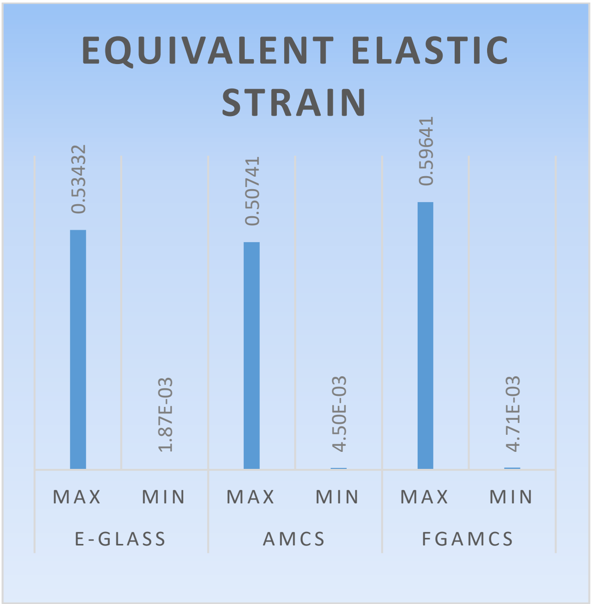


Figure (17) shows strains under static analysis

For strain, the FGAMCs clutch has the highest strain among the three models. The FGAMC is higher in strain the AMC by 17.6% while its higher than the E-glass with 11.6%.

Table (2) Shows the deformations, strain, stress of the FGAMC Model

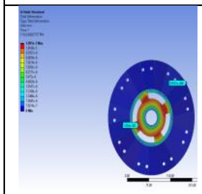
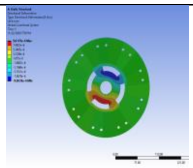
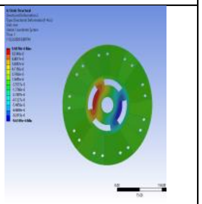
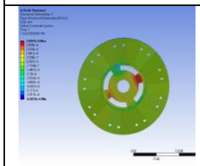
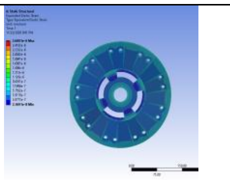
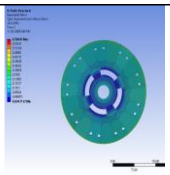
Total Deformation	Deformation in X	Deformation in Y
		
Deformation in Z	Equivalent (Von-Mises) Stress	Equivalent Elastic Strain
		

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Table (3) shows the properties of the different layers.

FGM\Layers	X/L	Density	young modulus	Poisson's ratio	bulk Modulus	Shear Modulus	tensile yield strength	compression yield strength	Hardness(Vickers)	Elongations	Friction Coefficient
0	0	2770	7.1E+10	0.33	6.96E+10	2.67E+10	280000000	2.8E+08	1.18E+08	0.5	0.47
1	0.0625	2790.625	9.2188E+10	0.31813	7.90E+10	2.76E+10	320781250	5.06E+08	1.83E+09	0.4688	0.478125
2	0.125	2811.25	1.1338E+11	0.30625	8.84E+10	2.85E+10	361562500	7.33E+08	3.54E+09	0.4375	0.48625
3	0.1875	2831.875	1.3456E+11	0.29438	9.78E+10	2.95E+10	402343750	9.59E+08	5.24E+09	0.4063	0.494375
4	0.25	2852.5	1.5575E+11	0.2825	1.07E+11	3.04E+10	443125000	1.19E+09	6.95E+09	0.375	0.5025
5	0.3125	2873.125	1.7694E+11	0.27063	1.17E+11	3.13E+10	483906250	1.41E+09	8.66E+09	0.3438	0.510625
6	0.375	2893.75	1.9813E+11	0.25875	1.26E+11	3.22E+10	524687500	1.64E+09	1.04E+10	0.3125	0.51875
7	0.4375	2914.375	2.1931E+11	0.24688	1.35E+11	3.32E+10	565468750	1.86E+09	1.21E+10	0.2813	0.526875
8	0.5	2935	2.405E+11	0.235	1.45E+11	3.41E+10	606250000	2.09E+09	1.38E+10	0.25	0.535
9	0.5625	2955.625	2.6169E+11	0.22313	1.54E+11	3.50E+10	647031250	2.32E+09	1.55E+10	0.2188	0.543125
10	0.625	2976.25	2.8288E+11	0.21125	1.64E+11	3.59E+10	687812500	2.54E+09	1.72E+10	0.1875	0.55125
11	0.6875	2996.875	3.0406E+11	0.19938	1.73E+11	3.69E+10	728593750	2.77E+09	1.89E+10	0.1563	0.559375
12	0.75	3017.5	3.2525E+11	0.1875	1.82E+11	3.78E+10	769375000	3E+09	2.06E+10	0.125	0.5675
13	0.8125	3038.125	3.4644E+11	0.17563	1.92E+11	3.87E+10	810156250	3.22E+09	2.23E+10	0.0938	0.575625
14	0.875	3058.75	3.6763E+11	0.16375	2.01E+11	3.96E+10	850937500	3.45E+09	2.4E+10	0.0625	0.58375
15	0.9375	3079.375	3.8881E+11	0.15188	2.11E+11	4.06E+10	891718750	3.67E+09	2.57E+10	0.0313	0.591875
16	1	3100	4.1E+11	0.14	2.20E+11	4.15E+10	932500000	3.9E+09	2.75E+10	0	0.6

6. RESULTS:

The functionally graded aluminum matrix composite has 5.7% and 26% more mass, with 200 g and 500 g more mass than AMC and the E-glass respectively. The first natural frequency for the FGAMC is 24.4 nearly the same as AMC and lower than the E-glass frequency by 3 Hz but with the lowest deformation of the three models less by 2.6% from AMC and 13.6% from E-glass. In forced vibration analysis, the working pressure of the FGAMC is ($.131 N/mm^2$)which is between the working pressure of the AMC ($.117\ N/mm^2$) and E-glass ($.141 N/mm^2$). In forced vibration analysis, the total deformations in X and Y for FGAMC are the highest but in Z are the lowest, which is the direction of applied pressure and the stresses in Z and X are the lowest for FGAMC in Y are the highest but not too far from the other two materials. In terms of strain, the FGAMC keeps values in the middle between AMC and the E-glass, as higher than AMC. In Static analysis, deformations and stresses values

FGAMC has the minimum one, lowery more than 40%. and from the strain point of view, it has the highest value by more than 11% from other materials.

7. DISCUSSION AND RECOMMENDATIONS:

As the result shows using FGAMC as a frictional lining has benefits as in thickness direction deformations is less than the other two materials. Also, there is an increase in the weight comparing to AMC but lower deformations are achieved. The strain of the functionally graded aluminum matrix composite increased and in certain situations it is near to E-glass material, giving it higher strength than its successor AMC. Stresses in most of the tests of the FGAMC is the lowest in term of magnitude, and with the anticipated higher wear resistance the developed clutch plate will have a longer lifetime. The future work of this study is to conduct dynamic analysis of the model and carry out optimum design research to mitigate the negatives founds, weight mostly. In addition, experimental studies can be done and compared to the theoretical results. Experimental tests can be done to examine the material wear behavior. It will be an important part to study the thermal behavior of the FGAMCs clutch plate and compare it to the other materials. Finally, it is recommended to study the model when the change in the material happens radial direction.

8. CONFLICT OF INTEREST:

‘Declarations of interest: none’

I have no financial and personal relationship with other people or organizations that could unprofessional influence my work

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