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Stress Analysis of Functionally Graded Disc Brake Subjected To Mechanical Loading

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ABSTRACT: *In this thesis, analytical investigation is to be done for functionally graded disc brake subjected to internal pressure. Different models of the disc brake are considered i.e. disc brake with 40, 50 and 60 holes. In this thesis, comparison is to be done by varying materials for disc brake, the materials are Cast Iron, FGM 1(Al_2O_3-Al) and FGM 2 (Zr-Al). FGM's are considered for material variation profile through the thickness for k =2, k =4 and k =6 .Theoretical calculations are done to calculate the material properties for each layer up to 10 layers for FGM's. Structural analysis and thermal analysis are done on the three models by varying materials. 3D modeling is to be done in Pro/Engineer and analysis is to be done in Ansys 14.5.*

Keywords: *Disc brake, Functionally graded material, Material variation Parameter.*

I. INTRODUCTION

Today technology is in need for speed, but at the same time, we need safety as well. For safety, we need deceleration to the maximum extent. These two things are moreover contradictory factors. For speed, we need engines of maximum efficiency and for keeping this speed in bounds, we need brakes of latest technology. For coping up with today's speed, new materials are introduced in the manufacture of disc brakes.

The disc brake is a device for slowing or stopping the rotation of a wheel while it is in motion. A disc brake is usually made of cast iron or ceramic composites (including carbon, Kevlar and silica). This is connected to the wheel and/or the axle.

Functionally graded structures are those in which the volume fractions of two or more materials are varied continuously as a function of position along certain dimension(s) of the structure to achieve a required function. Functionally graded materials are composite materials, which are microscopically in homogeneous, and the mechanical properties vary smoothly or continuously from one surface to the other. It is this continuous change that results in gradient properties in functionally graded materials.

Functionally graded materials are made from mixture of metals and ceramics or a combination of different metals. Unlike fiber-matrix composites, which have a strong mismatch of mechanical properties across the interface of two discrete materials, bonded together and may result in de-bonding at high temperatures.

Functionally graded materials have the advantage of being able to survive environment with high temperature gradient, while maintaining their structural integrity .The ceramic materials provides high temperature resistance due to its low thermal conductivity, while the ductile metal component prevents fracture due to thermal stresses.

The material property P is varied through the plate thickness in FGMs according to the expressions, (Power law)

$$P(z) = (P_t - P_b)\,V + P_b$$

$$\text{Where } V = \left(\frac{z}{h} + \frac{1}{2}\right)^k$$

Here P_t and P_b denote the property of the top and bottom faces of the plate, respectively, and k is a parameter that dictates the material variation profile through the thickness. Here it is assume that module E and G, density ρ, thermal coefficient of expansion α, and the thermal conductivity K vary according to the above equation.

Model calculation:
1) Young's Modulus:
Material properties for FGM 1 (Al_2O_3-Al):
Top material: Alumina, Al_2O_3 (E=380000 MPa)
Bottom material: Aluminium,Al (E=70000 MPa)
1) **For k = 2; z = 1**

$$E(z) = (E_t - E_b)\left(\frac{z}{h} + \frac{1}{2}\right)^k + E_b$$

$$= (380000 - 70000)\left(\frac{1}{10} + \frac{1}{2}\right)^2 + 70000$$

$$= (310000)(0.36) + 70000$$

$$= 181600 \text{ N/mm}^2$$

Above same procedure is repeated inorder to get different material properties for both FGM 1 (Al_2O_3-Al) and FGM 2(Zr-Al) at different layers.

Table 1.1: Material Input Values of FGM 1 (Al_2O_3-Al) For k = 2

Z	Young's modulus E (N/mm^2)	Density (Kg/mm^3)
+5	380000	3.96×10^{-6}
+4	321100	3.7206×10^{-6}
+3	268400	3.5064×10^{-6}
+2	221900	3.3174×10^{-6}
+1	181600	3.1536×10^{-6}
-1	119600	2.9016×10^{-6}
-2	97900	2.8134×10^{-6}
-3	82400	2.7504×10^{-6}
-4	73100	2.7126×10^{-6}
-5	70000	2.7×10^{-6}

II. DESIGN AND MODEING

Structural analysis for cast iron:
Element Type: Solid 20 node 95
Material Properties:
Young's Modulus: 103000N/mm^2
Poisson's Ratio: 0.3
Density: 0.0000071 kg/mm^3

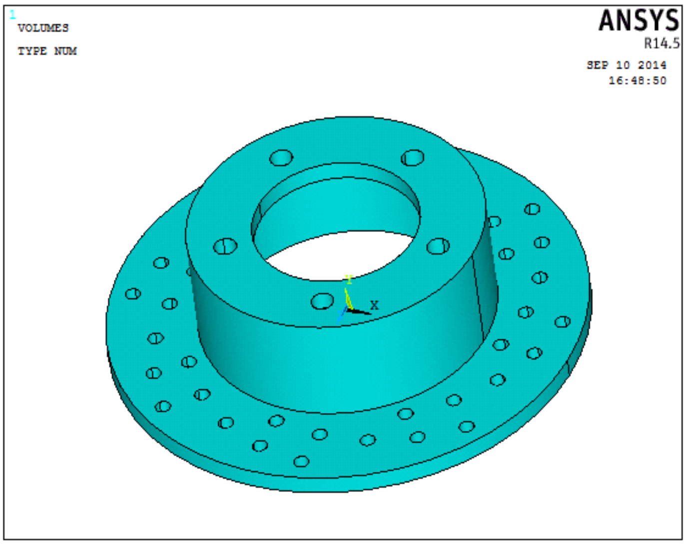

Fig 2.1 shows imported model from pro-e

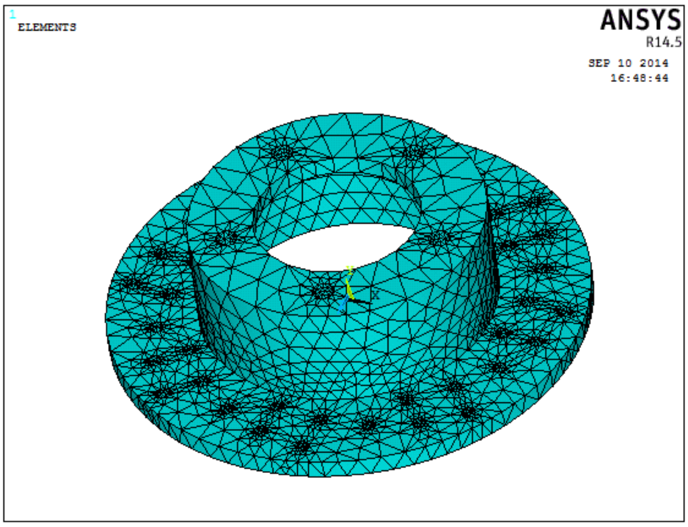

Fig 2.2 shows Meshed model of cast iron with 40 holes

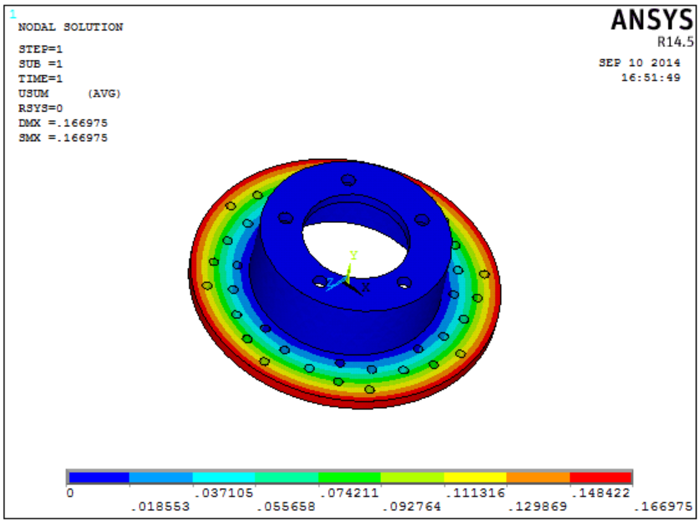

Fig 2.3 shows displacement vector sum

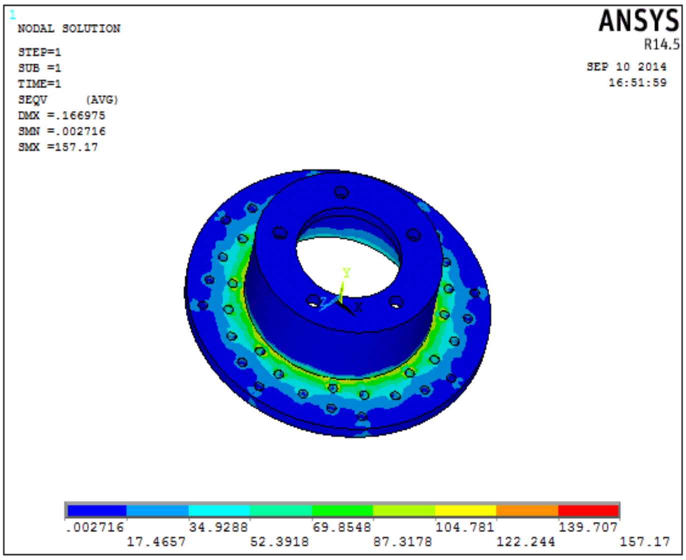

Fig 2.4 shows Von misses stress

Analysis of FGM 1 (Al_2O_3-Al) Disk Brake with 40 holes:

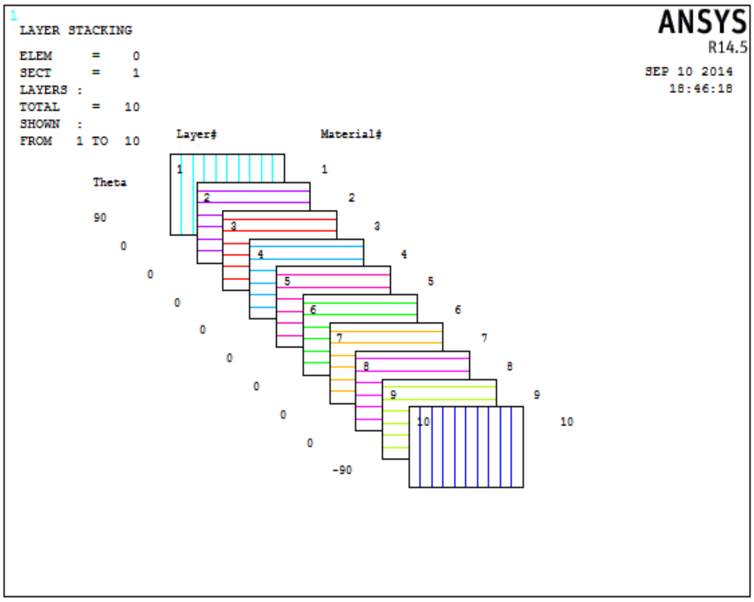

Fig 2.5 shows Layer Stacking method for FGM 1 (Al_2O_3-Al)

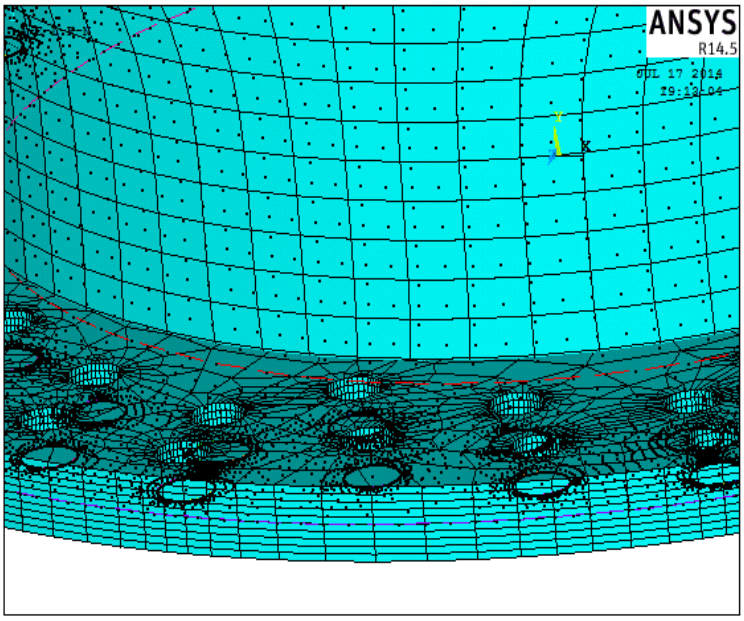

Fig 2.6 shows the layers of the FGM

STRUCTURAL ANALYSIS:

Table 2.1: Analytical results for Cast Iron Disc Brake

No of Holes	Displacement (mm)	Stress (N/mm^2)	Strain
40	0.521	157.17	0.675×10^{-3}
50	0.75	174.56	0.845×10^{-3}
60	0.88	182.56	0.902×10^{-3}

Table 2.2: Analysis results of FGM 1 (Al_2O_3-Al) For Material Variation Parameter k = 2

Number of Holes	Displacement (mm)	Stress (N/mm^2)	Strain
40	0.415	125.16	0.39×10^{-3}
50	0.734	162.24	0.83×10^{-3}
60	0.765	169.76	0.89×10^{-3}

Table 2.3: Analysis results of FGM 2(Zr-Al) For Material Variation Parameter k = 2

Number of Holes	Displacement (mm)	Stress (N/mm^2)	Strain
40	0.104	119.81	0.0010
50	0.111	121.33	0.0011
60	0.13	125.56	0.0015

THERMAL ANALYSIS:

Table 2.4: Thermal analysis results for Cast Iron Disc Brake

Number of holes	Thermal gradient	Thermal flux(W/m^2)
40	81.8071	9.2442
50	81.912	9.256
60	87.771	9.918

Table 2.5 :Thermal analysis of FGM 1(Al_2O_3-Al) for k = 2

Number of holes	Thermal gradient	Thermal flux(W/m^2)
40	10.526	0.315
50	11.617	0.3485
60	27.558	0.468

Table 2.6: Thermal analysis of FGM 2 (Zr-Al) for k=2

Number of holes	Thermal gradient	Thermal flux(W/m^2)
40	23.885	0.40
50	24.590	0.41
60	24.787	0.743

III. RESULTS AND DISCUSSIONS

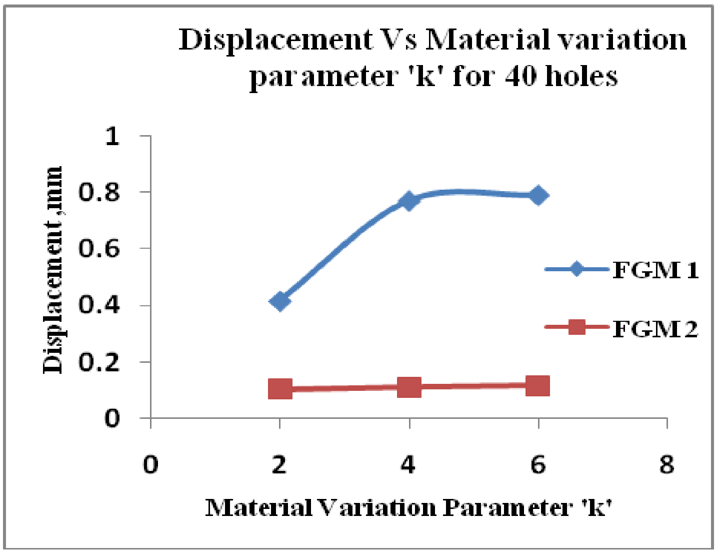

Fig 3.1: Displacement Vs material variation parameter ‘k’ for 40 holes

- Fig 3.1 shows the variation of displacement with respect to material variation parameter 'k' for FGM 1 (Al_2O_3-Al) and FGM 2 (Zr-Al) with number of holes 40 for disc brake.
- It can be observed with increase in material variation parameter 'k', displacement increases largely for FGM 1 and nominally for FGM 2.
- As material variation parameter 'k' increases, the volume fraction of ceramic decreases leading to an increase in the volume fraction of metal. So the material brittleness decreases leading to an increase in the deflection.
- FGM's attain full metallic property with variation of 'k' from zero to infinity. Minimum to maximum k variations results in pure metallic behaviors there the above trend is justified when k = 2 the displacement is low where as it is high when k = 6.
- From the above graph it is observed that FGM 1 (Al_2O_3-Al) has shown higher displacement variations as compared to FGM 2 (Zr-Al).It can be predicted that FGM 1 (Al_2O_3-Al) has high modulus values as compared to FGM 2 (Zr-Al). Hence FGM 1 with high material variation parameter has shown higher displacement as compared to FGM 2 for the same value of k = 6.

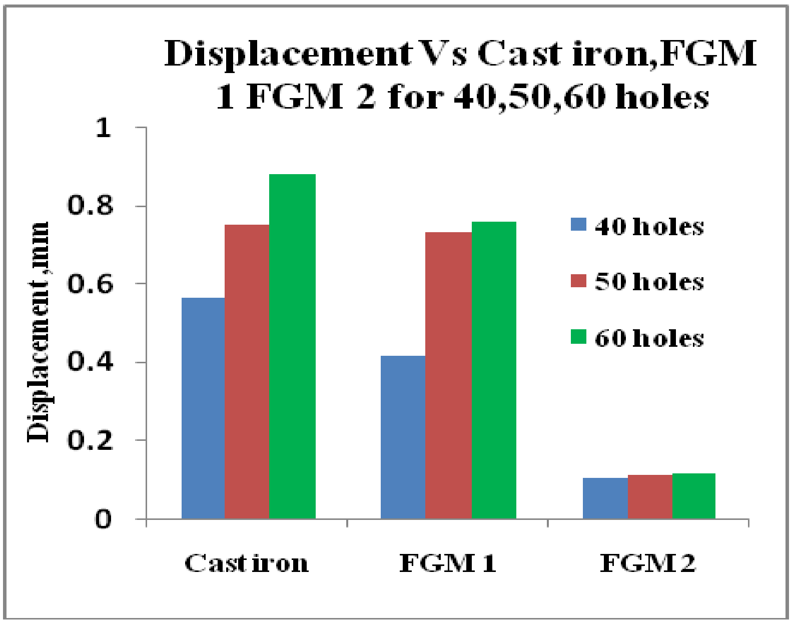

Fig 3.2: Displacement Vs cast iron, FGM 1, FGM 2

- Fig 3.2 shows the comparison of displacement for 40,50,60 holes with respect to cast iron, FGM 1 (Al_2O_3-Al),FGM 2 (Zr-Al).
- It can be observed that higher number of holes resulted in higher displacement.
- As the number of holes increases the disk may become weak due to reduction in load bearing area hence resulted in higher displacement. This is true for all cases of materials.
- The displacement variation is highest for cast iron as compared to FGM 1 and FGM 2.The reason for this behavior can be speculated in 2 ways. Cast iron being pure metal exhibited higher displacement upon load application. Whereas, FGM 1 (Al_2O_3-Al) and FGM 2 (Zr-Al) have shown poor response to displacement. Though cast iron is pure metal but brittle in nature, it's response to displacement as compared to FGM 1 and FGM 2 is superior.
- It can also be explained that both FGM 1 and FGM 2 are rich in ceramic composition at k = 2,results in more brittle behavior as compared to cast iron. Hence, FGM's produce lower displacement values as compared to cast iron.

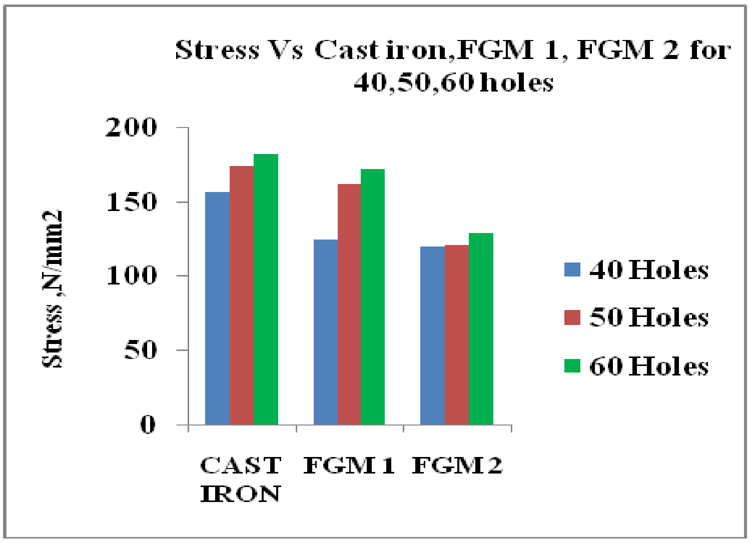

Fig 3.3: stress Vs cast iron, FGM 1(Al_2O_3-Al), FGM 2 (Zr-Al) for 40, 50, 60 holes.

- Fig 3.3 shows the stress variations for 40,50,60 holes. for cast iron ,FGM 1(Al_2O_3-Al) ,FGM 2(Zr-Al).
- It can be observed from the graph with increasing number of holes the stress generated are more. It is self explanatory upon increasing number of holes the surface area becomes less, thereby higher stresses will be developed. This is true for all cases of materials.
- From the above graph it can also be observed that FGM 1 (Al_2O_3-Al) generated higher stress as compared to FGM 2 (Zr-Al).As explained earlier FGM 2 is zirconium based which has got lower elastic modulus as compared to alumina based FGM 1.Further,it can be stated that the higher elastic modulus means higher capacity to bear the load as compared to the other.
- As compared to cast iron FGM 1 (Al_2O_3-Al) and FGM 2 (Zr-Al) showing low stresses. Though cast iron is brittle in nature, as it is metallic in general, the possibility of bearing the load and chances of early facilities are less as compared to FGM 1 and FGM 2 where they are rich in ceramic composition. Hence, the results are comparable.

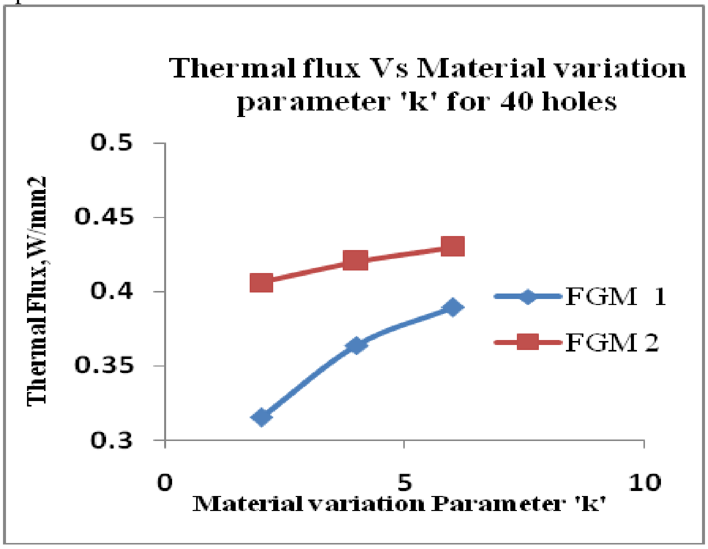

Fig 3.4: Thermal Flux Vs Material variation parameter ‘K’ for 40 holes

- Fig 3.4 shows the variation of thermal flux with respect to material variation parameter ‘k’ for disc brake with 40 holes.
- It is observed that with increase in material variation parameter ‘k’, thermal flux values are found to be increasing.
- It is true because as ‘k’ increases, the FGM’s attain near metallic properties, there by their behavior becomes more conductive. Hence, higher flux values have been observed for higher ‘k’ values.

- In addition it can also be observed that FGM 2 (Zr-Al) possess higher thermal flux as compared to FGM 1 (Al_2O_3-Al).as FGM 2 is zirconium based which has got higher conductivity value as compared to alumina based FGM .The results obtained are superior for FGM 2 compared to FGM 1 .As thermal flux is also one of the important parameter, higher thermal flux values are encouraged.

IV. CONCLUSIONS

- The proposed FGM 1 (Al_2O_3-Al) and FGM 2(Zr-Al) are found to be superior as compared to cast iron from generated stress point of view.
- FGM 2 can be preferred over FGM 1 because of less stress generation.
- Increment in stress values has been observed with increasing material variation parameter ‘k’.
- Higher is the number of holes, higher is the stress produced irrespective of materials i.e. Cast Iron, FGM 1, FGM 2.
- Higher displacement values and variation in displacement with increasing ‘k’ is superior for FGM 1as compared to FGM 2.
- The proposed FGM 2 exhibited higher thermal flux values compared to FGM 1, which is very much essential from heat dissipation point of view.

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