|| Volume 5 || Issue 7 || July 2020 || ISSN (Online) 2456-0774
INTERNATIONAL JOURNAL OF ADVANCE SCIENTIFIC RESEARCH
AND ENGINEERING TRENDS

MODELING AND THERMAL ANALYSIS OF DISC BRAKE ROTOR WITH DIFFERENT DESIGNS AND VARIOUS FUNCTIONAL GRADED MATERIALS USING FEM

[1] D.RAMBABU, [2] Mr.R.VIJAY KRISHNA (M.Tech, LMIAENG, LMISRD)
[1]M.Tech STUDENT, DEPT. OF MECHANICAL ENGINEERING, NRI INSTITUTE OF TECHNOLOGY (AUTONOMOUS), AGIRIPALLI(M), VIJAYAWADA, ANDHRAPRADESH
[2] ASSOCIATE PROFESSOR, DEPT. OF MECHANICAL ENGINEERING, NRI INSTITUTE OF TECHNOLOGY(AUTONOMOUS), AGIRIPALLI(M), VIJAYAWADA, ANDHRAPRADESH
[1] rambabudarshanala1@gmail.com, [2] vijaykrishnaclass@gmail.com

-- ***--

Abstract:- The disc brake is a device for slowing or stopping the rotation of a wheel. A brake disc, usually made of cast iron or ceramic composites (including carbon, Kevlar and silica), 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 In this thesis, analytical investigation is 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 holes. In this thesis, comparison are 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 will be considered for material variation profile through the thickness for k = 2, k = 4 and k = 6 .Theoretical calculations are to be done to calculate the material properties for each layer up to 10 layers for FGM'S. Structural analysis and thermal analysis are done on these three models by varying materials. 3D modeling is done in Pro/Engineer and analysis is to be done in Ansys.

--***--

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 todays 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 brake disc is usually made of grey cast iron or ceramic composites (including carbon, Kevlar and silica). This is connected to the wheel and/or the axle.

Two types of brake discs are generally used, the solid type and the ventilated type. The ventilated type is more efficient since it provides better cooling.

Cast iron is extensively used as the material for manufacturing disc brakes. This is much heavier and thus reduces initial acceleration and causes more fuel consumption.

Obviously, cast-iron disc is the heaviest part of a brake - about 8 kg each, or 32 kg per car. Though Aluminum alloy discs are light, they were less resistant to heat and fade, thus more powerful functionally graded materials are employed than conventional cast-iron for disc manufacturing.

1.1 FUNCTIONALLY GRADED MATERIALS:

The abrupt change in material properties across the interface between discrete layers in composites structures can result in large inter laminar stresses leading to de-lamination. One way to overcome these adverse effects is to use "functionally graded materials'' which are in homogenous materials with continuously varying material properties.

We consider a two- phase graded material with a power-law variation of the volume fractions of the constituents through the thickness. The effective material properties at a point are determined in terms of the local volume fractions.

Functionally graded materials are generally a mixture of ceramics and metals. The composition is varied from a ceramic-rich surface to a metal-rich surface, with a desired variation of the volume fractions of the two materials in between the two surfaces. The ceramic constituent of the material provides the high-temperature resistance due to its low thermal conductivity. The gradual change of material properties can be tailored to different applications and working environments. This makes functionally gradient materials preferable in many applications.

1.2 OBJECTIVES OF STUDY:

The present objective of this thesis is to do analytical investigation of disc brake with 258 mm diameter, 10 mm thickness, and holes with 12 mm diameter.

- Here disc brake with three models are compared i.e., disc brake with 40, 50, holes and also by varying materials of disc brake i.e., cast iron, FGM 1 (Al_2O_3-Al), FGM 2 (Zr-Al).
- A pressure of 1.2 N/mm^2 is considered in structural analysis and a temperature of 373 k is considered for thermal analysis.
- FGMs are assumed to be isotropic, and the grading is assumed to be only through the thickness.

1.3 THESIS OUTLINE

The remainder of this thesis is organized as follows:

The second chapter deals with previous work relevant to present investigations available in literature.The third chapter includes the design and modeling of disc brake of three models i.e., disc brake with 40, 50 holes. The fourth chapter presents the analysis of cast iron disc brake, FGM 1 (Al_2O_3-Al) disc brake, FGM 2 (Zr-Al) disc brake, including results of stress and thermal analysis.The fifth chapter presents the results and discussions based on the graphs plotted by the data obtained from the analysis.The sixth chapter includes the conclusions drawn by the findings of the investigation of the work.

II LITERATURE REVIEW

J. N. Reddy [1], studied the Theoretical formulation, Navier's solutions of rectangular plates, and finite element models based on the third-order shear deformation plate theory are presented for the analysis of through-thickness functionally graded plates. The plates are assumed to have isotropic, two-constituent material distribution through the thickness, and the modulus of elasticity of the plate is assumed to vary according to a power-law distribution in terms of the volume fractions of the constituents. Numerical results of the linear third-order theory and non-linear first-order theory are presented to show the effect of the material distribution on the deflections and stresses.

J .Suresh Kumar [2], observed the analysis of functionally graded material (FGM) plates with material variation parameter (k), boundary conditions, aspect ratios and side to thickness ratios are investigated using higher order displacement model. The derivation of equations of motion for higher order displacement model is obtained using principle of virtual work. The nonlinear simultaneous equations are obtained by Navier’s method considering certain parameters, loads and boundary conditions. The nonlinear algebraic equations are solved using Newton Rap son iterative method. The numerical results are obtained for various boundary conditions, material variation parameter, aspect ratio, side to thickness ratio and compared with the available solutions. The effect of shear deformation and nonlinearity response of functionally graded material plate.

Liu GR, Tani J, Ohyoshi T.Lamb (1990), investigated the dynamics of FGM plates; they also presented the concept of functionally graded piezoelectric materials for the first time and analyzed them using a hybrid numerical method.

Fukui Y, Yamanaka N (1992, investigated the effect of the gradation of the composition on the strength and deformation of the thick walled FGM tubes.

Obata Y, Nosa N (1992), conducted steady and transient thermal analysis and later on the optimal material design for FGM plates.

Tanigawa (1995), Compiled a comprehensive list of papers on the analytical models of thermo elastic behavior of functionally graded materials.

Praveen G N, Reddy JN (1998) [1], analyzed the nonlinear static and dynamic response of heated functionally graded ceramic-metal plates subjected to dynamic lateral loads by the finite element method.

Reddy J N (2000) [1], developed both theoretical and finite element formulations for thick FGM plates according to higher order shear deformation plate theory, and studied the nonlinear dynamic response of FGM plates subjected to sudden applied uniform pressure.

Fukui and Yamanaka, examined the effects of the gradation of components on the strength and deformation of thick-walled functionally gradient material tubes under internal pressure. Fukui et al. further extended their previous work by considering a thick-walled FGM tube under uniform thermal loading, and investigated the effect of graded components on residual stresses. They generated an optimum composition of the FGM tube by minimizing the compressive circumferential stress at the inner surface. Fuchiyama et al. used an eight-node quadrilateral axi symmetric element to study transient thermal stresses and stress intensity factors of functionally gradient materials with cracks. In their analysis, they concluded that temperature-dependent properties should be considered in order to obtain more realistic results.

Siti Nur Sakinah Jamaludin, studied the various fabrication techniques of FGMs composed by metallic and ceramic phases. Fabrication techniques in this field of work have incorporated many concepts from different background of gradation processes and consolidation or sintering processes. Each of these processes however has their own advantages and disadvantages. The best technique to be applied can be found by considering some critical issues highlighted in published literatures. He concluded the powder metallurgy (PM) as the most suitable technique certainly for mass production and up-scaling of the FGMs. The selection was strengthen after considering the advantages of the technique such as process cost-effectiveness, reliability of the practical implementation of the process and the high capability of the process to control the quality of the FGMs.

|| Volume 5 || Issue 7 || July 2020 || ISSN (Online) 2456-0774
INTERNATIONAL JOURNAL OF ADVANCE SCIENTIFIC RESEARCH AND ENGINEERING TRENDS

III OBJECTIVE OF THE PROJECT

Present work is concerned with the analytical investigation of various disc brake models i.e., disc brake with 40,50 holes and also analytical investigation comparison is done for different materials i.e., cast iron, FGM 1 (Al_2O_3-Al), FGM 2 (Zr-Al) , by varying the material variation parameter through thickness (k) i.e., (for k = 2,k = 4,k = 6) for FGM's.

3.1 BACK GROUND WORK

3.1.1 DISC BRAKE:

The disc brake is a device for slowing or stopping the rotation of a wheel while it is in motion. A brake disc (or *rotor*) is usually made of cast iron or ceramic composites (including carbon, Kevlar and silica). This is connected to the wheel and/or the axle. To stop the wheel, friction material in the form of brake pads (mounted on a device called a brake caliper) is forced mechanically, hydraulically, pneumatically or electro magnetically, against both sides of the disc. Friction causes the disc and attached wheel to slow or stop. Brakes (both disc and drum) convert friction to heat, but if the brakes get too hot, they will cease to work because they cannot dissipate enough heat. This condition of failure is known as brake fade. Disc brakes are exposed to large thermal stresses during routine braking and extraordinary thermal stresses during hard braking.

3.1.2 RUSTING:

The discs are commonly made from cast iron and a certain amount of surface rust is normal. The disc contact area for the brake pads will be kept clean by regular use, but a vehicle that is stored for an extended period can develop significant rust in the contact area that may reduce braking power for a time until the rusted layer is worn off again. Over time, vented brake discs may develop severe rust corrosion inside the ventilation slots, compromising the strength of the structure and needing replacement.

Fig 1 Disc brake without holes

Fig 2 Disc brake with holes

3.2 FUNCTIONALLY GRADED MATERIALS:

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. For example, thermal barrier plate structures for high temperature applications may form from a mixture of ceramic and a metal. The composition is varied from a ceramic rich surface to a metal-rich surface, with a desired variation of the volume fractions of the two materials in between the two surfaces. The gradual change of material properties can be tailored to different applications and working environments. This makes functionally gradient materials preferable in many applications.

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. Modern FGMs are constructed for complex requirements, such as the heat shield of a rocket or implants for humans. The gradual transition between the heat and corrosion resistant outer layer (often made of a ceramic material) and the tough metallic base material increases in most cases the life time of the component.

Typically these materials are made from a mixture of metals and ceramic, 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.

Laminated composite materials provide the design flexibility to achieve desirable stiffness through the choice of lamination scheme, the anisotropic constitution of laminated composite structures often result in stress concentrations near material and geometric discontinuities that can lead to damage in the form of de-lamination, matrix cracking, and adhesive bond separation.

Functionally graded materials (FGMs) are a class of composite materials where the composition or the microstructures are locally varied so that a certain variation of the local material properties is achieved. The gradual variation results in properties of the material reduces thermal stresses, residual stresses, and stress concentration factors. These are manufactured from isotropic components such as metals and ceramics since they are mainly used as thermal barrier structures in environments with severe thermal gradients. In some applications the ceramic heat and corrosion resistance, mean while the metal provides the strength and toughness.

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

$$P(z) = (P_t - P_b)\,V + P_b \quad \ldots \text{equation 1}$$

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

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 1, while V is assumed to be constant. It is taken as $P_t = P_c$ and $P_b = P_m$ as the properties of the ceramic and metal respectively. The metal content in the plate increases as the value of n increases. The value of k = 0 represents a fully ceramic plate.

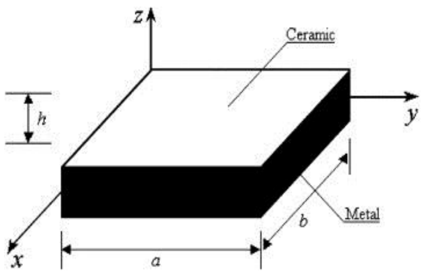

Fig 3 Functionally graded plate

3.3 FABRICATION TECHNIQUES FOR FGM's:

Whenever two or more dissimilar materials are bonded, large jump in the stresses occurred at the interface during the fabrication will leads to the de-lamination and poor load-bearing performance on the final structures. Functionally graded material (FGM) which has compositional and microstructure gradient along its thickness was introduced to be a great solution to this problem.

There are several different physical and chemical methods depending on type of materials, potential application and available facilities for the FGMs fabrication.

1) POWDER METALLURGY:

PM is an apparent technology for the FGMs fabrication and is increasingly being used to create gradients on material. This method is appropriate for FGMs fabrication using solid materials. In PM route, some steps are needed for the completion of the product preparation. These steps can be classified into four main steps namely: powder preparation, powder processing (weighing and mixing of powder according to desired percentage of composition), forming operations (stacking and ramming of premixed powders) and finally sintering or pressure assist hot consolidation. After completing the sintering process, optional secondary processing can be performed to enhance the performance of the structure.

Several techniques have been introduced for powder preparation such as through chemical reactions, electrolytic deposition, grinding or comminuting. These permit mass production rates of powder form materials and it usually offered within controllable size range of the final grain population. For the powder processing, the main consideration is focused on the precision in weighing amounts and the dispersion of the mixed powders. These elements will influence the structure properties and should be handled in a very careful way. In the subsequent processes, the forming operations is performed at room temperature while sintering is conducted at atmospheric pressure as the elevated-temperature used may cause other reaction that may affect the materials. At this stage, the atmospheric condition must be appropriate since high-temperature process has high sensitivity to the surroundings.

2) CONTROLLED BLENDING:

In controlled blending, the two FGM components are blended during forming and the ratio is continuously varied from 100% component 1 through to 100% component 2 (or variation thereof). This approach potentially offers the unique advantage of being able to produce precisely controllable regular functional gradients independent of the system-inherent issues of powder density and gravitational settling mechanisms. Also, unlike segregation, controlled blending enables very rapid processing rates.

3) SINTERING PROCESS:

The gradation that has been performed in the powder compact needs to be preserved during sintering or consolidation process. Some of light metallic powders such as magnesium and aluminum will tend to react with the oxygen and disperse to the atmosphere in oxidation which should be avoided in order to get proper resulting materials. The sintering process is performed simultaneously with the compaction process if the FGM is prepared using hot pressing process. However in cold pressing process, the sintering process is performed only after the powders were compacted. The effectiveness of three different sintering methods includes electric furnace heating, high frequency induction heating and spark plasma sintering.

4) THERMAL SPRAYING:

Thermal spraying is a technique by which a structure is coated with melted materials through spraying process. Relating the process with FGMs preparation, the melted materials will be the functionally varied which build the coating layers. In this process, the coating precursor is heated either electrically or chemically. One of the advantage of using this technique is the coating can provide thick coatings (20 µm to mm) over a large area at high deposition rate better than the other coating process such as electroplating and vapor deposition. In 2002, three types of functionally graded thermal barrier coatings (TBCs) as well as duplex coatings with the same thermal resistance have been designed in order to investigate the thermal fracture behavior of FGM structures.

5) VAPOR DEPOSITION METHOD:

Vapor deposition is a process by which materials in vapor phase are condensed to form a solid material. This process generally is being performed to make coatings for the alteration of the properties of the substrates such as in term of mechanical, electrical, thermal, wear and etc. Basically, vapor deposition is classified into two categories namely chemical vapor deposition (CVD) and physical vapor deposition (PVD).

In order to produce the desired deposit using CVD process, the substrate is exposed to the volatile precursors to allow the reaction and decomposition on the substrate surface. The chemical reaction part in CVD coating is replaced with purely physical processes such as high temperature vacuum evaporation or plasma sputter bombardment in PVD coating. The processing sources distinguish the two different methods under vapor deposition process.

IV DESIGNS AND MODELLING

4.1 Design of Disc Brake in Pro/Engineer Software:

Pro/ENGINEER is a feature based, parametric solid modeling program. As such, its use is significantly different from conventional drafting programs. In conventional drafting (either manual or computer assisted), various views of a part are created in an attempt to describe the geometry. Each view incorporates aspects of various features (surfaces, cuts, radii, holes, protrusions) but the features are not individually defined. In feature based modeling, each feature is individually described then integrated into the part. The other significant aspect of conventional drafting is that the part geometry is defined by the drawing. If it is desired to change the size, shape, or location of a feature, the physical lines on the drawing must be changed (in each affected view) then associated dimensions are updated. When using parametric modeling, the features are driven by the dimensions parameters. To modify the diameter of a hole, the diameter parameter value is to be changed. This automatically modifies the feature wherever it occurs drawing views, assemblies, etc. Another unique attribute of Pro/ENGINEER is that it is a solid modeling program. The design procedure is to create a model, view it, assemble parts as required, then generate any drawings which are required. It should be noted that for many uses of Pro/E, complete drawings are never created.

4.2 DESIGN OF DISC BRAKE:

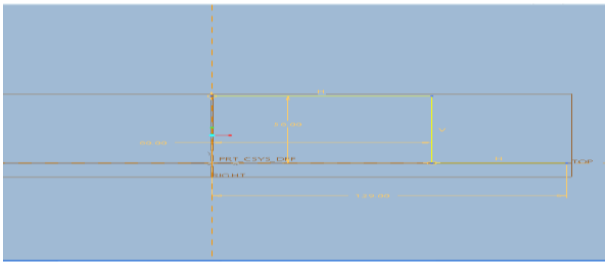

Fig 4 shows drawings in sketcher in Pro-E

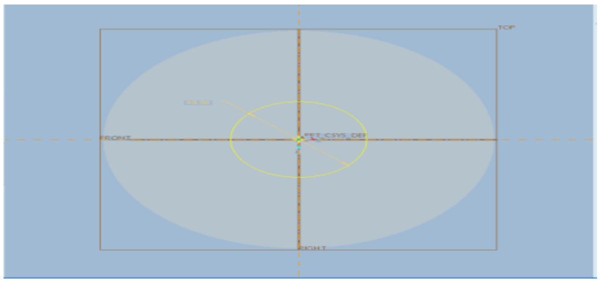

Fig 5 shows the drawing in sketcher in Pro -E

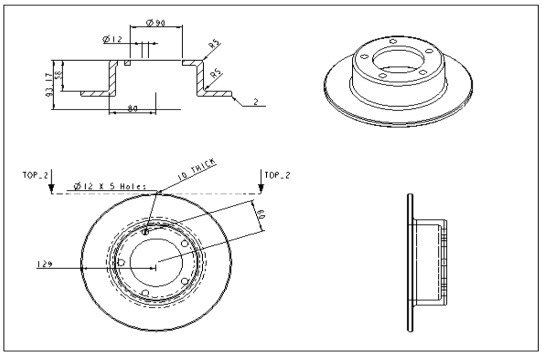

Fig 6 shows 2D drawing of disc brake

4.3 INTRODUCTION TO ANSYS:

ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements. The software implements equations that govern the behaviour of these elements and solves them all; creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated or graphical forms. This type of analysis is typically used for the design and optimization of a system far too complex to analyze by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations.

4.4 STEPS INVOLVED IN ANSYS:

In general, a finite element solution can be broken into the following these categories.

1. Pre-processing module: Defining the problem

The major steps in pre-processing are given below

- defining key points /lines/areas/volumes - define element type and material /geometric /properties - mesh lines/areas/volumes/are required The amount of detail required will depend on the dimensionality of the analysis (i.e. 1D, 2D, axis, symmetric)

2. Solution processor module: assigning the loads, constraints and solving. Here we specify the loads (point or pressure), constraints (translation, rotational) and finally solve the resulting set of equations.

3. Post processing module: further processing and viewing of results

In this stage we can see
List of nodal displacement
Elements forces and moments
Deflection plots
Stress contour diagrams.

4.5 MODEL CALCLUATIONS FOR MATERIAL PROPERTIES USED IN STRUCTURAL ANALYSIS:

1) Young's Modulus:

Material properties for FGM 1 (Al_2O_3-Al):

Top material: Alumina, Al_2O_3 (E=380000 MPa)

Bottom material: Aluminum, 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 N/mm^2

2) **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 (0.16) + 70000

=119600 N/mm^2

Above Same Procedure is repeated for k = 2;and z = 2,3,4,5,-2,-3,-4,-5.

Above Same Procedure is repeated for k = 4, k = 6 and for different layers (z) of FGM 1 (Al_2O_3-Al)

2) For Densities:

Top Material: Alumina, Al_2O_3 (ρ_t = 0.00000396)

Bottom Material: Aluminum, Al (ρ_b = 0.0000027)

1) **For k = 2; z =1**

$$\rho(z) = (\rho_t - \rho_b)\left(\frac{z}{h}+\frac{1}{2}\right)^k + \rho_b$$

$= (0.00000396 - 0.0000027)\left(\frac{1}{10}+\frac{1}{2}\right)^2 + 0.0000027$

$= 1.26\times10^{-6}(0.36) + 0.0000027$

$= 3.1536\times10^{-6}$ Kg/mm^3

2) **For k = 2; z = -1**

$$\rho(z) = (\rho_t - \rho_b)\left(\frac{z}{h}+\frac{1}{2}\right)^k + \rho_b$$

$= (0.00000396 - 0.0000027)\left(\frac{-1}{10}+\frac{1}{2}\right)^2 + 0.0000027$

$= 1.26\times10^{-6}$ (0.16) + 0.0000027

$= 2.9016\times10^{-6}$ Kg/mm^3

Above Same Procedure Is Repeated For k = 2;and z = 2,3,4,5,-2,-3,-4,-5.

Above Same Procedure is repeated for k = 4, k = 6 and for different layers (z) of FGM 1 (Al_2O_3-Al).

Above Same procedure is repeated for FGM 2 (Zr-Al) in order to get material properties, young's modulus and density for various material variation parameter 'k' at different layers (z).

4.6 MODEL CALCLUATIONS FOR MATERIAL PROPERTIES USED IN THERMAL ANALYSIS

1) Thermal Conductivity:

Material properties for FGM 1 (Al_2O_3-Al):

Top material: Alumina, Al_2O_3 (K=0.4498)

Bottom material: Aluminum, Al (K=0.18)

1) For k = 2; z = 1

$$K(z) = (K_t - K_b)\left(\frac{z}{h}+\frac{1}{2}\right)^k + K_b$$

$= (0.4498 - 0.18)\left(\frac{1}{10}+\frac{1}{2}\right)^2 + 0.18$

= 0.2698 (0.36) + 0.18

= 0.27712

2) For k = 2; z = -1

$$K(z) = (K_t - K_b)\left(\frac{z}{h}+\frac{1}{2}\right)^k + K_b$$

$= (0.4498 - 0.18)\left(\frac{-1}{10}+\frac{1}{2}\right)^2 + 0.18$

= 0.2698 (0.16) + 0.18

= 0.22316

Above Same Procedure Is Repeated For k = 2;and z =2,3,4,5,-2,-3,-4,-5. Above same procedure is repeated for different material variation parameter i.e for k = 4, k = 6 at different layers.

2) Specific Heat:

Top material: Alumina, Al_2O_3 (C=920)

Bottom material: Aluminum, Al (C=896)

1) For k = 2; z = 1

$$C(z) = (C_t - C_b)\left(\frac{z}{h}+\frac{1}{2}\right)^k + C_b$$

$$= (920-896)\left(\frac{1}{10}+\frac{1}{2}\right)^2 + 896$$

= 904.64

2) For k = 2; z = -1

$$C(z) = (C_t - C_b)\left(\frac{z}{h}+\frac{1}{2}\right)^k + C_b$$

$= (920-896)(-1/10+1/2)^2+896$

= 899.84

Above Same Procedure Is Repeated For k = 2;and z = 2,3,4,5,-2,-3,-4,-5.Above same procedure is repeated for different material variation parameter i.e. for k = 4, k = 6 at different layers.Above Same Procedure is repeated in order to get material properties for FGM 2 (Zr-Al) for different material variation parameter 'K 'i.e. for k =2, k =4, k =6 at different layers of functionally graded disc brake

4 .7 STRESS AND THERMALANALYSIS OR CAST IRON, FGM 1, FGM 2

4.7.1STRUCTURAL ANALYSIS FOR CAST IRON:

CAST IRON DISC BRAKE WITH 40 HOLES:

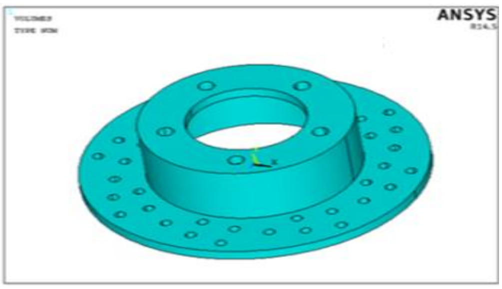

Fig 7 Meshed model of cast iron disc brake

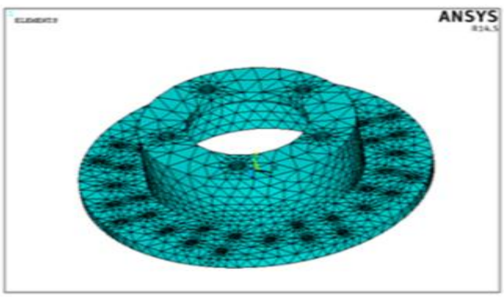

Fig 8 With 40 holes from pro-e with 40 holes

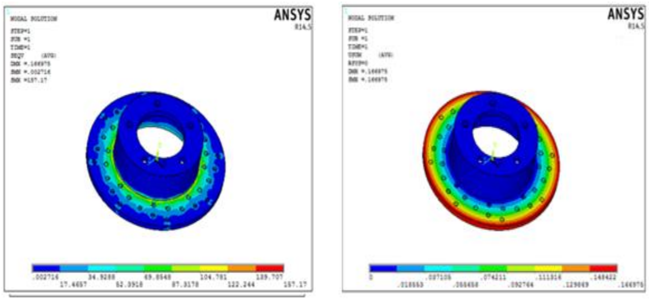

Fig 9 Displacement & Vonmises stress of CI

4.7.2 Structural Analysis of FGM 1 (Al_2O_3-Al) Disk Brake with 40 holes for material variation parameter 'k'=2:

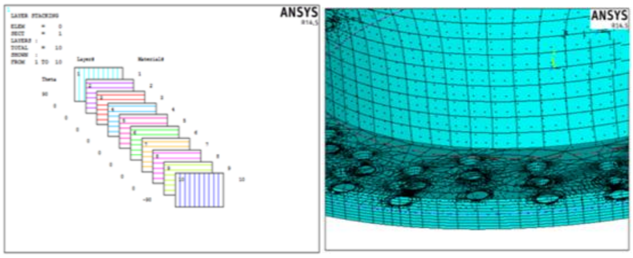

Fig 10 Layer Stacking method for FGM 1 (Al_2O_3-Al) showing the 10 layers of the FGM

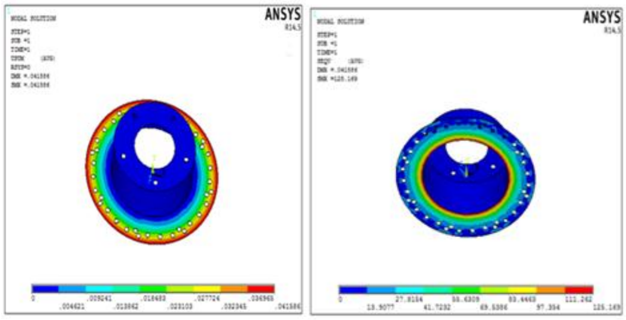

Fig 11 Displacement vector sum for FGM 1(Al_2O_3-Al)

Fig 12 Vonmises Stress for FGM 1

4.7.3 STRUCTURAL ANALYSIS FOR FGM 2(Zr-Al):

Analysis of FGM 2 (Zr-Al) Disk Brake with 40 holes for material variation parameter 'k'=2:

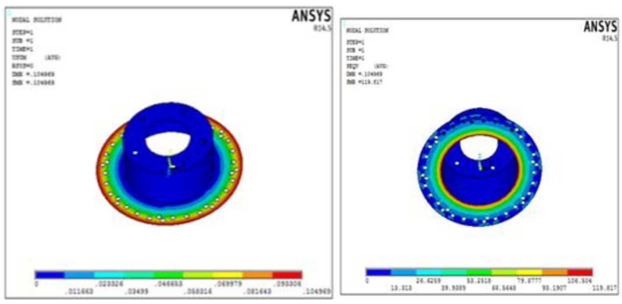

Fig 13 Displacement vector sum for FGM 2(Zr-Al)

Fig 14 Vonmises stress for FGM 2 (Zr-Al)

|| Volume 5 || Issue 7 || July 2020 || ISSN (Online) 2456-0774
INTERNATIONAL JOURNAL OF ADVANCE SCIENTIFIC RESEARCH
AND ENGINEERING TRENDS

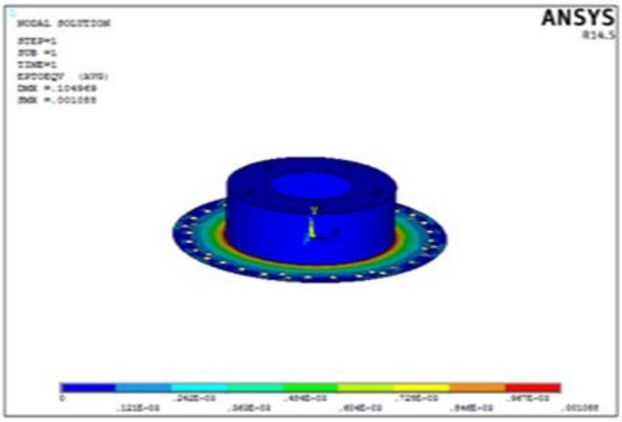

Fig 15 Strain for FGM 2(Zr-Al)

THERMAL ANALYSIS:

Thermal Analysis results of cast iron

number of Holes	Thermal gradient	Thermal flux(W/m²)
40	81.8071	9.2442
50	81.912	9.256

Thermal Analysis results of FGM 1 (Al_2O_3-Al)

Number of holes	k = 2		k = 4		k = 6	
	Thermal gradient	Thermal flux(W/m²)	Thermal gradient	Thermal flux(W/m²)	Thermal gradient	Thermal flux(W/m²)
40	10.526	0.315	12.150	0.364	12.972	0.389
50	11.617	0.3485	13.353	0.400	14.236	0.427

Analysis results of FGM 2(Zr-Al):

Number of holes	k = 2		k = 4		k = 6	
	Thermal gradient	Thermal flux(W/m²)	Thermal gradient	Thermal flux(W/m²)	Thermal gradient	Thermal flux(W/m²)
40	23.885	0.40	24.904	0.42	25.279	0.4297
50	24.590	0.41	25.650	0.436	25.905	0.4403

V RESULTS AND DISCUSSIONS

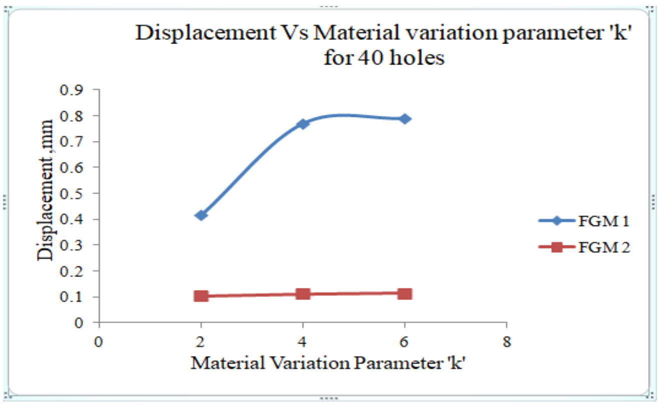

Fig 15 shows displacement Vs material variation parameter 'k' for 40 holes

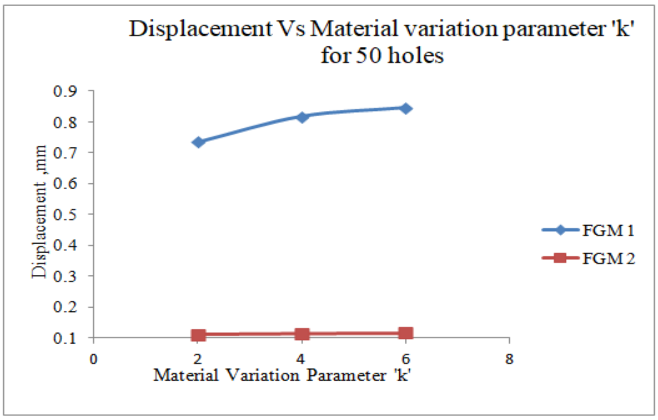

Fig 16 shows displacement Vs material variation parameter 'k' for 50 holes

5.1 Discussion for Displacement Vs material variation parameter 'k' for 40 holes:

- 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.

5.2 Discussion for Displacement Vs material variation parameter 'k' for 50 holes:

- 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 50 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 seen above the same trend is seen for disc brake with 50 holes. As explained earlier same discussion is applicable.

|| Volume 5 || Issue 7 || July 2020 || ISSN (Online) 2456-0774
INTERNATIONAL JOURNAL OF ADVANCE SCIENTIFIC RESEARCH
AND ENGINEERING TRENDS

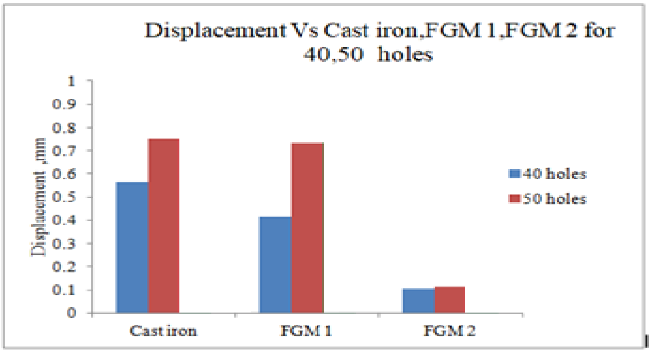

Fig 17 shows displacement Vs cast iron, FGM1, FGM2

5.3 Discussion for Displacement Vs material variation parameter 'k' for 60 holes:

- 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 60 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.

5.4 Discussion for Displacement Vs cast iron, FGM 1, FGM2:

- comparison of displacement for 40, 50, 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 high 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 exhibit 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.

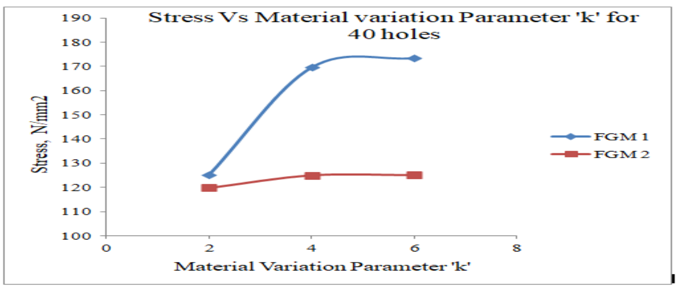

Fig 18 Shows stress Vs material variation parameter 'k' for 40 holes

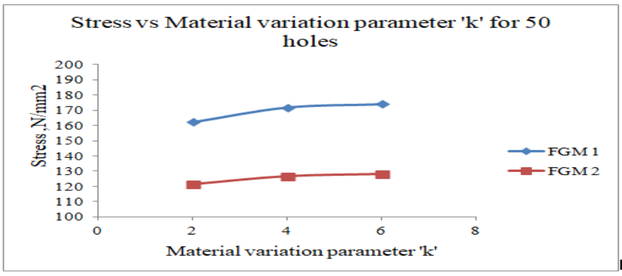

Fig 19 shows stress Vs material variation parameter 'k' for 50 holes

5.5 Discussion for stress Vs material variation parameter 'k' for 40 holes :

- Fig 5.5 shows the variation of stress with respect to material variation parameter 'k' for FGM 1 (Al_2O_3-Al) and FGM 2 (Zr-Al) for 40 number of holes.
- It can be seen that with increase in material variation parameter 'k', stress increase largely for FGM 1 (Al_2O_3-Al) and nominally for FGM 2 (Zr-Al).
- It is true because FGM 1 which consists of (Al_2O_3) possesses higher strength as compared to FGM 2 which consists of (Zr).
- In addition to the above, the variation of 'k' from minimum to maximum attains near metallic property but rich in ceramic composition. Hence, the alumina based FGM has more stress when compared to Zr based FGM.

5.6 Discussion for stress Vs material variation parameter 'k' for 50 holes:

- The variation of stress with respect to material variation parameter 'k' for FGM 1 (Al_2O_3-Al) and FGM 2 (Zr-Al) for 50 number of holes.
- It can be seen that with increase in material variation parameter 'k', stress increase largely for FGM 1 (Al_2O_3-Al) and nominally for FGM 2 (Zr-Al).
- Same trend is observed for 50 holes disc brake as seen earlier. Same discussion is applicable.

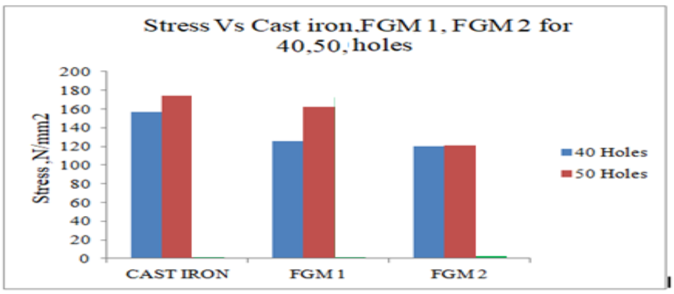

Fig 20 shows stress Vs cast iron, FGM 1,FGM 2 for 40,50, holes

5.7 Discussion for stress Vs cast iron, FGM 1,FGM 2 for 40,50, holes:

- The stress variations for 40, 50, 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 failures are less as compared to FGM 1 and FGM 2 where they are rich in ceramic composition. Hence, the results are comparable.

THERMAL ANALYSIS:

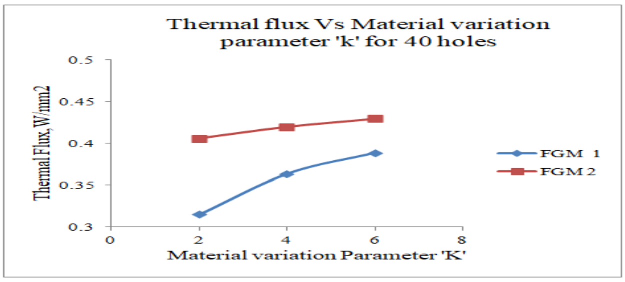

Fig 21 shows thermal flux Vs material variation parameter 'k' for 40 holes

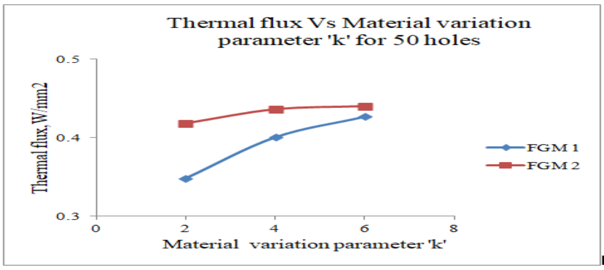

Fig 22 shows thermal flux Vs material variation parameter 'k' for 50 holes.

5.8 Discussion for thermal flux Vs material variation parameter 'k' for 40 holes:

- The variation of thermal flux with respect to material variation parameter 'k' for disk 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) possesses 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.

5.9 Discussion for thermal flux Vs material variation parameter 'k' for 50 holes:

- The variation of thermal flux with respect to material variation parameter 'k' for disk brake with 50 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.

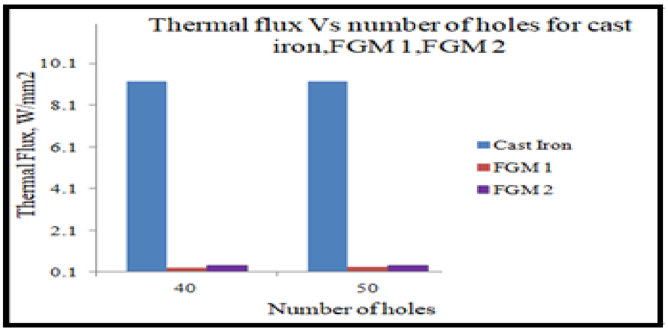

Fig 24 shows thermal flux Vs number of holes for cast iron, FGM 1, FGM 2

5.10 Discussion for thermal flux Vs number of holes for cast iron, FGM 1, FGM 2:

- The variation of thermal flux with respect to number of holes for Cast iron, FGM 1 (Al_2O_3-Al), FGM 2 (Zr-Al).
- It is observed that as number of holes increases, thermal flux also increases.
- Thermal flux for cast iron is more as compared to FGM's because cast iron is a metal which is a good conductor when compared to FGM's which contain ceramic.

VI CONCLUSION

 The proposed FGM 1 (Al2O3-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 1(Al2O3-Al) as compared to FGM 2(Zr-Al).

 The proposed FGM 2 (Zr-Al) exhibited higher thermal flux values compared to FGM 1(Al2O3-Al), which is very much essential from heat dissipation point of view.

Scope for Future Work:

Analytically studies show that FGMs are better, but investigations are to be done experimentally for practical use of FGM as a material for disc brake.

REFERENCES:

[1] Reddy, J.N. ‘‘Analysis of functionally graded plates’’, International Journal for Numerical Methods in Engineering, 47, pp. 663–684 (2000).

[2] J.suresh kumar, ‘‘Geometrically non linear analysis of functionally graded material plates using higher order theory’’ Vol. 3, No. 1, 2011, pp. 279-288.

[3] Timoshenko, S.P. and Woinowsky-Krieger, S., Theory of Plates and Shells, McGraw-Hill, New York (1959).

[4] Koizumi, M. ‘‘The concept of FGM’’, Ceramic Transactions, Functionally Gradient Materials, 34, pp. 3–10 (1993).

[5] Birman V., Byrd L.W.. 2007. Modeling and analysis of functionally graded materials and structures, Applied Mechanics Reviews, Vol. 60, No. 5, pp.195-216.

[6] Matsunaga, H. 2009. Stress analysis of functionally graded plates subjected to thermal and mechanical loadings, Internatioal Journal of Composite Structures, Vol. 87, pp.344-357.

[7] Hirai, T. and Chen, L. ‘‘Recent and prospective development of functionally graded materials in Japan’’, Materials Science Forum, pp. 308–311 (1999).

[8] Şimşek, M. ‘‘Fundamental frequency analysis of functionally graded beams by using different higher-order beam theories’’, Nuclear Engineering and Design, 240, pp. 697–705 (2010).

[9] Thermal behavior of full and ventilated disc brakes of vehicles by A. Belhocine, M. Bouchetara.

[10] Modeling and Analysis of Functionally Graded Materials and Structures by Victor Birman and Larry W. Byrd.

[11] Stress and Temperature Distribution Study in a Functionally Graded Brake Disk by P. Hosseini Tehrani, M.Talebi.