Structural and Thermal Analysis of Metal - Ceramic Disk Brake

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Abstract— Disk brakes are using from so many years in automotive and still researches are going on in this field for decreasing the temperature effect so that by this we can operate easily. Many new materials are introduced for the disk brake rotor to withstand high temperature produced during braking action. Apart from the high temperature property, the disc rotor materials must also have high thermal conductivity property, as this property decides the amount of heat dissipation to the air stream from the disk rotor. A brake material with good temperature and high thermal conductivity property gives maximum efficiency by overcoming the problem of thermo-mechanical instability [TEI] in the rotor which is more common in low thermal conductivity brake rotor material. In the present work, a Grey cast iron material and metal-ceramic has been chosen for the disk brake rotor. Number of methods before already introduced to know the history of the different materials related to disk brakes, analysis will be done in 2d and 3d in analytical and numerical methods. With different types of assumptions these numerical methods ranges from finite differences to finite elements. To conclude the temperature history for the Grey cast iron material, and metal-ceramic, a numerical simulation technique called finite element method is used. Transient analysis is carried out in ANSYS to predict temperature distribution as a function of time in the disk brake rotor. The results from the transient analysis are compared. As the brake rotor can be treated as the coupled field problem, it is mandatory to do structural analysis after performing thermal analysis in ANSYS to study the stability and rigidity behavior of the rotor material. The results from the transient analysis are given as the input to the structural analysis in order to conclude the stress distribution and displacement in disk brake rotor under thermal loading. The stability behavior of different brake rotor material is compared to facilitate the conceptual design of the disk brake system.

Key words: ANSYS, TEI, partially stabilized zirconia, Aluminium, etc.

I. INTRODUCTION

Improvements of disk brake in automotive industries, is taking place since from past 30 years. Till the researches are going on, to reduce the mass and to increase performance. Simultaneous with this improvement it is complete effort to maintain the quality of automobiles. The most important quality factor of brake systems can be considered thermal mechanical instability.

The property of disk brake material takes a critical role here, because the K.E is converted into heat energy at the wheel which does not dissipate at rate to stream of air from brake to disk of brake, at that situation this property will handle the friction heat generated.

Because of ununiformed contact thermal vibration occurs, initially due an effect of localized Thermo-elastic instabilities near the disk brake rotor surface cycles will be generated between pad and the disk brake rotor. Around the rubbing paths hot spots will generate where the thermo-elastic instability will form. For many researches the TEI mechanism is very interest during braking process. However, in this project some assumption had made that, thermo mechanical phenomenon of each disk is same about the disk's mid plane. The wear taking place in this process due to friction between disk brake and pad is assumed to be very small and is neglected.

The FEA model produced is simulating the breaking action by investigating both elastic and thermal actions during rubbing action between sliding surfaces. The pad and the disk made of metal-ceramic and grey cast iron.

II. OBJECTIVES

The main objective of this project work is

1) To decrease the failure of the disk.
2) Some other types of materials are used to achieve the weight reduction.
3) Compositions of two materials are used to get the improved properties of the complete disk component.
4) Composition of two materials may decrease the coat of the disk component.
5) Linear static analysis will be carried to to find the stress displacement and also some thermal calculations.

III. METHODOLOGY

A. Geometric Modeling

The dimension of the disk brake rotor is taken from the Chevrolet car which is in international edition 2008. The below figure shows the disk brake. The disk brake consists of wheel hub which is bolted by cast iron. Stationary housings are disk and caliper. Because the caliper is connected to a constant or motionless part of the vehicle like stub axel or casing, they are manufacture into two parts and each part having piston. The friction pad is held in between each piston and the disk by retaining the pins, spring plates etc. for fluid entering and exhausting passages in caliper are drilled. For the purpose of bleeding passages are also connected to another one. Between the cylinder and piston rubber sealing is provided.

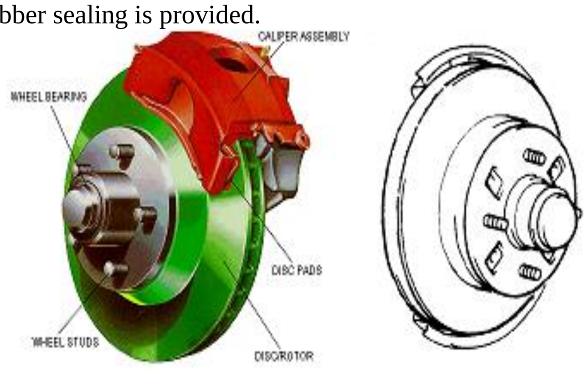


Fig. 1: Disk brake

The disk brakes main components are

1) The Brake Pads
2) The Caliper which contains the piston
3) The Rotor, which is mounted to the hub

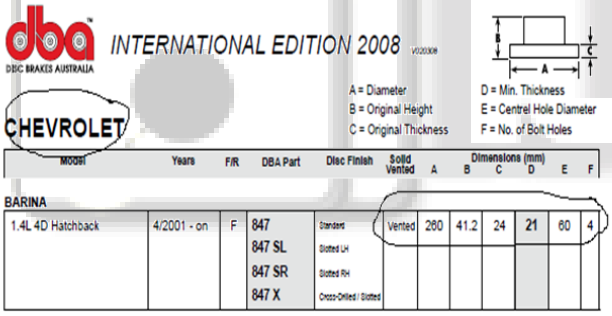
Friction pads will be come into contact with rotating disks when they are moved by hydraulically actuated pistons. Generating equal and opposite forces on the disk this happens when brakes are applied. Due to friction between pad surface and disk heat generates which is converted result of kinetic energy rotating wheel, by that energy vehicle has to stop within certain distance. On removing the brake applied, rubber sealing ring acts as return spring and retracts the piston and the friction pads move away from the disk

B. Functionally Grade Material

FGM is almost same as the composite material. But in here we made the composite material in the sense that first layer is completely made of metal, the next most layer of the material is composed of 99% metal and 1% ceramic. And then in the next layer 98% metal and 2% ceramic. This process will be continued till the end layer in the last layer 100% ceramic middle layer is composed of both the materials in 50% composition. Here the metal used is aluminium and ceramic is partially stabilized zirconia.

C. Dimensions of the Component

The dimension of the disk brake rotor is taken from Chevrolet car 2008 and all the dimensions are in millimeter only.


dba DISC BRAKES AUSTRALIA — INTERNATIONAL EDITION 2008

A = Diameter, B = Original Height, C = Original Thickness, D = Min. Thickness, E = Central Hole Diameter, F = No. of Bolt Holes

CHEVROLET

Model	Years	F/R	DBA Part	Disc Finish	Solid Vented	A	B	C	D	E	F
BARINA											
1.4L 4D Hatchback	4/2001 - on	F	847 847 SL 847 SR 847 X	Standard Slotted LH Slotted RH Cross-Drilled / Slotted	Vented	260	41.2	24	21	60	4

Table 1: Dimensions of Chevrolet car

D. Dimensions Given For the Analysis Which Shown In Fig Below

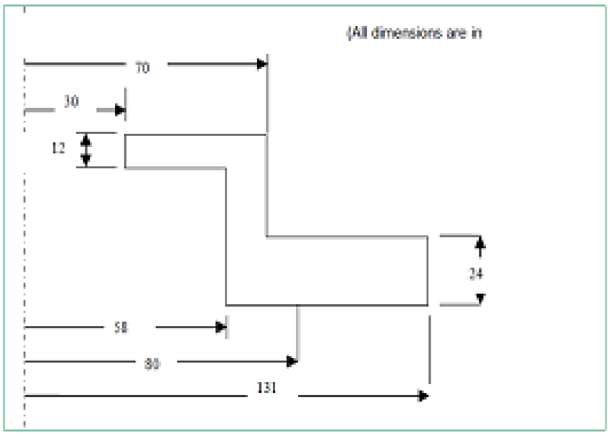


Fig. 2: Dimensions of disk brake rotor

E. Model with Mesh

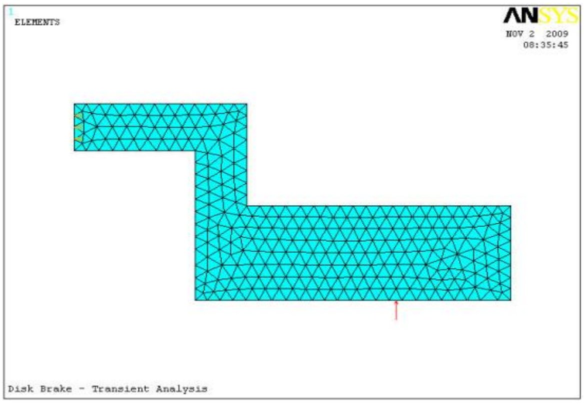


Fig. 3: Meshed model of disk brake rotor

The boundary conditions for the structural analysis of the brake rotor are given into the model as pressure 2 Mpa acting from the pad to the surface and the inner edge of the brake rotor is arrested in all the directions which shown in the figure above. The very important load required for the structural analysis in addition to the pressure load is thermal load from the previous thermal analysis which is stored in the Ansys database as result thermal file with extension. The material properties required for the structural analysis are young's modulus and thermal expansion coefficient which are given as input in the material properties under preprocessor.

F. For Thermal Analysis

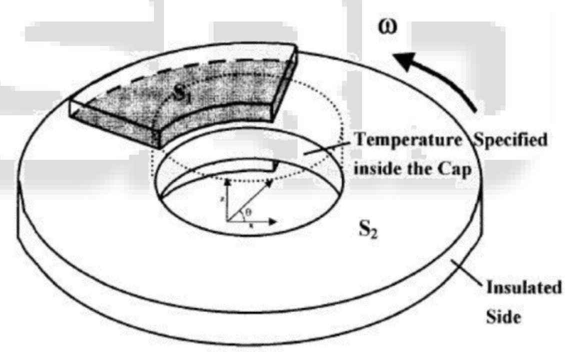


Fig. 4: Disk brake for thermal analysis

The above fig shows, a model showing a 3-D solid disk compressed by two finite width friction material called pads. Complete surface S, of the disk has three different regions including S1 and S2. On S1 heat flux is mentioned due to the frictional heating between the pads and disk, and convection boundary is S2. The rest of the region, except S1 AND S2, is either temperature specified or assumed to be insulated. Material properties of metal and ceramic material used.

Material properties	Ex (Gpa)	υ	ρ Kg/m³	α_x 1/k	K_{xx} W/mK	C J/kgK	μ
Psz	151	0.3	5700	10×10^{-6}	2.0	400	0.75
Aluminium	70	0.3	2700	23×10^{-6}	209	900	1.4

Table 2: Material properties

Property	Grey cast iron
Density kg/m^3	7.06 *10^3 -7.34 *10^3
Modulus of elasticity Gpa	124
Thermal expansion c^{-1}	9.0*10^{-6}
Thermal conductivity m*k	53.3

Table 3: Material properties of grey cast iron

IV. RESULTS AND DISCUSSION

A. *Thermal Analysis*

Transient analysis of the disc brake rotor for different materials such as grey cast iron and metal-ceramic are carried out. The properties of different brake rotor materials such as thermal conductivity, thermal expansion, density, specific heat, young's modulus are given as input for the transient analysis. The heat flux which has been calculated for the specified operating conditions is given as the thermal load in to the FEA model. The results for the two different disc brake rotor materials are given below. It has been concluded from the results that among the two materials chosen for the transient analysis, the metal-ceramic material is best as far as heat dissipation is concerned compared to the other material, grey cast iron.

1) *Grey Cast Iron Transient Thermal Analysis*

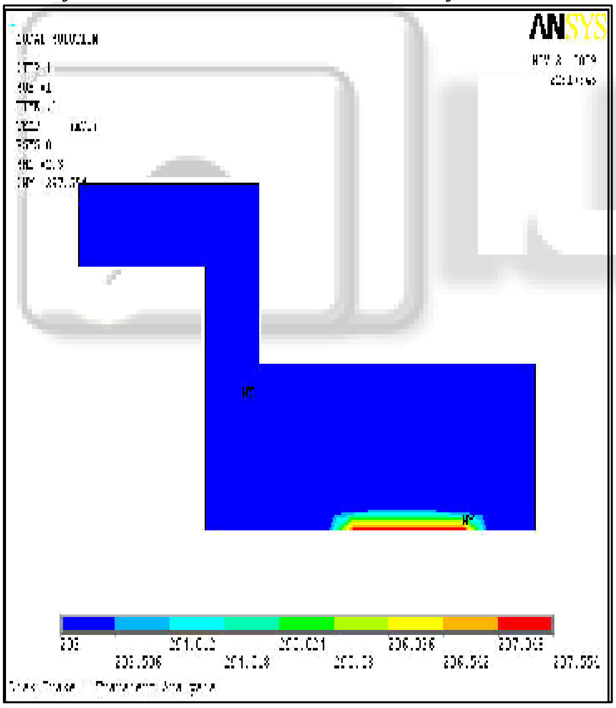


Fig. 5: Transient thermal analysis at t=1sec

Thermal analysis is done for 5 and 10 seconds also. In next fig we shown graph considering all the three.

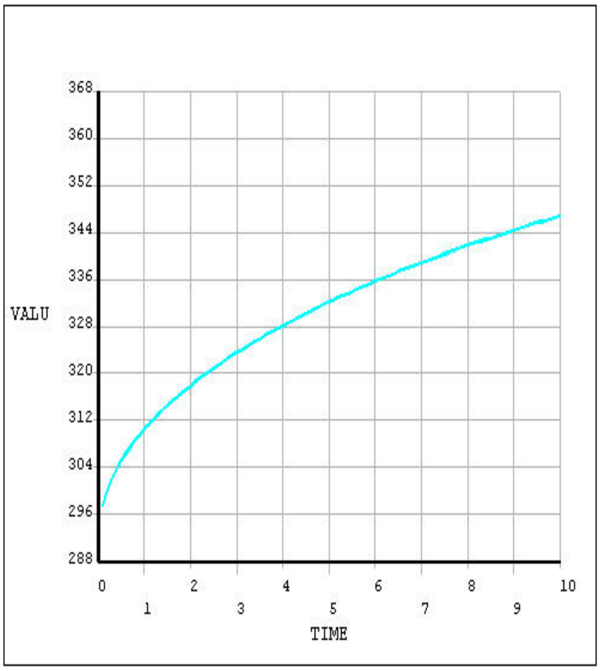


Fig. 6: Temperature v/s time

2) *Metal-Ceramic*

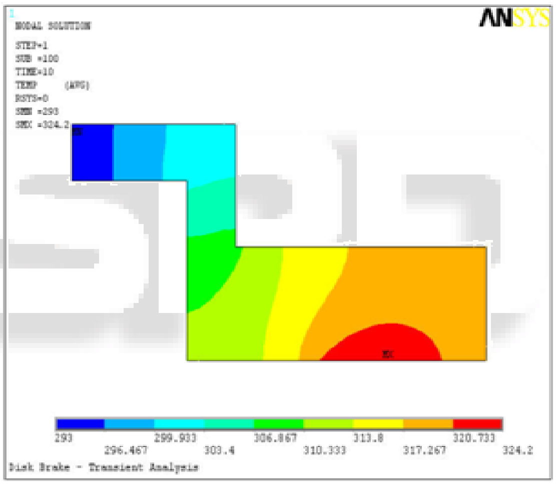


Fig. 7: Temperature distribution at time 10 sec

The graph is created by considering times at 1, 5 and 10 seconds.

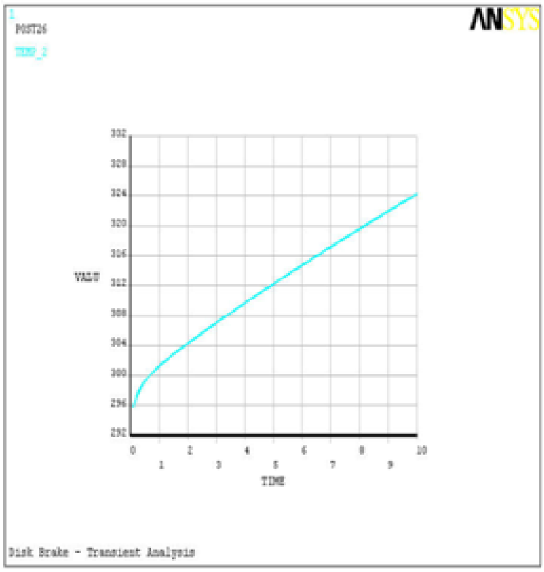


Fig. 8: Temperature v/s time

3) *Comparison of Two Types of Materials*

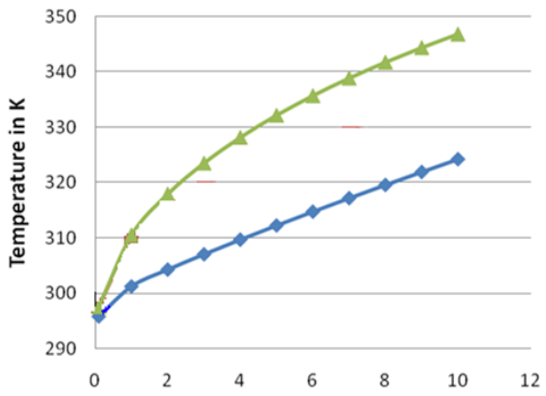


Fig. 9: comparison of two material thermal expansions

The above graph clearly describes the salient features of the metal-ceramic i.e. when t=10 sec, the maximum temperature at the NODE NUMBER 25 which is located near the heat zone, is 324 k but in grey cast iron, temperature is 347 k. From the temperature values, it's been concluded that the metal-ceramic is comparatively best material for the disc brake rotor as it dissipates heat rapidly to the atmosphere which is very important phenomenon as far as thermo-mechanical instability factor is concerned. In the next step of the project, structural analysis will be investigated for the disc brake rotor material metal-ceramic.

B. *Structural Analysis*

The static structural analysis of disc brake rotor for other materials such as grey cast iron and metal-ceramic are carried out. The properties of different brake rotor materials such as thermal expansion, young's modulus are given as input for the structural analysis. The pad pressure from the literature study has been given as the mechanical load in to the FEA model. The results for the two different disc brake rotor materials are given below. It has been concluded from the results that among the three materials chosen for the structural analysis, the metal-ceramic is best as far as stiffness is concerned compared to the other material, grey cast iron.

1) *Grey Cast Iron Structural Analysis Results*

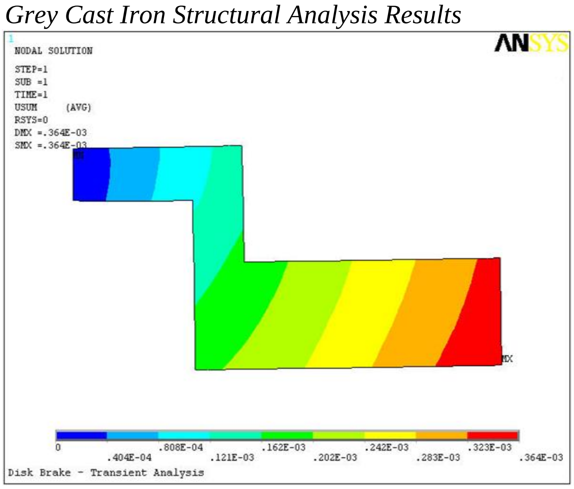


Fig. 10: Displacement

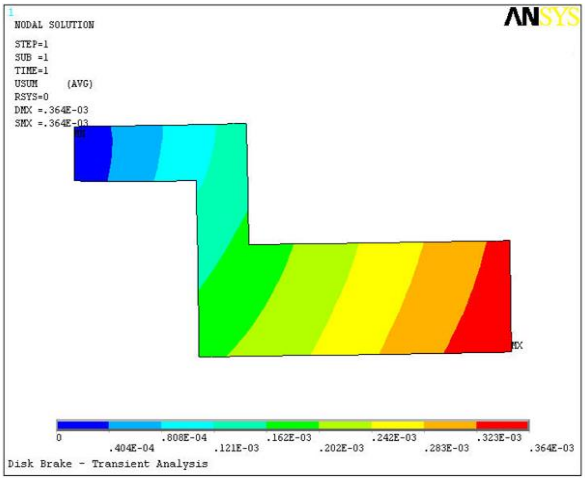


Fig. 11: Stress distribution

2) *FGM Displacement and Stress Distribution*

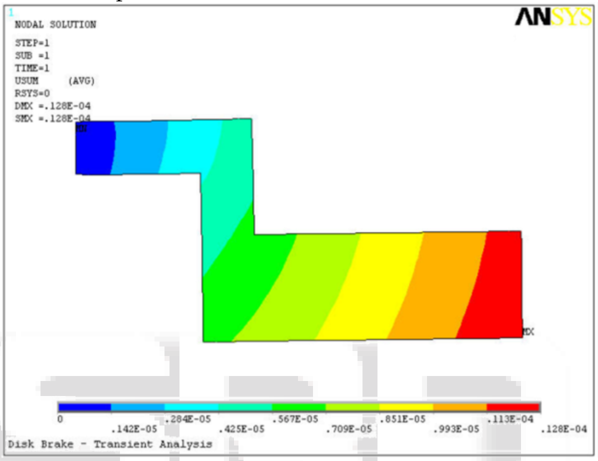


Fig. 12: Displacement

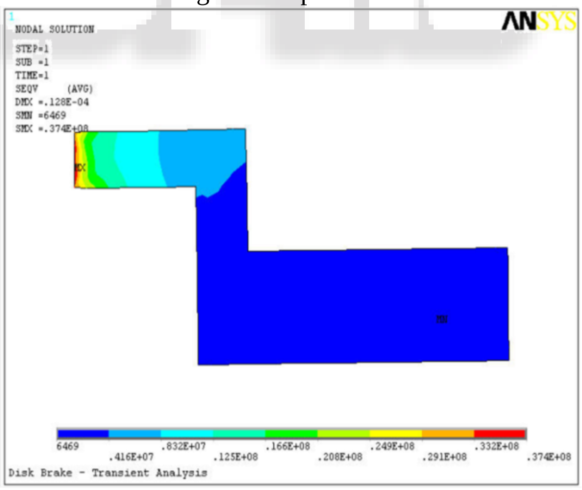


Fig. 13: Stress distribution

Material	Displacement(mm)	Stress(N/mm^2)
Grey cast iron	0.36	670
FGM	0.0128	37.4

Table 4: Stress and displacements

From the results shown above for all 2 brake materials, its been concluded that the displacements and stress values for the FGM material is very less than the values of other material[Grey CI] for the same thermal load and Structural loads. It's evident from the analysis, the best material for the brake Rotor is FGM as far as thermal and structural behavior is concerned in order to prevent "thermal elastic instability".

V. CONCLUSIONS

The study of transient thermal analysis of disk brake rotor for the different materials such grey cast iron and metal-ceramic has been carried out. ANSYS software is used to the transient thermal analysis problem with frictional heat generation. To obtain the simulation of thermal behavior appearing in different disk brake rotor material, the basic governing equation for the heat conduction is solved with the initial boundary conditions and the thermal load such as heat flux at the brake rotor and pad interface for the three materials. Through the axis symmetric disk brake model, the thermal elastic instability [TEI] phenomenon on the disc brake rotor surfaces has been investigated. It has been observed from the analysis; metal-ceramic is comparatively best material for the disc brake rotor as it dissipates heat rapidly to the atmosphere which is very important phenomenon as far as thermo- elastic instability factor is concerned.

The second part of the project i.e., structural analysis for the two materials generates excellent result by treating the problem as coupled field analysis. from the structural analysis results for all the 2 brake materials, for the same thermal load and Structural loads it’s been concluded that the displacements and stress values for the FGM material is very less than the values of other two material [Grey CI]. It’s proved from the analysis, the best material for the brake Rotor is FGM as far as thermal and structural behavior is considered in order to prevent “thermal elastic instability”.

REFERENCES

[1] Prashant Chavan, Amol Apte, Axisymmsetric analysis of bolted disc brake assembly to evaluate thermal stresses December 2012.
[2] V.P.Sergienko, V.M. Tkachev, and A.I. Stolyarov, Thermal-stress analysis of real brake systems December 2011.
[3] Azriszul Mohd Amin, Suzairin Mohd. Seri and Vijay R. Raghavan, study of the0temperature distribution in disk brakes by the method of order-of-magnitude analysis April2010.
[4] Janis Feldmanis, mathematical modeling of disc brake friction lining heat and wear.
[5] Samuel ARTUS, a brake disc's temperature estimation module.
[6] Muhammad Z.0Hassan, Peter C. Brooks and David C. Barton, Fully Coupled Thermal-Mechanical Analysis of Automotive Disc Brake Squeal.