

## **Design and Coupled Field Analysis of Solid and Vented Disc Brake Using Ansys and Matlab**

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### **Abstract**

Safety aspects in automotive engineering has been considered as a number one priority in development of new vehicle. Due to critical system in the vehicle, many of the researchers have conducted a study on brake system and its entire component. In this project we have conducted a study of performance of normal disc brake rotor of normal passenger at different speed when different materials (Carbon Ceramic & Grey Cast Iron) are used. The study is more concern of temperature distribution on disc brake rotor, deformation and stresses developed on it due to heat flux and temperature at different speeds. The widely used brake rotor material is Cast Iron which consumes much fuel due to its high specific gravity. The aim of this paper is to select the optimum material for the application of brake disc system emphasizing on the substitution of Cast Iron by any other light material. The present paper is aimed to study the given brake rotor for its stability and rigidity, for this Coupled field Analysis is carried out on a disc brake rotor to find out its deformation, stress when different materials are used. The theoretical calculations are carried out for finding pressure and MATLAB Software is used for Heat flow. Further procedure is carried by using CATIA and ANSYS WORKBENCH Software for modelling and Analysis.

**Key words:** Disc Brake, CATIA, ANSYS, Couple field analysis, Structural analysis, Transient analysis.

## Introduction

A literature review was conducted to investigate the past research that has been done in many areas related to this work:

GAO and Lin (2002) presented Transient temperature field analysis of a brake in a non-axisymmetric three-dimensional model [1]. An analytical model is presented in this paper for the determination of the contact temperature distribution on the working surface of a brake.

Voller, *et al.* (2003) performed an Analysis of automotive disc brake cooling characteristics [2]. The aim of this investigation was to study automotive disc brake cooling characteristics experimentally using a specially developed spin rig and numerically using FEM and CFD methods.

Choi and Lee (2004) presented a paper on Finite element analysis of transient thermo elastic behaviour in disk brakes [3]. A transient analysis for thermo elastic contact problem of disk brakes with frictional heat generation is performed using the finite element method.

Qi and Day (2007) discussed that using a designed experiment approach, the factors affecting the interface temperature, including the number of braking applications, sliding speed, braking load and type of friction material were studied [4].

Eltoukhy and Asfour (2008) presented a paper on Braking Process in Automobiles Investigation of the Thermo elastic Instability phenomenon. In this chapter a case study regarding a transient analysis of the thermo elastic contact problem for disk brakes with frictional heat generation, performed using the finite element analysis (FEA) method is described in details. The computational results are presented for the distribution of the temperature on the friction surface between the contacting bodies (the disk and the pad) [5].

Zaid(2009) presented a paper on an investigation of disc brake rotor by Finite element analysis. In this paper, the author has conducted a study on ventilated disc brake rotor of normal passenger vehicle with full load of capacity [6].

## Statement of Problem

Brakes is such a crucial system in stopping the vehicle on all moving stages including braking during high speed, sharp cornering, traffic jam and downhill. All of those braking moments give a different value of temperature distribution and thermal stress. Good performance of disc brake rotor comes from good material with better mechanical and thermal properties. Good designs of disc brake rotor are varying across the range of the vehicles. There are different design and performance of disc brake rotor if compared between passenger, commercial and heavy duty vehicle. There are also other constraints such as cost, weight, manufacturing capability, robustness and reliability, packaging, maintenance and servicing. This project concerns of the temperature distribution and constraint of the disc brake rotor on different materials. Most of the passenger cars today have disc brake rotors that are made of grey cast iron. Grey cast iron is chosen for its relatively high thermal conductivity, high thermal diffusivity and low cost. In this project, the author will investigate on the thermal issues of normal passenger vehicle disc brake rotor for

different materials, where the investigation are to determine the temperature behaviour and stresses developed on the disc brake rotor made of different materials due to severe braking of the disc brake rotor by using Finite Element Analysis(FEA). Braking performance of a vehicle can be significantly affected by the temperature rise in the brake components. High temperature during braking will caused to brake fade, premature wear, Brake fluid vaporization, Bearing failure, Thermal cracks, Thermally-excited vibration. Therefore, it is important to study and predict the temperature rise of a given brake component and assess its thermal performance in the early design stage. Finite element analysis (FEA) has been preferred and chosen method to investigate some of the above concerns such as disc brake rotor temperature rise and thermal cracks.

### **Objective and Scope**

The aim at the end of this project is to study the behaviour of disc brake rotor when different materials were used and suggest the optimum material in terms of performance as well as cost. In achieving this aim, project objectives are set as below:

- To understand working principles, components, standards and theories through a literature study.
- To understand the working principle of FEA Software (ANSYS)
- To understand the fundamental of heat transfer through thermal analysis of disc brake rotor.
- To study the distribution of temperature, stress on disc brake rotor at different speeds.

The knowledge gained from this project is to be able to understand the steps needed in thermal analysis of disc brake rotor by using FEA method. The methods used in this project can later be used in future as reference for similar research and development. There is the wide range of study on the disc brake rotor. The disc brake rotor could be studied on the various areas such as material improvement on the disc brake rotor, vibration on the disc brake, noise and squeal of the disc brake and thermal stress analysis on the disc brake rotor. However, on this project, the author will intend to emphasize details on the thermal analysis on the disc brake rotor of normal passenger vehicle with full capacity of passenger.

### **Research Methodology:**

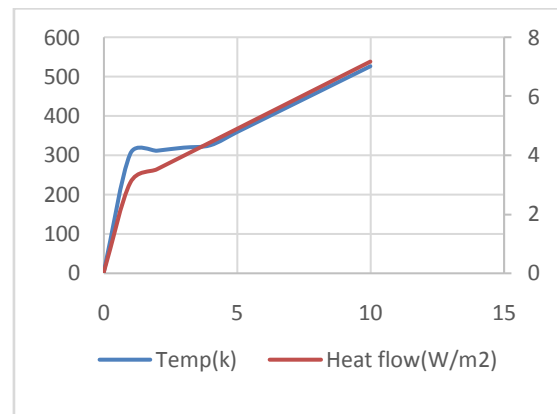
Begin with a literature review, a lot of paper's and journal has been read up and a part of it has been considered in this project. Later, the precise dimensions have been used to develop a 3D drawing by using CATIA. In the second stage, thermal analysis has been done where the heat flux has been calculated. Further Heat Flow is taken from MATLAB software using coding and Temperature values are taken from it and substituted in ANSYS WORKBENCH for thermal results. Heat flux is calculated based on kinetic energy processed by the rotor rotating at a speed of 90kmph of a normal passenger vehicle. Later, value of heat flux and temperature has been applied

on finite element analysis and temperature distribution Next, the fractional 3D model of disc brake rotor has been transfer to finite element software which is ANSYS.

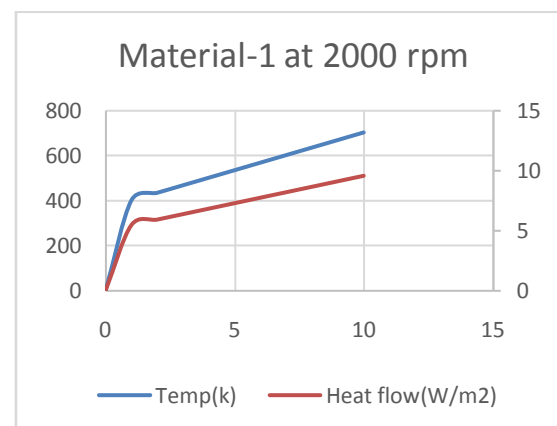
Thermal analysis has been done on transient state and static structural analysis has been done. Assigning material properties, angular velocity to the meshing model has been done in this stage. Then, completed meshing model has been submitted for analysis. Finally deformation, stresses developed at different speeds 1500rpm, 2000rpm, 2500rpm. Same procedure has been adopted for different materials. Tabulating all the results obtained and better material for is proposed.

### Matlab Output Valves

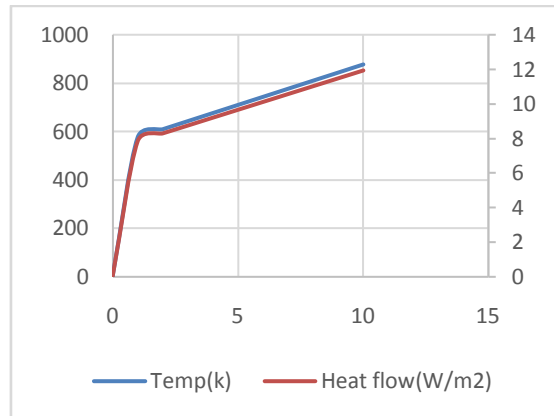
The coding is generated in MATLAB to obtain the temperature and heat flow values for the disc operating at different speeds. The plots are shown below



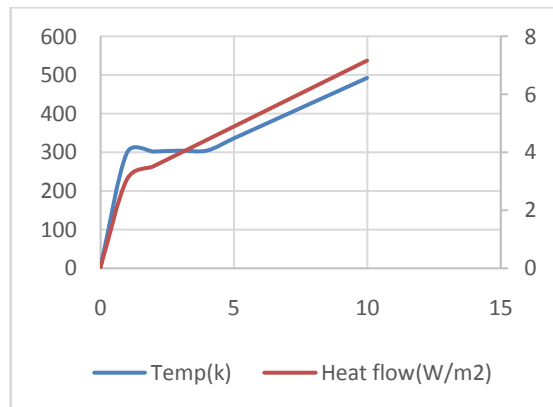
**Figure 1:** Temperature and Heat flow for grey cast iron material when disc is operating at 1500 rpm.



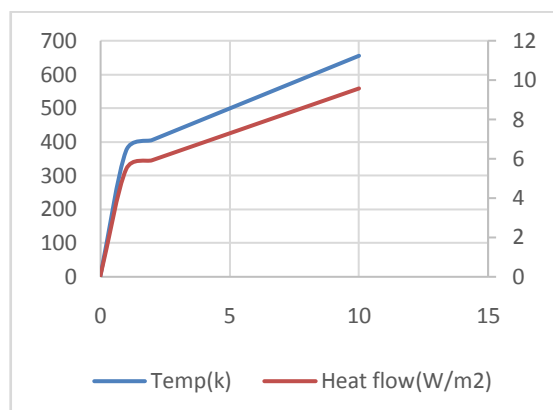
**Figure 2:** Temperature and Heat flow for grey cast iron material when disc is operating at 2000 rpm.



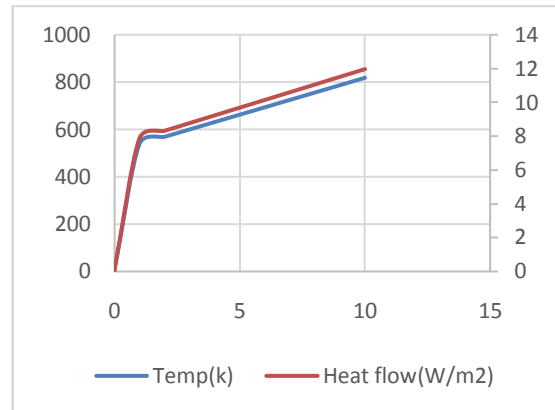
**Figure 3:** Temperature and Heat flow for grey cast iron material when disc is operating at 2500 rpm.



**Figure 4:** Temperature and Heat flow for carbon ceramic matrix material when disc is operating at 1500 rpm.



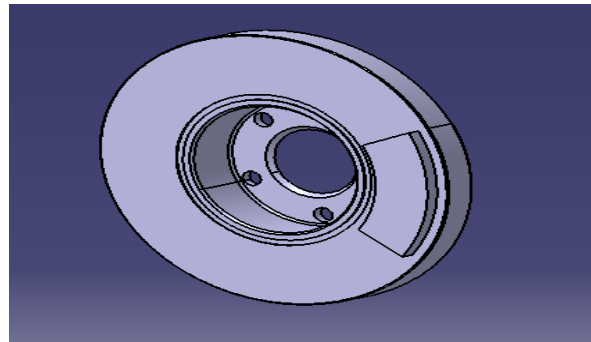
**Figure 5:** Temperature and Heat flow for carbon ceramic matrix material when disc is operating at 1500 rpm.



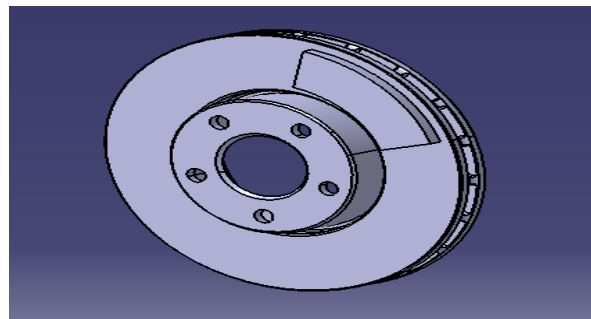
**Figure 6:** Temperature and Heat flow for carbon ceramic matrix material when disc is operating at 2500 rpm.

### Modeling and Analysis

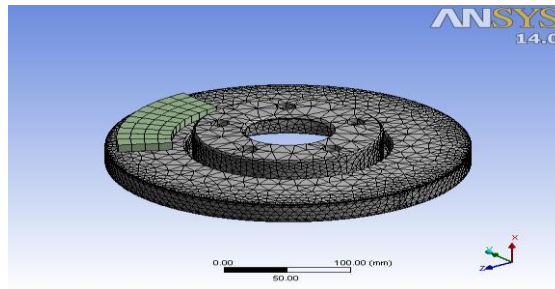
The modelling of solid and vented disc brakes is carried out using CATIA software. The analysis is done in ANSYS Workbench software. The figures are shown below:



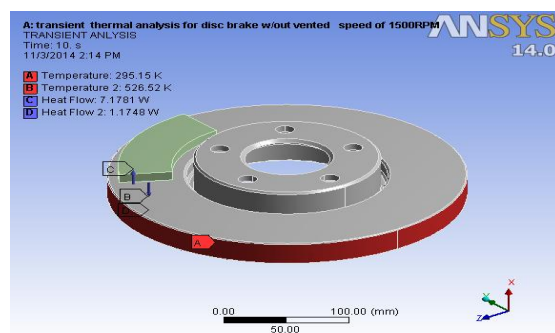
**Figure 7:** Modeling of Solid disc



**Figure 8:** Modeling of Vented disc



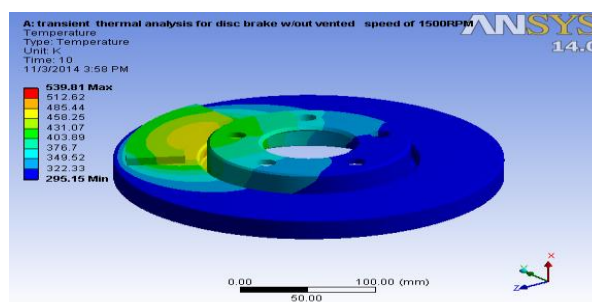
**Figure 9:** Meshing of Solid Disc



**Figure 10:** Transient Analysis of Solid Disc

**Coupled Field Analysis:**

First by selecting the grey cast iron material for discs the coupled field analysis was done to obtain the maximum Temperature, Total Heat Flux distribution, Equivalent Stress and total deformation for Solid and vented discs operating at 1500 rpm. The results are as shown below:



**Figure 11:** Temperature of Solid disc

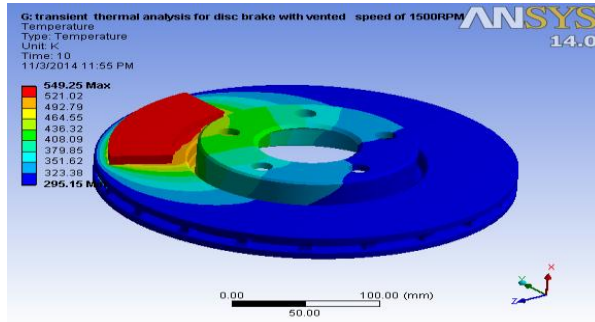


Figure 12: Temperature of vented disc

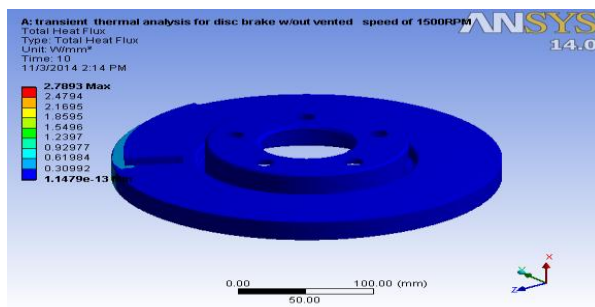


Figure 13: Heat flux for Solid disc

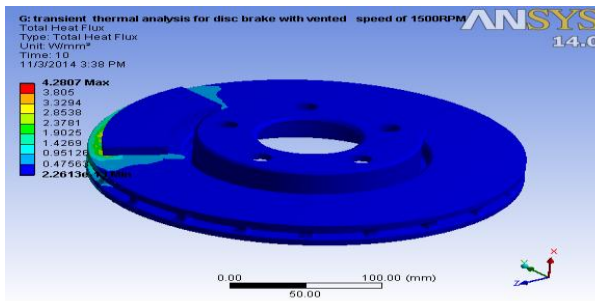


Figure 14: Heat flux for vented disc

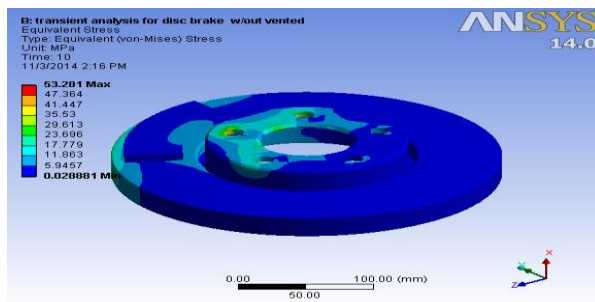


Figure 15: Equivalent Stress for solid disc

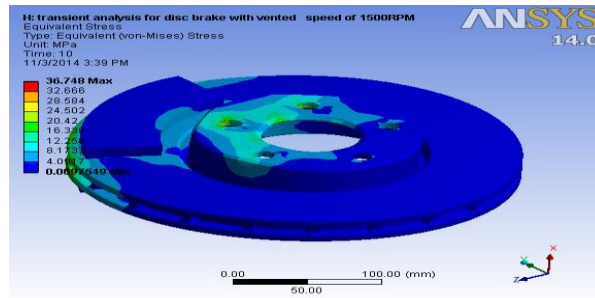


Figure 16: Equivalent Stress for vented disc

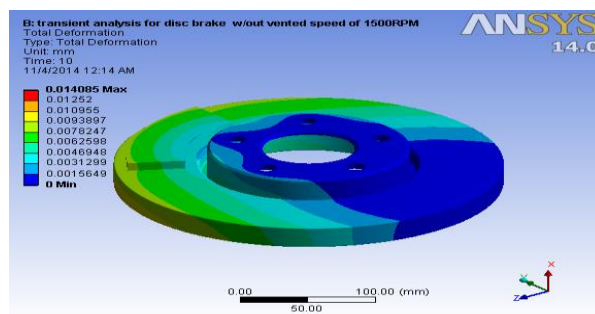


Figure 17: Total Deformation for solid disc

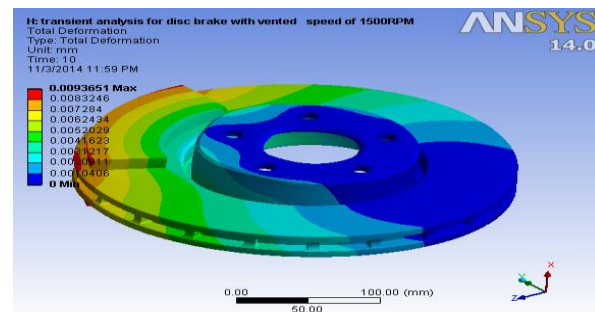
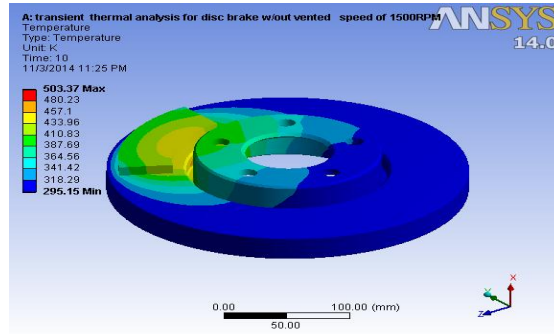
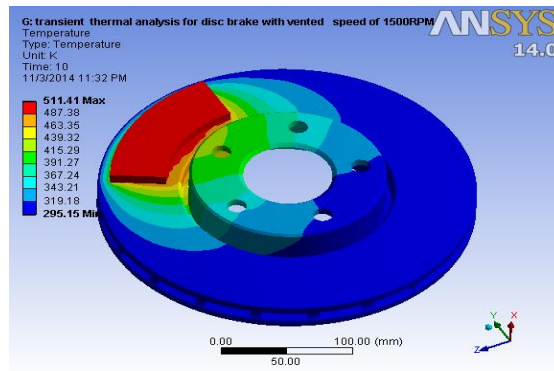


Figure 18: Total Deformation for vented disc

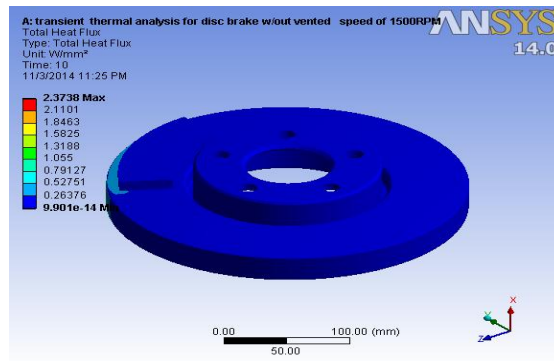
Later the Analysis was done by selecting the Carbon ceramic matrix material for the discs and the results are as shown below:



**Figure 19: Temperature of Solid disc**



**Figure 20: Temperature of vented disc**



**Figure 21: Heat flux for Solid disc**

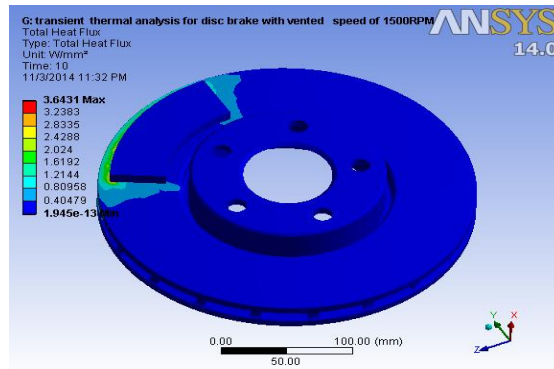


Figure 22: Heat flux for vented disc

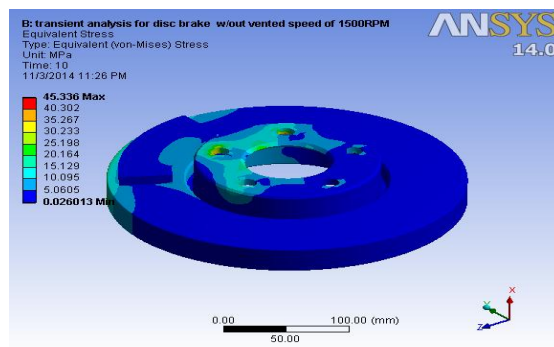


Figure 23: Equivalent Stress for solid disc

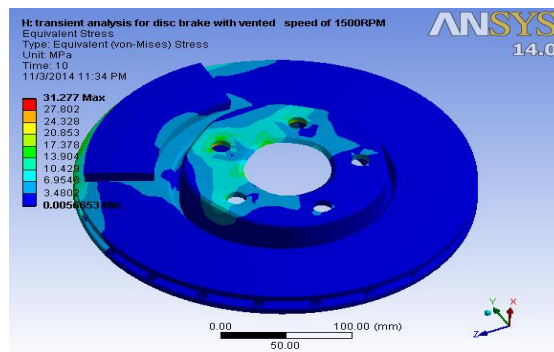


Figure 24: Equivalent Stress for vented disc

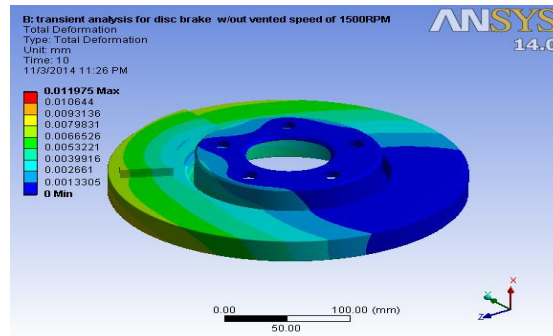


Figure 25: Total Deformation for solid disc

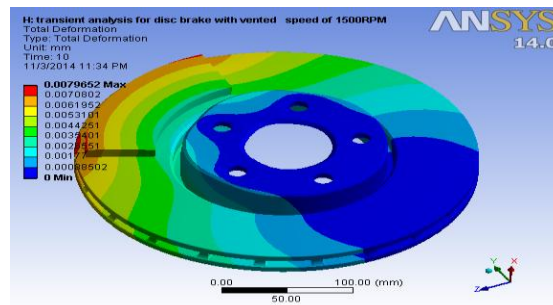


Figure 26: Total Deformation for vented disc

## Results and Discussions

The obtained results were compared for different discs operating at different speeds and are tabulated as shown below

Table 1: MATERIAL-1(Gray Cast Iron)

	SOLID DISC			VENTED DISC		
Rpm	1500	2000	2500	1500	2000	2500
Temp (K)	539.81	725.41	911.01	549.25	742.02	934.79
TOTAL HEAT FLUX (W/Mm <sup>2</sup> )	2.7893	5.6579	8.1255	4.2807	7.528	10.775
Directional Heat Flux (W/Mm <sup>2</sup> ) (X-Axis)	2.712	4.4183	6.3255	2.6125	4.5948	6.5769
Directional Heat Flux (W/Mm <sup>2</sup> ) (Y-Axis)	2.1389	4.3522	6.2297	3.3235	5.8448	8.3661
Directional Heat Flux (W/Mm <sup>2</sup> ) (Z-Axis)	1.8209	3.7051	5.3033	3.7861	6.6594	9.532

<b>Equivalent Stress (Mpa)</b>	53.28	138.25	186.46	36.74	64.691	92.483
<b>Total Deformation (Mm)</b>	0.0140	0.0345	0.0494	0.0093	0.0164	0.0236

**Table 2:** MATERIAL-2(Carbon Ceramic Matrix)

	<b>SOLID DISC</b>			<b>VENTED DISC</b>		
<b>Rpm</b>	1500	2000	2500	1500	2000	2500
<b>Temp(K)</b>	503.37	676.83	858.29	511.41	691.57	871.72
<b>Total Heat Flux(W/Mm<sup>2</sup>)</b>	2.3738	5.0349	7.3223	3.6431	6.6781	9.713
<b>Directional Heat Flux (W/Mm<sup>2</sup>) (X-Axis)</b>	1.0847	3.9194	5.7808	2.2236	4.076	5.9284
<b>Directional Heat Flux (W/Mm<sup>2</sup>) (Y-Axis)</b>	1.8203	3.8608	5.6154	2.8285	5.1849	7.5412
<b>Directional Heat Flux (W/Mm<sup>2</sup>) (Z-Axis)</b>	2.1389	6.2297	9.7804	3.2459	8.3661	8.5922
<b>Equivalent Stress (Mpa)</b>	45.336	115.54	168.08	31.277	57.321	83.365
<b>Total Deformation (Mm)</b>	0.0197	0.0306	0.0445	0.0079	0.0146	0.0293

**Table 3:** Comparison of Materials at Maximum operating speed (2500 rpm)

<b>MATERIAL</b>	<b>STRESS (MPa)</b>	<b>TOTAL DEFORMATION (mm)</b>
<b>GRAY CAST IRON</b>	92.483	0.12366
<b>CARBON CERAMIC MATRIX</b>	83.365	0.016499

## Conclusions

The Coupled Field Analysis (Static Structural and Transient Thermal) is carried out for solid disc and vented disc brakes with different materials (GRAY CAST IRON & CARBON CERAMIC) by varying the speeds at 1500 rpm, 2000rpm and 2500rpm by using ANSYS. The input values (heat flow) for Transient Thermal analysis are obtained from MATLAB.

The following conclusions are drawn from the present work:

- By using optimization technique the disc mass is reduced of 15% by giving vented to the disc brake.
- Using MATLAB coding the heat flow and temperatures are generated and imported to ANSYS workbench for transient analysis.
- Transient thermal analysis is carried out using the direct time integration technique for the application of braking force due to friction for time duration of 4, 5 and 6 up to 10 seconds.

- The maximum temperature obtained in the disc is at the contact surface (vented disc with carbon ceramic material) and is observed to be at different speeds 1500, 2000, 2500rpm is follows 511.4k, 691.57, 871.72 k. compared to without vented disc temperatures are varies.
- Coupled Field Analysis is carried out by coupling the thermal solution to the structural analysis and the maximum equivalent stresses is observed at different speeds 1500, 2000, 2500rpm is as follows 31.27mpa, 57.32mpa, 83.365 M Pa. is low compared to without vented so the vented disc is better.
- The Brake disc design is safe based on the Strength and Rigidity Criteria.

To arrive at a best combination of parameters of the Disc Brake like Material, Transient Thermal and Structural Analysis for two different materials in each of the different analyses are carried out separately and the results were compared.

Comparing the different results obtained from the analysis, it is concluded that disc brake of material Carbon ceramic matrix is the Best possible material for the present application.

Average percentage of carbon ceramic matrix is reduced 15% of stresses and deformation compared to gray cast iron material. This is important to understand action force and friction force on the disc brake carbon ceramic material, which use disc brake works more efficiently, which can help to reduce the accident that may happen in each day.

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