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Structural and Thermal Analysis of Rotor Disc for Weight Reduction

Chetan Kumar Yadav , Upendra Kumar Joshi[2]
[1]*M.E. Scholar, Dept. of Mechanical Engineering, Jabalpur Engineering College, Jabalpur,India*
[2]*Associate Prof., Dept. of Mechanical Engineering, Jabalpur Engineering College, Jabalpur,India*

Abstract: ***The Disc brake is a Mechanical device which is used to slow down or stop the vehicle. This is achieved by dissipating the kinetic energy possessed by the vehicle in the form of heat into the environment by the action of friction between disc rotor and brake pad. If the rotor gets too hot then It will not be able to dissipate enough heat and the brake will fail, this high temperature also increase the wear rate of brake pads, along with this high thermal stresses will get generated which can be fatal for the rotor. In this paper we will study the vented disc rotor of Honda City Car. Vented disc rotor will be used for coupled thermal and structural analysis. Gray Cast iron and SiC(silicon carbide) will be used and their results will be compared to find out the best.***

Keyword: Vented Disc brake, Design, Structural analysis, thermal analysis, weight reduction

I. INTRODUCTION

A. Disc brake

A disc brake is a type of brake that uses calipers to squeeze pairs of pads against a disc or rotor to create friction. This action retards the rotation of a shaft, such as a vehicle axle, either to reduce its rotational speed or to hold it stationary. The energy of motion is converted into waste heat which must be dispersed. The brake disc (or rotor) is the rotating part of a wheel's disc brake assembly, against which the brake pads are applied. The material is typically gray iron, a form of cast iron. The design of the discs varies somewhat. Some are simply solid, but others are hollowed out with fins or vanes joining together the disc's two contact surfaces (usually included as part of a casting process). The weight and power of the vehicle determines the need for ventilated discs.The "ventilated" disc design helps to dissipate the generated heat and is commonly used on the more-heavily loaded front discs. Under extreme conditions, such as descending a steep hill with a heavy load, or repeated high-speed decelerations, drum brakes would often fade and lose effectiveness. Compared with their counterpart, disc brakes would operate with less fade under the same conditions. An additional advantage of disc brakes is their linear relationship between brake torque and pad/rotor friction coefficient.

B. Objective

In a current scenario the Automobile industry is very much concerned about weight reduction and hence new materials and composites are being developed. Composite materials such as Carbon Ceramic and SiC Silicon Carbide shows good thermal and physical properties. Our aim is to design a disc brake rotor with significant weight reduction without compromising the performance and strength. The new disk brake must have enough strength to perform at high temperatures which are raised during braking because high temperatures drastically affect the overall strength of component and increases wear rate.

II. EXPERIMENTAL WORK

A. Designing of 3D Model in Autodesk Fusion 360.

Autodesk fusion 360 is the latest 3D CAD software released by Autodesk. The 3D Model created in this software. Vented disc rotor is created as per the dimensions given below

Disc dimensions
outer diameter = 240 mm
inner diameter = 148 mm
disc thickness = 20 mm
total height = 42 mm

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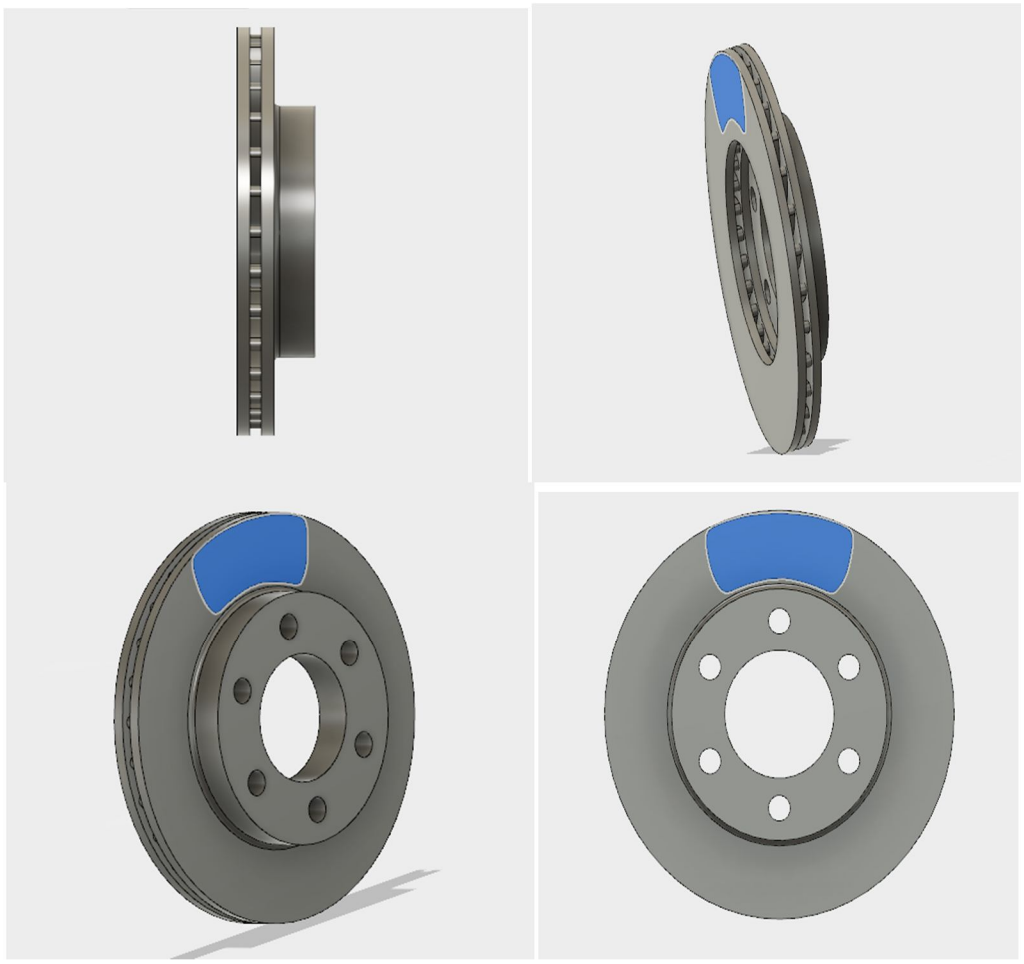

B. Boundary Conditions

Properties	Gray Cast iron	Silicon Carbide
Density (kg/m^3)	7200	3100
Young's Modulus(GPa)	110	410
Poisson's Ratio	0.28	0.14
Specific Heat (J/Kg-K)	447	750
Thermal Conductivity (W/m-K)	52	120
Coeff of thermal exp (10^{-5} C^{-1})	1.1	0.4

Table 1 refer [8]

The mass of Honda city car is 1200kg, we assume that 4 passengers are sitting inside the car which further add 300 kg to it so total mass is 1500kg.
Mass = 1500kg
Initial velocity of car = 150 km/hr or 41.66 m/s .
The stopping distance is set to 120 m. (assuming normal braking condition)
Deacceleration = $41.66^2/(-2*120) = -7.23$ m/s^2 .
Time of braking = 41.66/7.23 = 5.67s.
Kinetic energy of car before braking = $0.5*1500*41.66^2 = 1301666.7$ J
This energy has to be dissipated by the brakes in order to stop the car. During breaking conditions,There is a dynamic weight shift and 70% or the energy is dissipated by front brakes. Energy dissipation per front wheel is (0.7*1301666.7)/2 = 455583.35 J
Power = 455583.35 J/5.67s = 79094.3 W
Heat flux = power/area of contacting surfaces = 79094.3 W/0.0614 m^2 = 1288180.8 W/m$^{2.}$

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The tyre diameter of Honda city is 60cm and hence we can calculate the angular velocity which comes out to be 138 rad/s .
Torque = 570 Nm.
Assuming uniform pressure theory effective radius can be calculated.
R_{eff} = 99mm and Frictional force/break pad = 570/(2*99*10^{-3}m) = 2878.78 N
F_n (Normal force) = 2878.78/0.3 = 9595.95 N
Break pad area = 4000mm^2
Pressure per breakpad = 9595.95/4000 = 2.4 MPa
Heat transfer coefficient ranges from 90W/m^2K to 10 W/m^2K as vehical slows down.

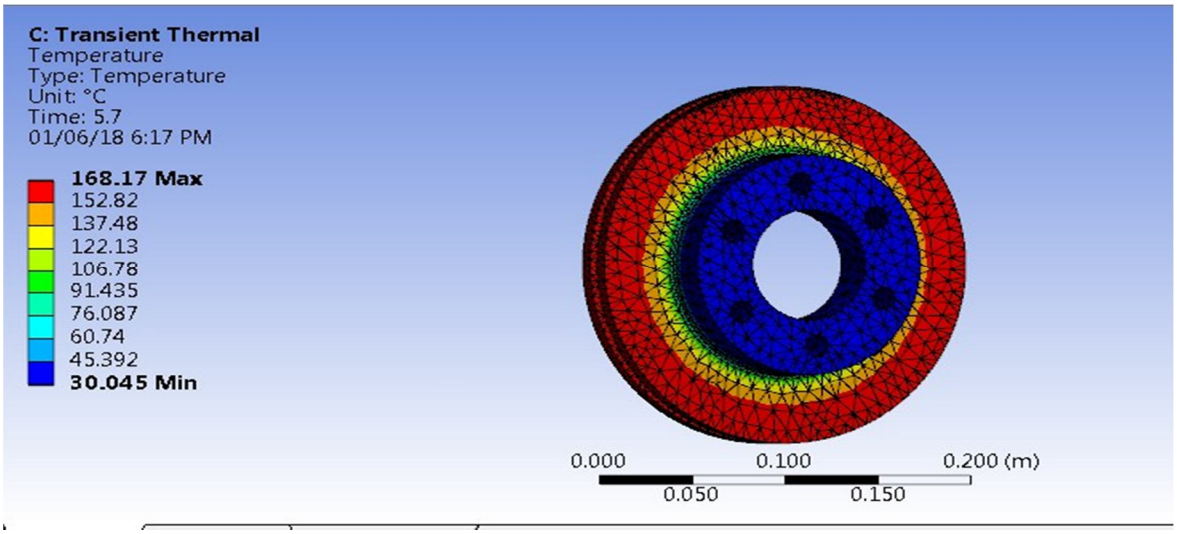
C. Analysis

At first transient thermal analysis will be performed to find out the temperature variation in the model and then the temperature data will be exported to structural analysis where we will study the performance of disc rotor under high temperature conditions.

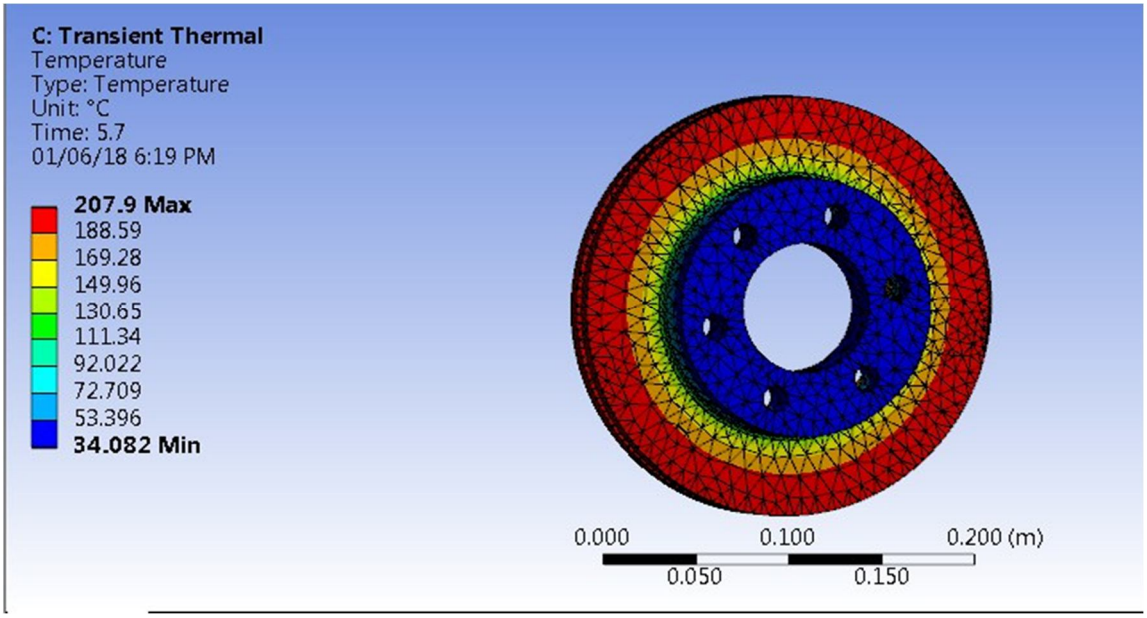
D. Transient thermal analysis

The heat flux changes with respect to time as the vehicle slows down and to meet this criteria, transient thermal analysis is chosen

1) Gray Cast iron



2) Silicon Carbide



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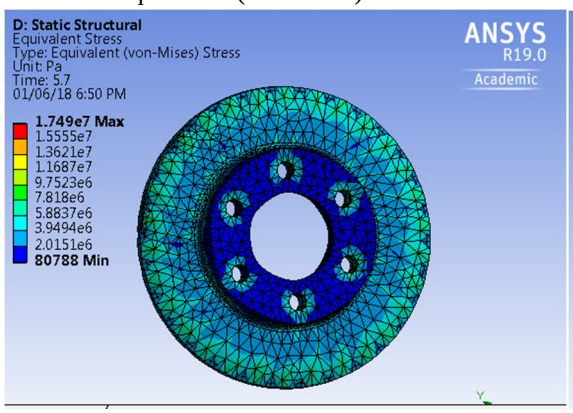
E. Static Structural Analysis

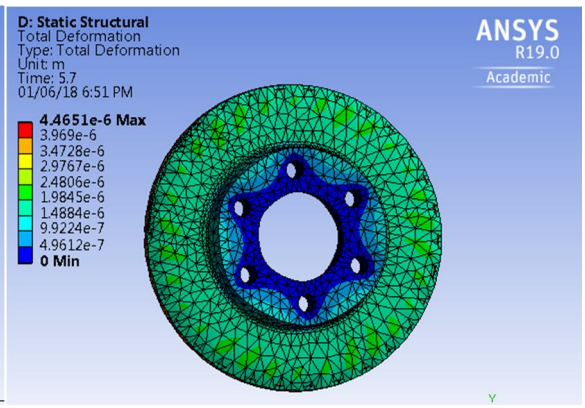
During braking conditions, the rotor experiences both structural and thermal loads and hence the analysis should be performed to analyse the break under static loads such as torque,pressure and inertial loads.

1) Gray Cast iron

Equivalent (von-mises) Stress

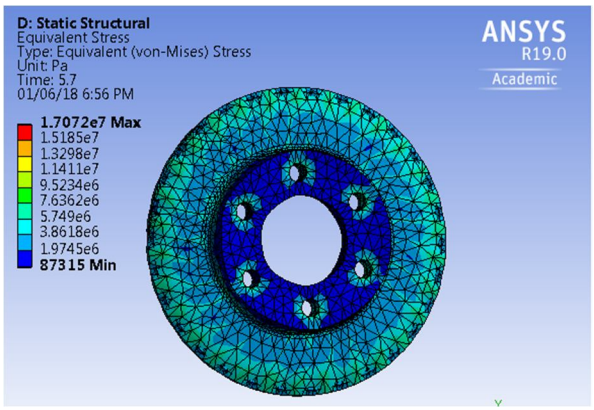


Total deformation

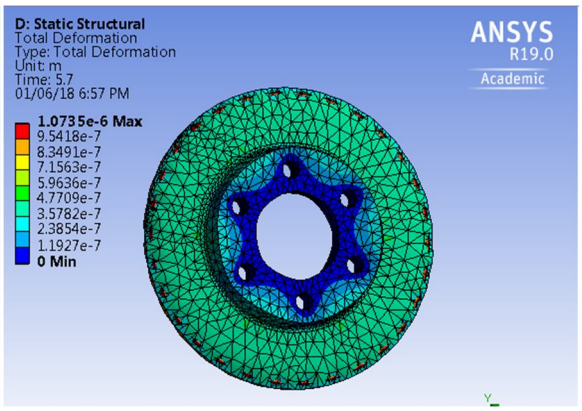


2) Silicon Carbide

Equivalent (von-mises) Stress



Total deformation



III. RESULT

Material/Properties	MASS (kg)	MAXIMUM TEMPERATURE(˚C)	EQUIVALENT STRESS (MPa)	TOTAL DEFORMATION(mm)
GRAY CAST IRON	5.44	168.17	17.49	0.004465
SILICON CARBIDE	2.3458	207.9	17.07	0.001707

Table 2

IV. DISCUSSION

Numerical Analysis now plays a major role in the design of new components, we have performed FEA and compared two most widely used materials and As per the results obtained from the analysis, we can say that the silicon carbide rotor performed similar to gray cast iron rotor and did not fail in the test. Also the weight of silicon carbide rotor is almost half as compared to the gray cast iron rotor. Thought the temperature obtained in silicon carbide rotor is more but can easily be tolerated. The parameters obtained from the analysis are under the failure limits.

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V. CONCLUSION

" The analysis was successful and a total of 56.8 % reduction in mass of disc rotor is achieved. This is a significant reduction in weight and hence we can say that very soon composite materials will overcome traditional materials in brake rotor manufacturing "

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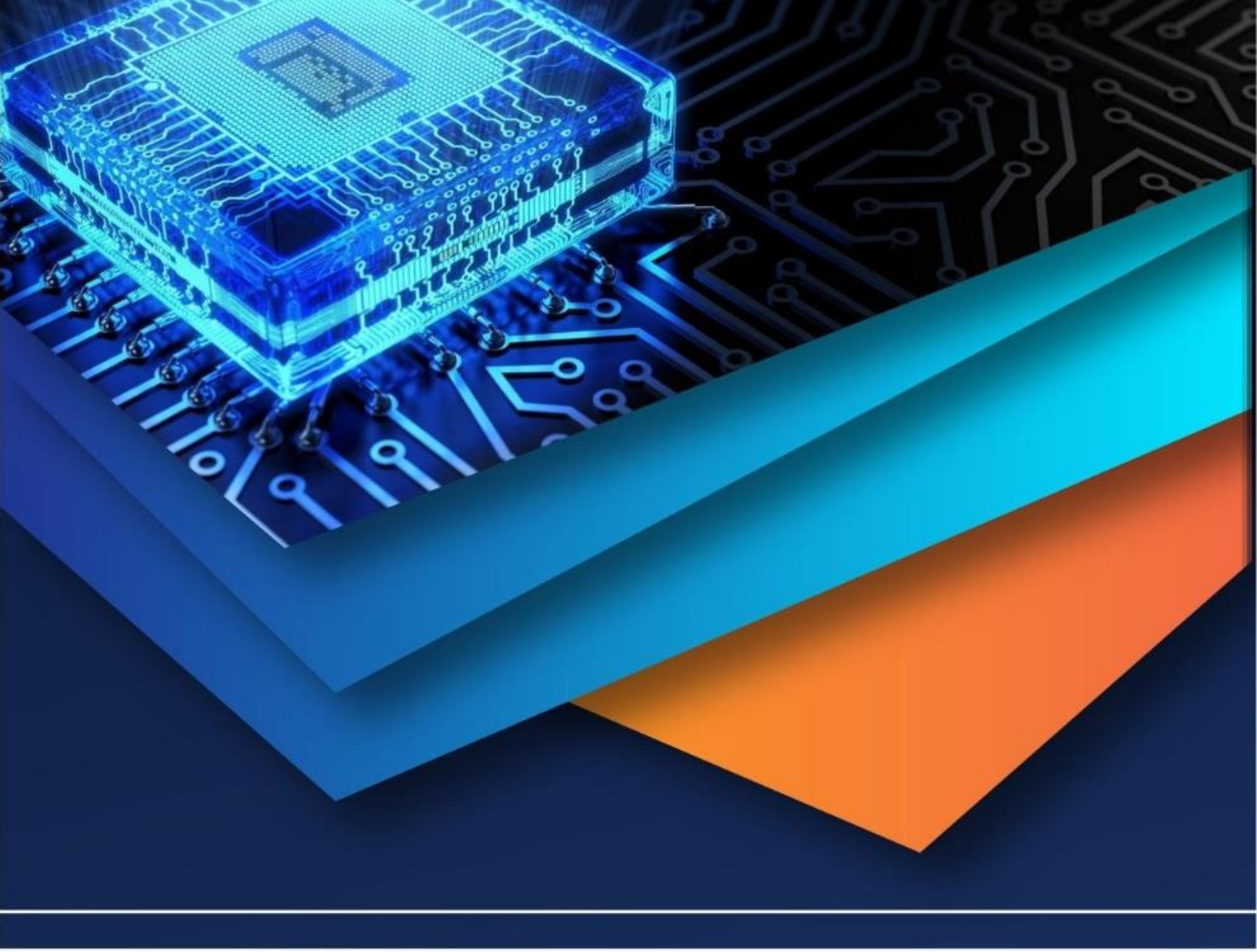

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