Coupled Field (Thermal + Structural) Analysis of Disc Brake

Mohite Komal[1], Kosbe Pradnya[2]
[1,2]Dept of Mechanical Engineering
[1, 2]JSPM's JSCOE, Hadapsar, Pune

Abstract- *The brake system is important component in an automobile vehicle. The vehicle without brake system will put a passenger in unsafe position. So for all vehicles have proper brake system. During braking the kinetic energy and potential energy of a moving vehicle is converted to thermal energy in the form of frictional heat in the brake disc and pads, this heat transferred to surrounding air to ensure safe operation. The actual disc brake rotor has no holes; The design is changed by giving holes in the disc brake rotor for more heat dissipation. The disc brake modeling is to be done in CATIA V5 and analysis is to be done in ANSYS 16.0. Analysis is done by changing the design of disc brake.The disc brake is made up of gray cast iron with different profiles, the static structural & transient analysis is carried out at varying pressure and time for selection of suitable profile. The best type of disc brake has been suggested based on the magnitude of temperature distribution and total heat flux.*

Keywords- Disc brake, CATIA, Analysis, Vented disc

I. INTRODUCTION

A brake is defined as a mechanical device, which is used to absorb the energy possessed by a moving system or mechanism by means of friction. The primary purpose of the brake is to slow down or completely stop the motion of a moving system, such as a rotating drum, machine or vehicle. It is also used to hold the parts of the system in position at rest. An automobile brake is used either to reduce the speed of the car or to bring it to rest. It is also used to keep the car stationary on the downhill road. The energy absorbed by the brake can be either kinetic or potential or both. In automobile application, the absorbs the kinetic energy of the moving vehicle. In hoists and elevators, the brake absorbs the potential energy released by the objects during the braking period. The energy absorbed by brake is converted into heat energy and dissipated to the surroundings. Heat dissipation is the serious problem in brake applications.

There are three types of brakes are as follows:1) Mechanical brakes 2) Hydraulic and pneumatic brakes 3) Electrical brakes. Mechanical brakes are classified into two groups according to the direction of the actuating force, namely, radial brakes and axial brakes. Internal and external shoe brakes are radial brakes, while disc and cone brakes are axial brakes.

It is consist of a cast iron disc bolted to the wheel hub and a stationary housing is called caliper. The caliper consists of Brake pads, a piston and hydraulic system as shown in fig 1. The caliper is connected to stationary part of vehicle, like the axle casing or the stub axle and it has two parts, each part containing a piston. The friction pad held in position by retaining pins, spring plates etc. the cavity is provided in the caliper for the fluid to enter or leave each housing in between each piston and the disc. Cylinder contains rubber-sealing ring between the cylinder and piston.

If the wheel is stopped, the friction material in the form of brake pads, mounted on a device is called a brake caliper. The brake pad acting force on both sides of the disc mechanically, hydraulically, pneumatically or electromagnetically. Friction causes the disc and attached wheel to slow or stop. Brake is used for converting motion to heat, and if the brakes get too hot, they become less effective, this phenomenon is called brake fade. Disc brakes offer better stopping performance compared to drum brake, because the disc is more readily cooled.

Principle: The applied force (pressure) acts on the brake pads, which comes into contact with the moving disc. At this point of time due to friction the relative motion is constrained.

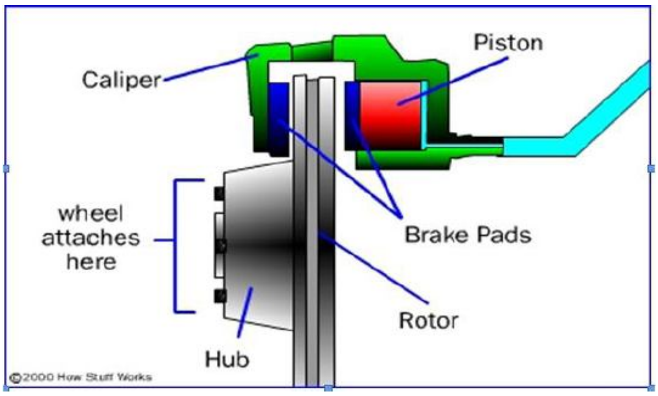


Fig. 1: Working principle of disc brake

Working: When the brakes are applied, hydraulically pistons are moves the friction pads in to contact with the disc, applying equal and opposite forces on it. When brakes are released the rubber-sealing ring acts as return spring and retracts the pistons and the friction pads away from the disc. The main components of the disc brake are:

- The Brake pads
- The caliper, which contains the piston
- The Rotor, which is mounted to the hub

There are two pads, on either side of the disk, in the form of annular sector. The friction lining is attached to each pad. A caliper attached to non-rotating member exerts a force P on each pad. When the pads are pressed against the rotating disk, the friction force between the surface of friction lining and the disk retards the speed and finally stops the disk. The brake pad occupies only a small portion of the disk, where the heat is generated due to friction. The complete surface area of the disk is available for dissipation of heat.

II. HEAT FLUXCALCULATION

The Specification of commercial vehicle is taken for calculating the heat flux created during maximum speed condition. The maximum friction force created will be found to find the deceleration to find the time taken to stop the vehicle.

Table 1 Disc specification

Disc diameter(D)	271.40 mm
Disc material	Gray Cast Iron
Coefficient of friction (μ)	0.3
Mass of the vehicle(M)	2510 kg
Maximum speed (V)	100 Km/hr
Acceleration due to gravity (g)	9.81 m/s^2

$F = \mu . M . g$ (1)

Hence deceleration of the vehicle is $a = F / M$ (2)

Time taken to stop the vehicle is $t = v / a$ (3)

In this case it is assumed that entire Kinetic energy is converted into heat energy hence Kinetic energy is

$K.E. = 0.5\, M\, V^2$ (4)

$= 0.5\ (2510)\ (27.7778)^2 = 968365.781$ J = 968.365781 KJ

Total Kinetic energy is equal to Heat Generated = K.E./ 4= $\frac{968.365781}{4}$ =242.0914453 KJ

Heat flux is defined as heat power per unit time and per unit area. Hence heat flux will be $H.F = P / t / A$

Table 2 Area of Contact for Different Discs

Sr.No.	Types of Disc	Area of contact in m^2
1	Vented Disc	0.06952
2	Slotted Disc	0.067409
3	Drilled & SlottedDisc	0.066698

Results of Heat Flux

V in Km/hr	a in m/s^2	T in sec	Vented Disc in W/m^2	Slotted Disc in W/m^2	Drilled & Slotted Disc in W/m^2
30	2.943	2.8	1229818.97	1268332.34	1281852.751
50	2.943	4.7	737891.382	760999.405	769111.6508
80	2.943	7.5	461182.114	475624.628	480694.7817
100	2.943	9.5	368945.691	380499.702	384555.8254

III. COUPLED-FIELD ANALYSIS

The Steady state thermal analysis of the brake discs was done in Ansys Workbench v16. Ansys makes use of FEM (Finite elementmethod) to estimate the results of a problem based on the applied loads, boundary conditions and material properties which are provided as inputs. The results can also be simulated.

Table 3 Material properties of GrayCast Iron

Properties	Gray Cast Iron
Density, ρ	7100 Kg/m^3
Thermal conductivity, k	54 W/mK
Young's Modulus , E	125x10^9 N/m^2
Poisson's Ratio, υ	0.25
Specific Heat , Cp	586 J/Kg-K
Coefficient of Expansion, α	8.1x10^{-6}/K
Ultimate Strength	2400 MPa

Table 4Material properties of Brake Pad

Properties	Brake Pad
Coefficient of Friction,μ	0.576
Thermal conductivity, k	1.080 W/mK
Tensile Strength	9.60N/mm^2
Density, ρ	2252 Kg/m^3

Case	Velocity of vehicle in km/hr	Stopping Time in sec	Pressure in MPa
1	30	2.8	2
2	50	4.7	4
3	80	7.5	6
4	100	9.5	8

A. Analysis ofVented Disc

The analysis is performed on the different disc brake profiles with gray cast iron discs and pads. Bolt holes of the mounting zone are applied with fixed boundary conditions and pressure is applied on the both pads varying from 2 MPa to 8 MPa.

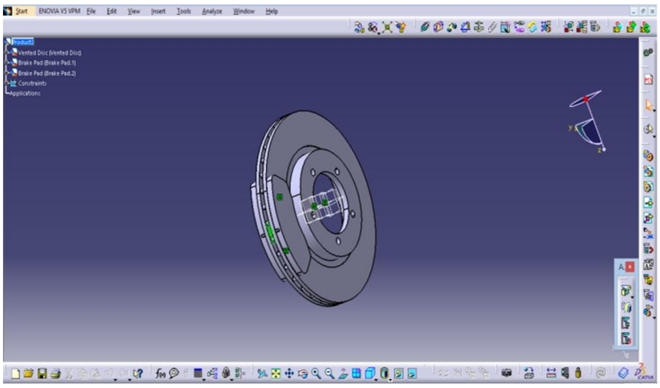


Fig.2 Ventilated disc with brake pad assembly CATIA model

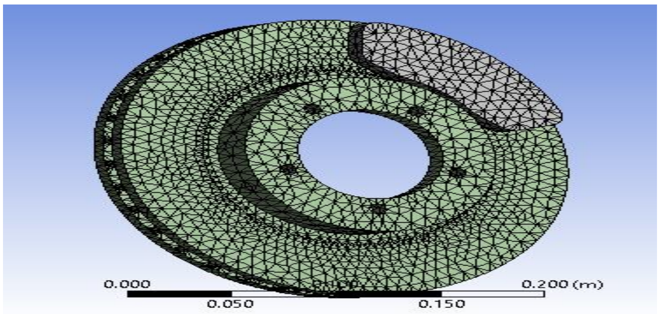


Fig. 3 Meshing of Ventilated type disc brake

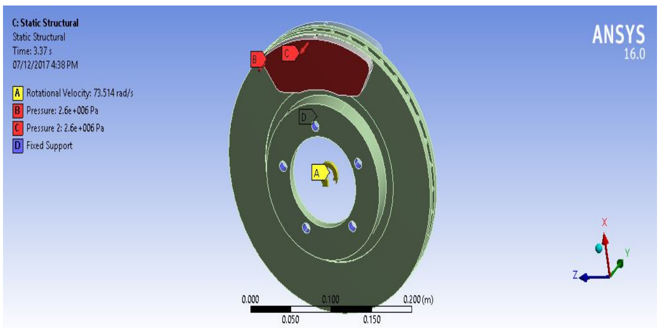


Fig.4 Boundary condition for the static structural analysis

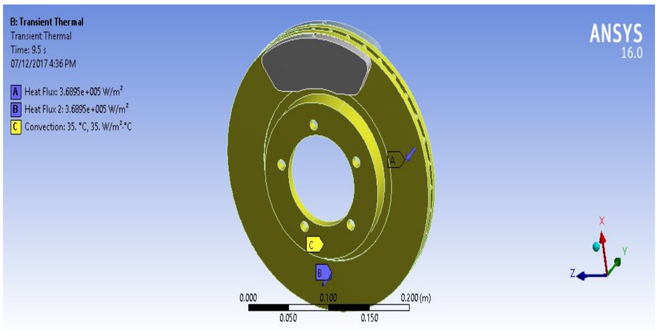


Fig.5Boundary condition for the transient thermal analysis

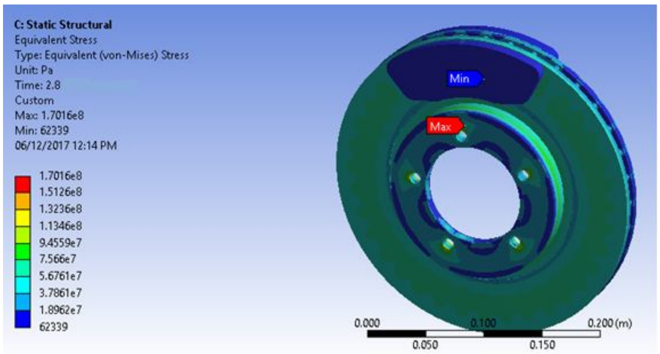


Fig.6 Equivalent (Von-Mises) Stress

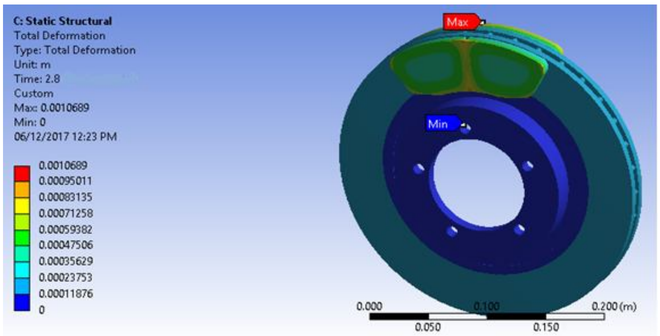


Fig.7 Total Deformation

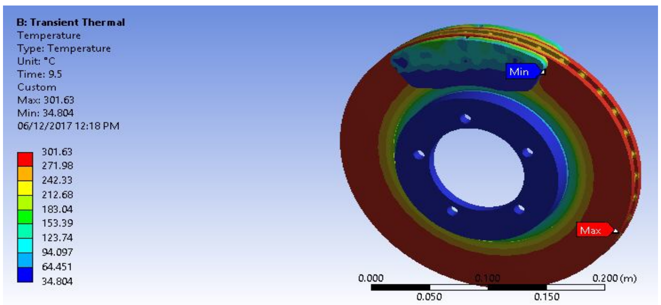


Fig.8 Temperature distribution

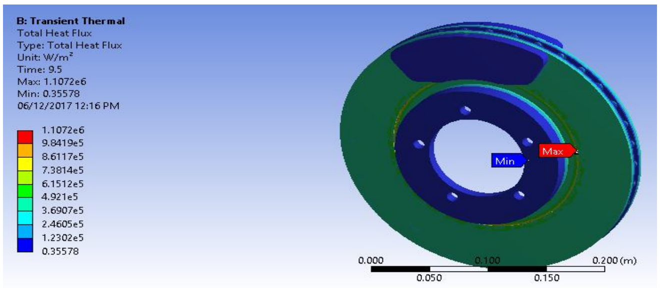


Fig.9 Total Heat Flux

B. Analysis ofSlotted Disc

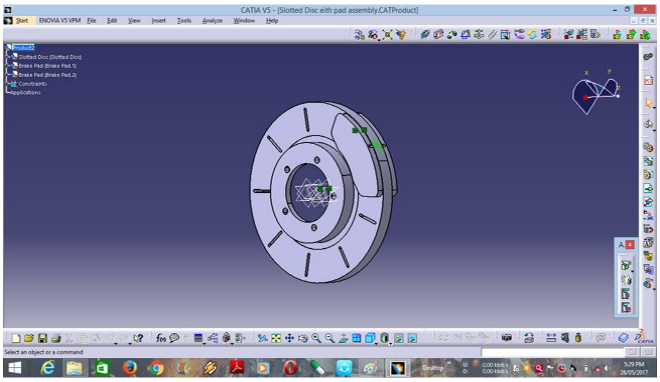


Fig.10Slotted rotor with brake pad assembly CATIA model

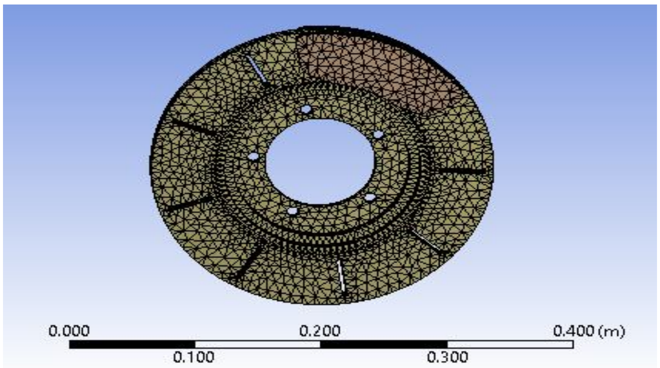


Fig.11 Meshing of Slotted type disc brake

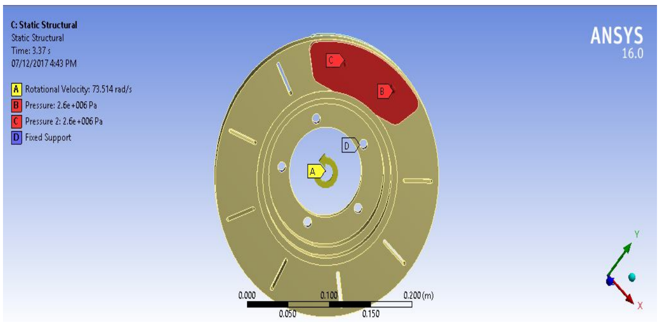


Fig.12 Boundary condition for the static structural analysis

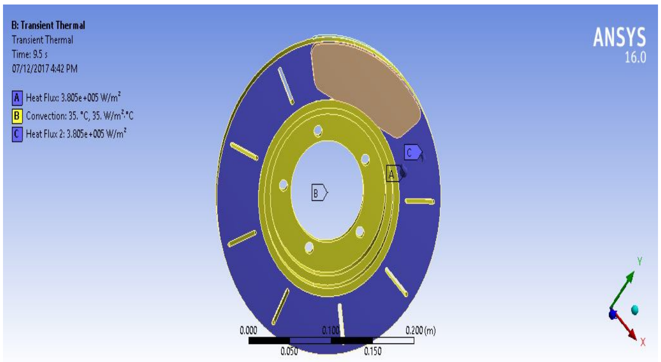


Fig.13 Boundary condition for the transient thermal analysis

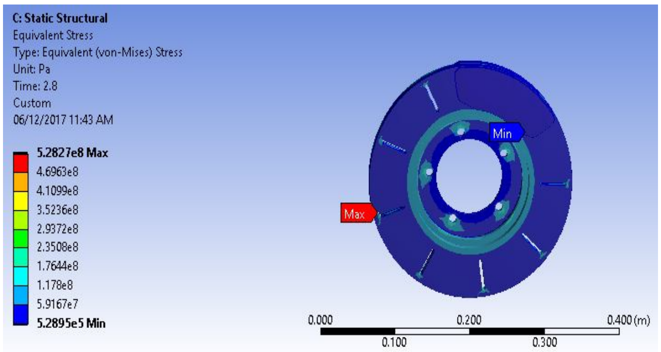
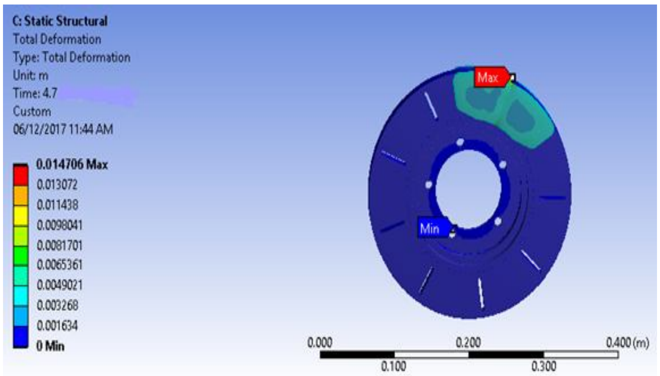


Fig.14Equivalent (Von-Mises) Stress



.Fig.15 Total Deformation

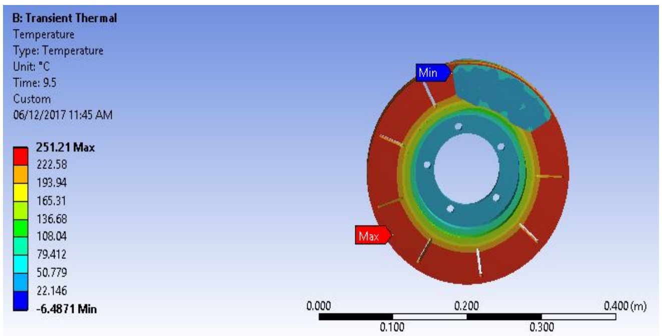


Fig.16 Temperature distribution

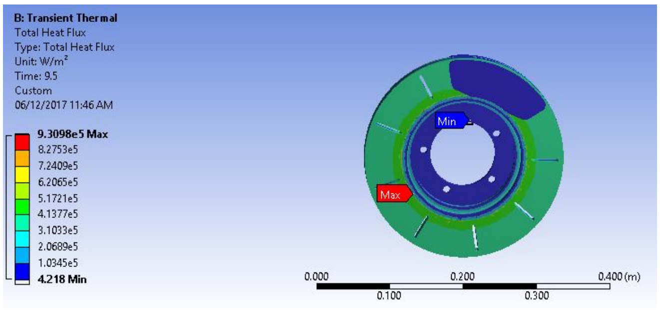


Fig.17 Total Heat Flux

C. Analysis ofSlotted & Drilled Disc

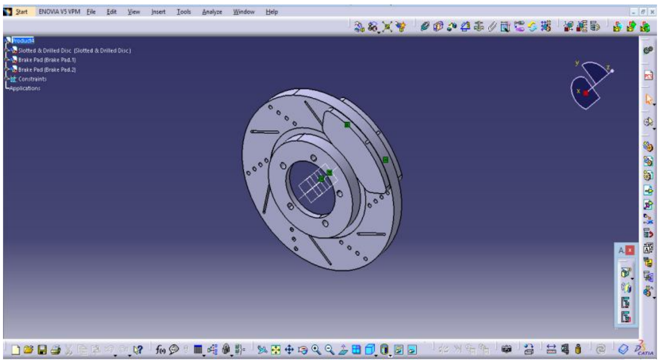


Fig. 18 Combined Drilled and Slotted rotor with brake pad assembly CATIA model

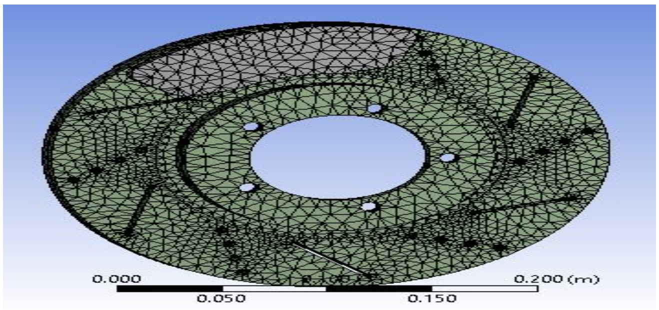


Fig. 19 Meshing of Slotted & Drilled type disc brake

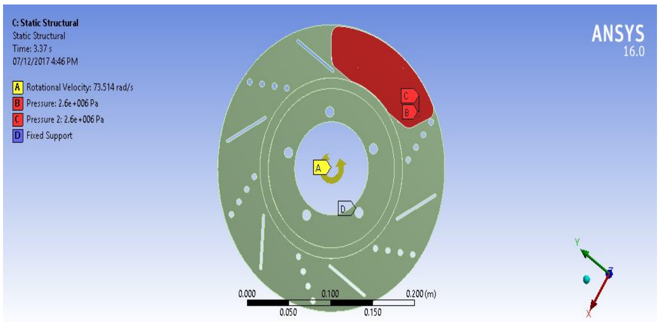


Fig.20 Boundary condition for the static structural analysis

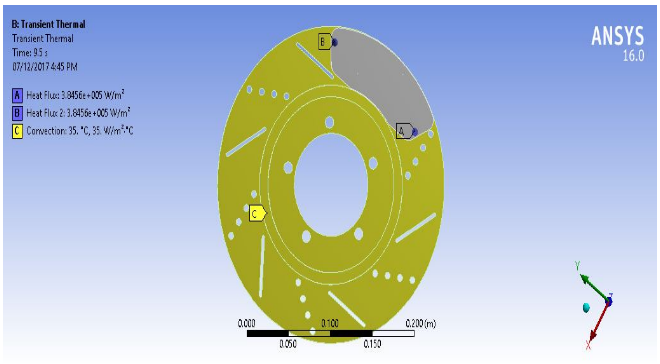


Fig.21 Boundary condition for the transient thermal analysis

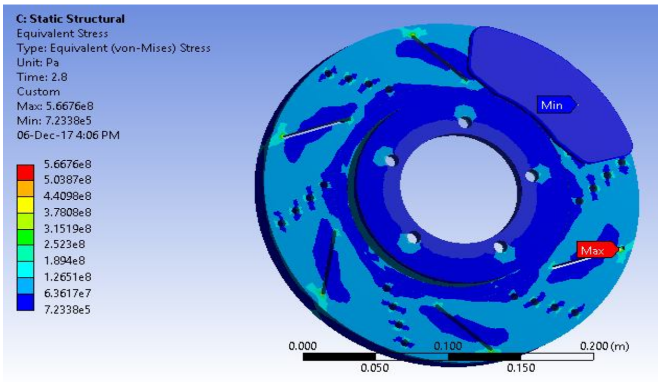


Fig.22 Equivalent (Von-Mises) Stress

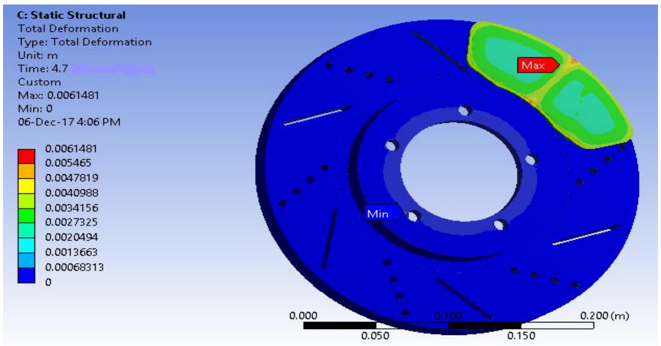


Fig.23Total Deformation

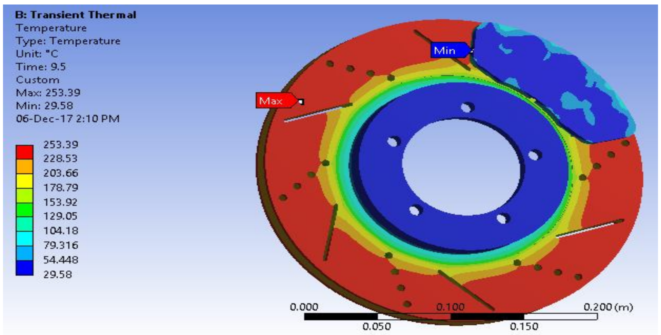


Fig.24Temperature distribution

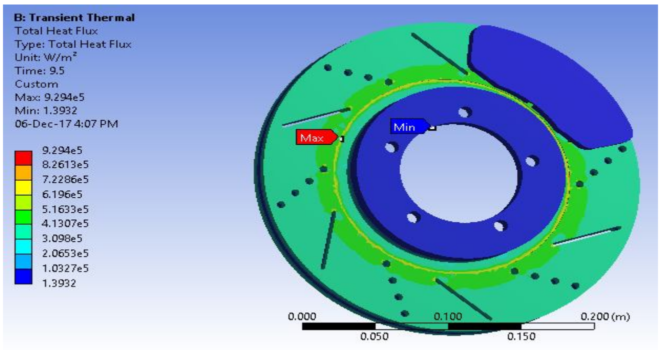


Fig.25Total Heat Flux

IV. RESULTS AND DISCUSSION

A. Static Structural Analysis

Type of Disc	Vented Disc	Slotted Disc	Slotted & Drilled Disc
Equivalent (Von-Mises) Stress in Pa	1.7016e8	5.2827e8	5.6676e8
Total Deformation in m	0.0010689	0.014706	0.0061481

The maximum equivalent (von-mises) stress produced in slotted disc and slotted & drilled disc is 5.2827e8 Pa and 5.6676e8 Pa respectively. The maximum total deformationproduced in slotted disc and slotted & drilled disc is 0.014706 m, 0.0061481 m respectively. The minimum equivalent (von-mises) stress and total deformation produced in vented disc is 1.7016e8 Pa and 0.0010689 m respectively.

B. Transient Thermal Analysis

Type of Disc	Vented Disc	Slotted Disc	Slotted & Drilled Disc
Temperature in $^{\circ}C$	301.63	251.21	253.39
Total Heat Flux in W/m^2	1.1072e6	9.3098e5	9.294e5

The temperature distribution over the slotted disc and slotted & drilled disc is almost similar. The maximum temperature produced in vented disc is 301.63 $^{\circ}C$. The total heat flux over the slotted disc and slotted & drilled disc is almost similar. The maximum total heat flux produced in vented disc is 1.1072e6 W/m^2.

V. CONCLUSION

Disc brakes are commonly manufactured by gray cast iron material. Since its heavy weight results in high fuel consumption. So weight reduction in disc brake is needed. Discs are modified by using slots and circles on profile of disc. The geometric design of the disc is an essential factor in the improvement of the cooling process of the discs.

It is concluded that the best suitable disc brake is slotted disc and slotted & drilled disc based on the magnitude of temperature distribution and total heat flux.

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