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Design, Manufacturing and Analysis of Alloy Steel Brake Disc

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***Abstract* - Each single system has been studied and developed in ordered to meet the safety requirement. Instead of having air bag, good suspension systems, good handling and safe cornering, there is one most critical system in the vehicle which is brake system. Without brake system in the vehicle will put a passenger in unsafe position. Therefore, it is must for all vehicles to have proper brake system. In this paper alloy steel disc brake material use for calculating normal force, shear force and piston force And also calculating the brake distance of disc brake. The standard disc brakes two wheelers model using in ANSYS and done the Thermal analysis and Model analysis also calculate the Heat flux and Temperature of disc brake model. This is important to understand action force and friction force on the disc brake new material, how disc brake works more efficiently, which can help to reduce the accident that may happen in each day.**
***Keywords*: Disc, brake assembly, wheel rotor, pad, caliper, alloy material, ANSYS, Solid Works, Boundary condition.**

I. INTRODUCTION

A disc brake is a type of brake that uses calipers to squeeze pairs of pads against a disc in order to create friction that 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. Hydraulic disc brakes are the most commonly used form of brake for motor vehicles but the principles of a disc brake are applicable to almost any rotating shaft. Compared to drum brakes, disc brakes offer better stopping performance because the disc is more readily cooled. As a consequence discs are less prone to the brake fade caused when brake components overheat.

The brake disc is usually made of cast iron, but may in some cases be made of composites such as reinforced carbon–carbon or ceramic matrix composites. This is connected to the wheel and/or the axle. To retard the wheel, friction material in the form of brake pads, mounted on a device called a brake caliper, is forced mechanically, hydraulically, pneumatically, or electromagnetically against both sides of the disc. Friction causes the disc and attached wheel to slow or stop.

They are also found in industrial applications where the ceramic disc's light weight and low-maintenance properties justify the cost relative to alternatives. Composite brakes can withstand temperatures that would make steel discs bendable. Porsche's Composite Ceramic Brakes (PCCB) are siliconized carbon fiber, with very high temperature capability, a 50% weight reduction over iron discs (therefore reducing the unsprung weight of the vehicle), a significant reduction in dust generation, substantially increased maintenance intervals, and enhanced durability in corrosive environments over conventional iron discs. Found on some of their more expensive models, it is also an optional brake for all street Porsches at added expense. It is generally recognized by the bright yellow paintwork on the aluminum six-piston calipers that are matched with the discs. The discs are internally vented much like cast-iron ones, and cross-drilled.

Study of Disc Brake Assembly

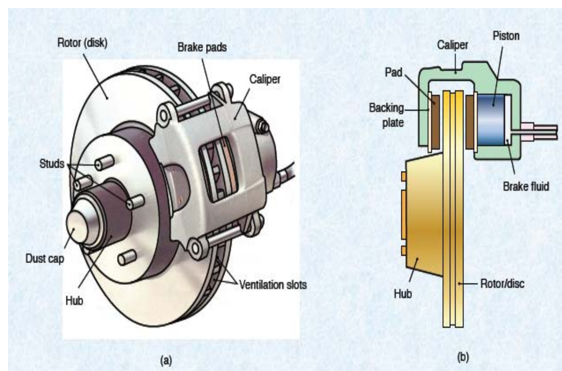


Fig.1 Brake Assembly

The brakes transmit the force to the tires using friction, and the tires transmit that force to the road using friction also.

There are three principles of braking system.

1. Leverage 2. Hydraulics 3. Friction

Leverage and Hydraulics

In the figure below, a force F is being applied to the left end of the lever. The left end of the lever is twice as long (2X) as the right end (X). Therefore, on the right end of the lever a force of 2F is available, but it acts through half of the distance (Y) that the left end moves (2Y). Changing the relative lengths of the left and right ends of the lever changes the multipliers.

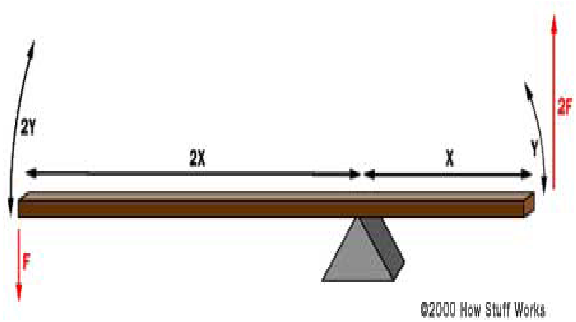


Fig.2 Leverage System

The pedal is designed in such a way that it can multiply the force from your leg several times before any force is even transmitted to the brake fluid. The basic idea behind any hydraulic system is very simple: Force applied at one point is transmitted to another point using an incompressible fluid, almost always an oil of some sort. Most brake systems also multiply the force in the process.

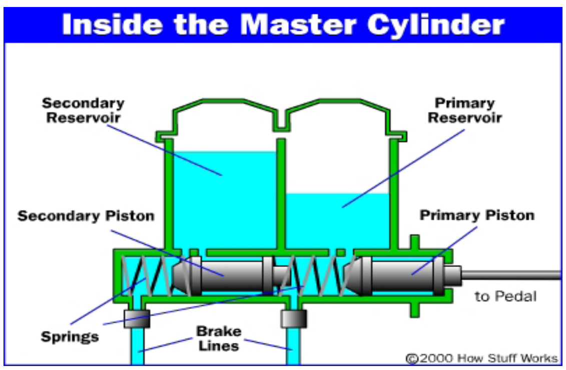


Fig.3 Operation of Master Cylinder

When the brake pedal is pressed, it pushes on the primary piston through a linkage. Pressure builds in the cylinder and lines as the brake pedal is depressed further. The pressure between the primary and secondary piston forces the secondary piston to compress the fluid in its circuit. If the brakes are operating properly, the pressure will be the same in both circuits. If there is a leak in one of the circuits, that circuit will not be able to maintain pressure.

The main components of a disc brake are

1. The brake pads
2. The caliper, which contains a piston
3. The rotor, which is mounted to the hub

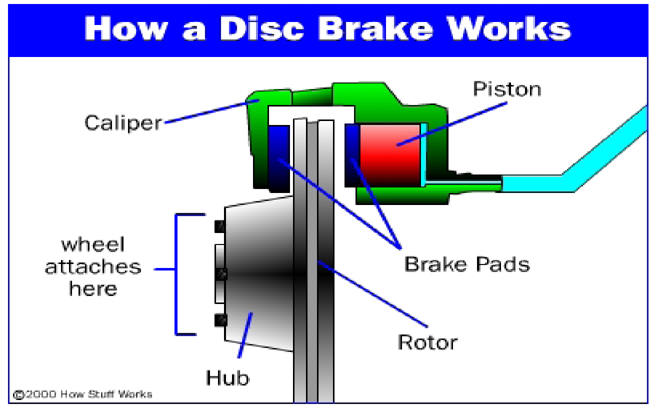


Fig.4 Brake Disc Operation

The disc brake is a lot like the brakes on a bicycle. Bicycle brakes have a caliper, which squeezes the brake pads against the wheel. In a disc brake, the brake pads squeeze the **rotor** instead of the wheel, and the force is transmitted hydraulically instead of through a cable. Friction between the pads and the disc slows the disc down [6].

Material Finalizing

The material chosen for the existing model of the disc was Cast Iron. The material chosen for optimizing the disc was Alloy steel [1].

Material composition

-Aluminum(18-20%)-Chromium(12-15%)-Steel (65-70%)-Silicon (1-2%)-Manganese (1-2%)-Carbon(0.12-0.15%)-Sulphur (0.02-0.04%)

II. DESIGN CALCULATIONS

Disc Brake Standard

Rotor disc dimension = 220 mm. (220×10^{-3} m)
Rotor disc material = Alloy steel
Pad brake area = 2000 mm^2 (2000×10^{-6} m)
Pad brake material = Asbestos / Graphite
Coefficient of friction (Wet) = 0.07-0.13
Coefficient of friction (Dry) = 0.3-0.5
Maximum temperature = 350 ºC
Maximum pressure = 1MPa (10^6 Pa)…...[2]

Tangential force between pad and rotor (Inner face), FTRI

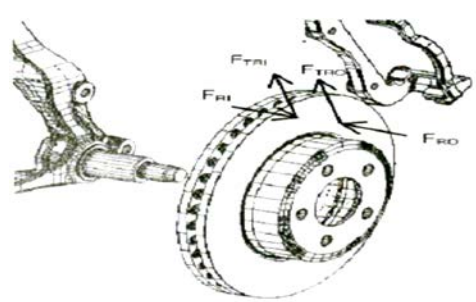


Fig.5 Force Analysis

FTRI = μ1.FRI

Where, FTRI = Normal force between pad brake And Rotor (Inner)

μ1 = Coefficient of friction = 0.5

FRI = P max / 2 * A

Where, A= pad brake area

So, FTRI = μ1.FRI

$FTRI = (0.5)*(0.5)*(1\times10^{6}\ N/m2)*(2000\times10^{-6} m2) = 500\ N$……..[2]

Brake Torque (TB)

With the assumption of equal coefficients of friction and normal forces FR on the inner and outer faces[2]:

TB = FT.R

Where TB = Brake torque R = Radius of rotor disc.

μ = Coefficient of friction

FT = Total normal forces on disc brake, = FTRI + FTRO

FT = 1000 N.
So,
$TB = (1000)\ (110\times10^{-3}) = 110$ N.m

Brake Distance (x)

We know that tangential braking force acting at the point of contact of the brake, and

Work done = FT. X.................. (Equation A)

Where FT = FTRI + FTRO

X = Distance travelled (in meter) by the vehicle before it come to rest.

We know kinetic energy of the vehicle.

Kinetic energy = $(mv^2) / 2$................ (Equation B)
Where, m = Mass of vehicle v = Velocity of vehicle

In order to bring the vehicle to rest, the work done against friction must be equal to kinetic energy of the vehicle [2].

Therefore equating (Equation A) and (Equation B)

FT. X = $(mv^2) / 2$

Assumption v = 100 km/h = 27.77 m/s, M = 150 kg. (Dry weight of vehicle)

So we get, $x = (mv^2) / 2\ FT = (150\times27.77^2) / (2\times1000)$ m = 57.83 m

Temperature generated on disc surface

Heat Generated (Q) = M *Cp* ΔT J/s

Heat Flux (q) = Q/A W/m²

Thermal Gradient (K) = q/k K/m

Steel Aluminium Alloy

Heat generated Q = M*Cp*ΔT

Mass of disc = 0.65 kg

Specific Heat Capacity = 320 $J/kg^{0}c$

Time taken Stopping the Vehicle = 4sec

Developed Temperature difference = $15\ ^{0}$ c

Q = 0.65 * 320 * 15= 3120 J

Area of Disc = $\Pi * (R^2 - r^2) = \Pi * (0.110^2 - 0.055^2) = 0.0357\ m^2$

Heat Flux =Heat Generated /Second /area = 3120/4 /0.0357 = 21848.7394 $W/m^{2\ 0C}$

Thermal Gradient = Heat Flux / Thermal Conductivity = 21848.7394 / 60= 364.14 k/m……. [2]

Thermal Analysis of Disc Brake

1. **Heat Flux =** 21848.7394 $W/m^{2\ 0}C$ as per above calculations [2].

2. **Radiation**
   Emissivity,
   For Steel = 0.87

   For C.I. = 0.80

3. **Convection**
   Film Coefficient [10],

   For steel = 230 $W/m^{2\ o}$ C

   For C.I. = 130 $W/m^{2\ o}$ C

Modeling of Brake Disc in Solid works

We did modelling of brake disc in solidworks on the basis of preselected dimensions of disc above. The figure is shown below:

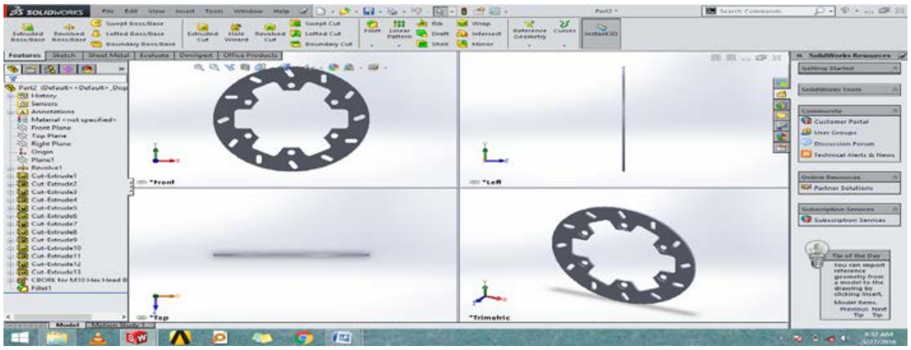


Fig.6 Views of Disc

III. MANUFACTURING OF BRAKE DISC

A mechanical stir caster/rheometer as illustrated in Fig. 7 was designed and built to produce the various cast morphologies. The semi-solid alloy was sheared in a heated tubular zone between a grooved rotor and a crucible. The caster furnace was heated by means of four resistance heating elements. One element around the wide reservoir at the top of the crucible and three along the lower narrow section were used to control the temperature in the semi-solid range of the alloy. This configuration enabled a maximum temperature of 1150 °C and control of the temperature gradient within the narrow section of the crucible, where the shearing occurred[3].

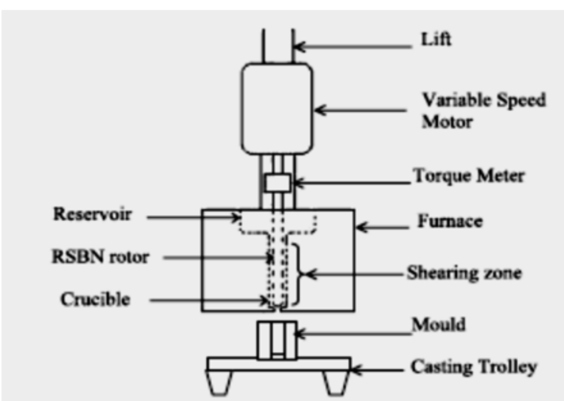


Fig.7 Stir Casting Device

The rotor and crucible (Fig. 8) were both, uniquely, of Reaction Bonded Silicon Nitride (RSBN), which enabled these two parts to be easily lapped together during operation of the stir caster. RBSN has good thermal shock resistance, good high temperature strength, does not contaminate the melt, and has a low coefficient of thermal expansion and moment of inertia. An additional external immersion heating element was needed in the reservoir to provide sufficient molten alloy there for an adequate metallostatic head for stir casting at higher fractions solid. A batch casting trolley which also held a plug against the crucible outlet, was used to carry the chill moulds into which the stir cast material poured. Control of stirring speed, stirring time, stirrer height, and the temperature profile of the furnace, was implemented on a PC by means of LABVIEW control software, and data input and output control boards. The software also displayed and logged the stirring speed, height of the stirrer, temperatures in the furnace, and the torque experienced by the stirrer, on a real time basis [8].

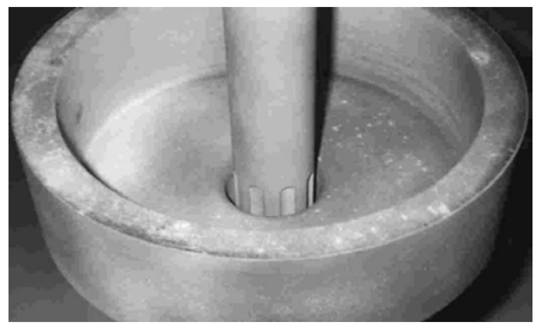


Fig.8 Crucible reservoir and rotor

Operation

Alloy Steel 420 is melted in a furnace at around 1460^0C. The composition of stainless steel 420 is 0.15% C, 1% Si, 1% Mn, 0.04% P, 0 .03% S, 12% Cr. Aluminium 6061 is a raw material which is in cubic form melted in a stir casting furnace at the temperature upto 1200^0C.The stir casting method is provided with a stirrer used for the continuous mixing of melted material. Then the melted steel alloy cooled upto 1200^0C to put it into a stir casting furnace. Stirrer continues the mixing of the mixture and then it gives the matrix of steel and aluminium. Because of stirrer action the layers of aluminium and steel are formed and thus they generate fibers. The combination which is to be taken for the study is of 80% of stainless steel alloy 420 and 20% of Aluminium 6061.The highest percentage of steel ensures high strength and presence of aluminium provides better finishing for friction in contact with the brake pad,ultimately achieving better braking action with minimum force. Aluminium-steel alloy disc provide best strength to weight ratio and also reduction in weight of the disc brake than the conventional material used (like cast-iron)[2].

Fig.9 Stir Casting Furnace

Thus we manufactured and developed the brake disc using above procedure which is shown as below:

Fig.10 Brake Disc

IV. FINITE ELEMENT ANALYSIS OF DISC BRAKE ROTOR

The basic steps involved in FEA

The following are the five basic steps involved in an FEA analysis[9]:

1. ***Pre-processing:***

Discretization of the Domain

Applications of Field/Boundary conditions

Assembling the system equations

2. Solution:

Solution for the system equations

3. Post processing:

Review of results

Modeling in ANSYS Workbench Design Modular

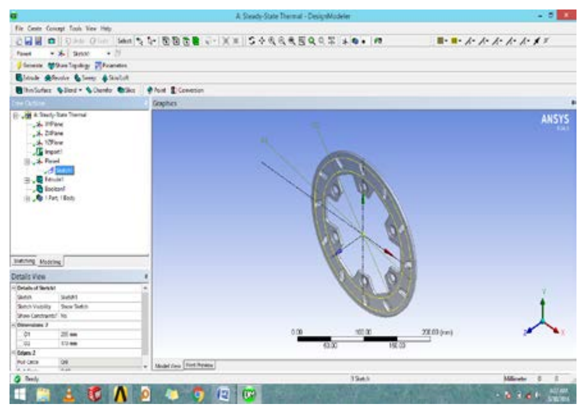


Fig.11 Diameters For Imprint Faces

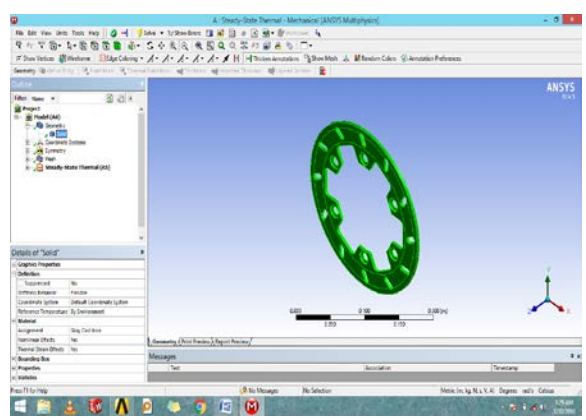


Fig.12 Material Assigning

Mesh generation
MESH MODEL

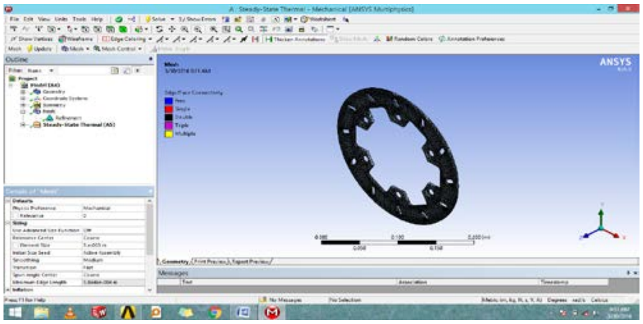
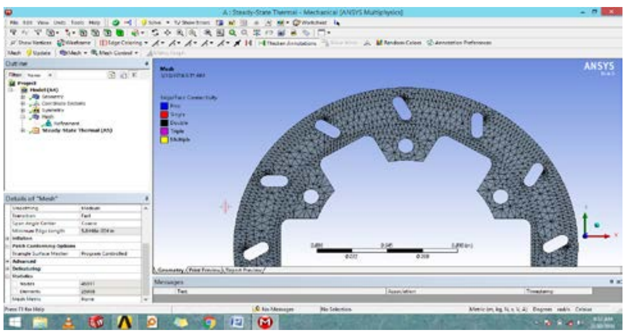


Fig.13 Mesh Model of Disc Brake Rotor



Statistics	
Nodes	45911
Elements	25908
Mesh Metric	None

Fig.14 Statistics result of Disc Brake Rotor

BOUNDARY CONDITIONS

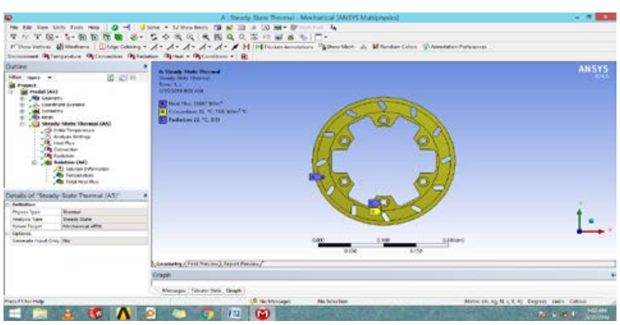


Fig.15 Boundary Conditions

Various boundary conditions in embedded configurations imposed on the model (disc-pad), taking into account its environment direct, are, respectively, the simple case as shown in fig no.20. The initial temperature of the disc and the pads is22^{0}C, the surface convection condition is applied at all surfaces of the disc with the values of the coefficient of exchange calculated previously, and the convection coefficient (h) of Cast iron 130^{0} W/m^{2} ^{0}C and alloy steel 230^{0} W/m^{2} ^{0}C. The heat flux into the brake disc during braking can be calculated in the design part and heat flux value is 21847W/m^{2} ^{0}C.

V. RESULTS OFANALYSIS

Simulation Results For Cast Iron

Temperature Distribution

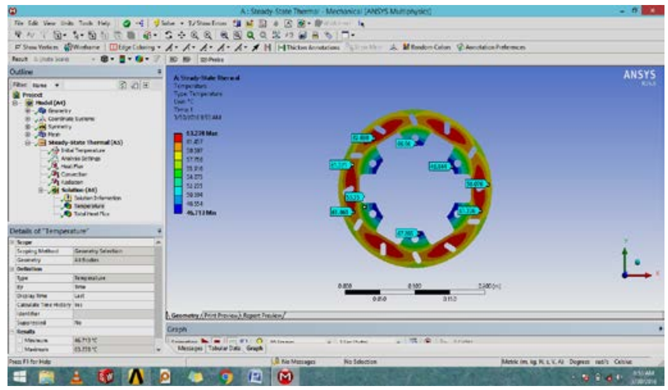


Fig.16 Temperature Distribution of Cast-iron Disc

Total Heat Flux

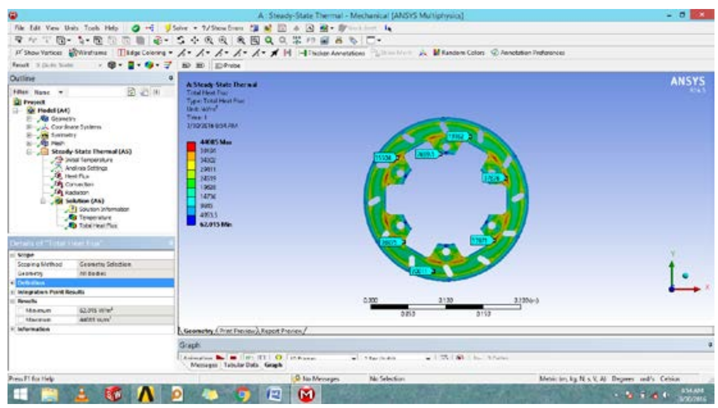


Fig.17 Total Heat Flux on Cast-iron Disc

Simulation Results For Alloy Steel

Temperature Distribution

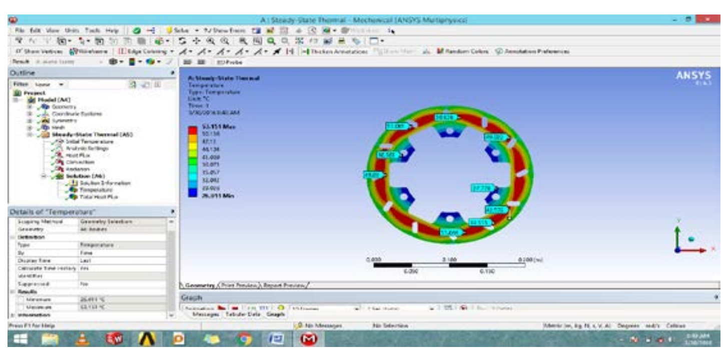


Fig.18 Temperature Distribution of Alloy steel Disc

Total Heat Flux

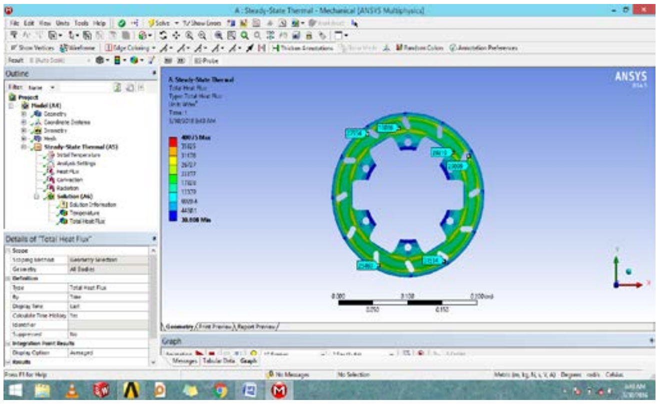


Fig.19 Total Heat Flux on Alloy steel Disc

Comparison of Simulation Results

S. No.	Parameters	Cast Iron	Alloy Steel
1	Film Coefficient	130 W/m^{2} ^{0}C	230 W/m^{2} ^{0}C
2	Emissivity	0.80	0.87
3	Temperature Range	46-63 ^{0}C	26-53 ^{0}C
4	Total Heat Flux	44085 W/m^{2}	40075 W/m^{2}

VI. CONCLUSION

From thermal analysis we can conclude that temperature distribution over the alloy steel disc rotor is low intensity as compare to cast iron disc rotor. Heat flux also same maximum at cast-iron disc brake rotor than alloy steel disc brake rotor. So, here clear that intensity of temperature generated on the alloy steel disc is low so pressure acted on the disc is high through pad at minimum external force.

Most important criteria for change the material of brake disc rotor is reduce the weight. Alloy steel (20% Aluminium) is used for the brake rotor and manufactured disc rotor weight is 0.65Kg and this is 30% lighter than cast iron.

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