Design and Analysis of Rotor Disc of Disc Brake System

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Abstract-A brake is a device by means of which artificial frictional resistance is applied to moving machine member, in order to stop the motion of machine. The disc brake is a device for slowing or stopping the rotation of a wheel. Friction causes the disc and attached wheel to slow or stop. Brakes convert friction to heat, but if the brakes get too hot, they will cease to work because they cannot dissipate enough heat. This condition of failure is known as brake fade. Disc brakes are exposed to large thermal stresses during routine braking and extraordinary thermal stresses during hard braking. Number of times using the brake for vehicle leads to heat generation during braking event, such that disc brake undergoes breakage due to high temperature.Modelling is to be done in CATIA Software and Analysis is to be done in ANSYS WORK BENCH 14.5. Finite element analysis is carried out as a coupled field analysis which involves both thermal and structural. The thermal analysis which precedes structural analysis gives the temperature distribution in the disc brake. The structural analysis involves determination of induced stresses and deformation of the disc brake. Thermal & static structural analysis (couple field analysis) is to be done on the disc brake using materials such as Grey Cast Iron, Stainless steel, Structural steel and Aluminium Alloy by varying the shape of ventilated models. A comparison between analytical and results obtained from FEM for temperature and Vonmisses stresses are done and all the values are validated to check the adequacy. A Comparison is made between four different materials for analysis of thermal and structural thermal analysis of disk brakes and has planned to study the influence of different shapes of ventilated holes for the disc brakes to know the effect of cooling rate and stress distributions and factor of safety. The 36 holes with gray cast iron give better results in comparison with stainless steel, aluminium alloy and structural steel. The results obtained as per the geometry of ellipsoid shaped holes in the disc brakes gives better cooling rate and weight reduction in comparison with circular shaped holes with all the materials.

Keywords – Disc Brake, Design, Validation, Optimized material and shape, Ventilated Disc

I. INTRODUCTION

1.1 Principle

Brakes are most important safety parts in the vehicles. Generally all of the vehicles have their own safety devices to stop their bike. Brake function to slow and stop the rotation of the wheel. To stop the wheel, braking pads are forced mechanically against the rotor or disc on both surfaces. They are compulsory for all of the modern vehicles and the safe operation of vehicles. In short, brakes transform the kinetic energy of the car into heat energy, thus slowing its speed.

1.2 Braking Requirements

a) The Brakes must be strong enough to stop the vehicle within a minimum distance in an emergency. But this should also be consistent with safety. The driver must have proper control over the vehicle during emergency braking and the vehicle must not skid.

b) The Brakes must have good anti-fade characteristics i.e. their effectiveness should not decrease with constant prolonged application e.g., while descending hills. This requirement demands that the cooling of the brakes should be very efficient.

1.3 Brake Fade

Brake fade is the reduction in stopping power that can occur after repeated or sustained application of brakes, especially in high load or high speed conditions. Brake fade can be a factor in any vehicle that utilizes a friction braking system including automobiles, trucks, motorcycles, airplanes, and even bicycles. Brake fade is caused by a buildup of heat in the braking surfaces and the subsequent changes and reactions in the brake system components and can be experienced with both drum brakes and disc brakes. Loss of stopping power, or fade, can be caused by friction fade, mechanical fade, or fluid fade. Brake fade can be significantly reduced by appropriate equipment and materials design and selection, as well as good cooling.

Brake fade occurs most often during high performance driving or when going down a long, steep hill. It is more prevalent in drum brakes due to their configuration. Disc brakes are much more resistant to Brake fade because the heat can be vented away from the rotor and pads more easily, and have come to be a standard feature in front brakes for most vehicles.

1.4 Disc Brake

A disc brake which slows rotation of the wheel by the friction caused by pushing brake pads against a brake disc with a set of calipers. The brake disc is usually made of Stainless Steel, 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 stop 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. Brakes convert motion to heat, and if the brakes get too hot, they become less effective, a phenomenon known as brake fade.

1.5 Components of a Disc Brake

A disc brake assembly consists of:

- Stainless steel disc (disc rotor) that rotates with the wheel.
- Caliper assembly attached to the steering knuckle.
- Friction materials (disc pads) that are mounted to the caliper assembly.

1.5.1 Operation of disc pad

Brake pads are designed for high friction with brake pad material embedded in the disc in the process of bedding while wearing evenly. Friction can be divided into two parts: Adhesive and abrasive. Depending on the properties of the material of both the pad and the disc and the usage, pad and disc wear rates will vary considerably.

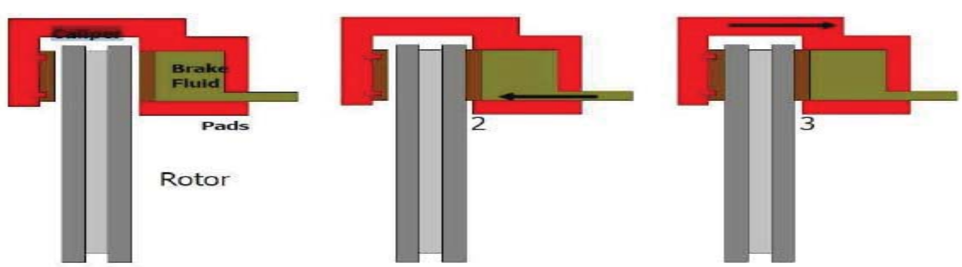

Fig 1.1Operation of a Disc Brake

When hydraulic pressure is applied to the caliper piston, it forces the inside pad to contact the disc. As pressure increases the caliper moves to the right and causes the outside pad to contact the disc. Braking force is generated by friction between the disc pads as they are squeezed against the disc rotor. Since disc brakes do not use friction between the lining and rotor to increase braking power as drum brakes do, they are less likely to cause a pull. The friction surface is constantly exposed to their, ensuring good heat dissipation, minimizing brake fade. It also allows for self- cleaning as dust and water are thrown off, reducing friction differences.

Unlike drum brakes, disc brakes have limited self-energizing action making it necessary to apply greater hydraulic pressure to obtain sufficient braking force. This is accomplished by increasing the size of the caliper piston. The simple design facilitates easy maintenance and pad replacement. Fig 1.1 shows a Operation of a Disc Brake.

II. LITERATURE REVIEW

A brake is a device by means of which artificial frictional resistance is applied to moving machine member, in order to stop the motion of a machine. In the process of performing this function, the brakes absorb either kinetic energy of the moving member or the potential energy given up by objects being lowered by hoists, elevators etc. The energy absorbed by brakes is dissipated in the form of heat. This heat is dissipated in to the surrounding atmosphere.

Lee, K. and Barber, J.R [1] were discussed about the various modes of heat transfer in disc brakes .The braking performance of vehicle can be significantly affected by the temperature. Poor heat dissipation may cause brake fade, premature wear, brake fluid vaporization, bearing failure, thermal cracks and thermally excited vibration.

loquet, A. & Dubourg [2] explains that the brake torque variation phenomenon which induces seat, steering and body vibration on passenger vehicles these days. This phenomenon is popularly known as brake judder. One root cause of the brake judder is the non-uniform radial thermal expansion of rear brake drums due to localized temperature increase, or known as hot spots.

Ali Belhocine et al. [3] aims for studying the thermal distribution in the disc brake used in heavy load vehicles and the results obtained are compared with those of specialized literature. It also gives a brief account of ANSYS CFX-CFD to find the convection coefficient. The modeling of the temperature distribution in the disc brake is used to identify all the factors and entering parameters concerned at the time of braking operation such as type of braking ,the geometric ,design of the disc and the used material

KengLengKhong [4] carried out a thermal stress analysis on heavy truck brake disc rotor for steady state and transient condition. The heat dissipation along the brake disc surface during the Periodic braking via conduction, convection and radiation is studied. In order to get the stable and accurate result of element size.

Gnanesh, P et al [5] describes that disc brake is a device for slowing or stopping the rotation of a wheel. Friction causes the disc and attached wheel to slow or stop. Brakes convert friction to heat, but if the brakes get too hot, they will cease to work because they cannot dissipate enough heat. This condition of failure is known as brake fade

P.K.Zaware et al [6] investigated on "Design modification & optimization in stress, deformation and weight of Disc brake rotor, which studies about on disc brake rotor by modeling & analysis of different shapes of slots of different vehicle's disc brake rotor with same outer diameter& inner mounting position of holes on wheel hub as like Bajaj Pulsar 150.Analysis done on real model of disc brake rotor of Bajaj pulsar 150 and disc brake Rotor of different shapes of slots of different vehicle's in one Disc brake rotor. Therefore, it gives optimize stress, deformation & weight of the modified disc brake rotor &also good heat dissipation.

III. METHODOLOGY

Computer Aided Three Dimensional Interactive Application (CATIA) is the world's leading Computer Aided Design (CAD)/Computer Aided Manufacturing (CAM)/Computer Aided Engineering (CAE) package. Developed by Dassault System and marketed worldwide by IBM, CATIA delivers one of the best Product Lifecycle Management (PLM) solutions. It is written in C++ programming language. It provides a single platform to design, analyze and manufacture a product; this makes the product development faster and easier. CATIA is used by various industries, including automobiles, aerospace, industrial equipment, and ship building. CATIA V5 provides three basic platforms: P1, P2, and P3. P1 is for small and medium sized process oriented companies that wish to grow toward the large scale digitized product definition. P2 is for the advance design engineering companies that require product, process, and resource modeling. P3 is for high-end design applications and is basically for Automotive and Aerospace Industry, where high quality surfacing or Class-A surfacing is used for designing.

3.1. Finite Element Analysis

ANSYS is a general-purpose finite element modelling package for numerically solving a wide variety of mechanical problems. ANSYS simulation software enables organizations to confidently predict how their products will operate in the real world. It expands the use of physics. It gains access to any form of engineering field someone may account in. The ANSYS program has many finite element analysis capabilities, ranging from a simple, linear, static analysis to a complex, nonlinear, transient dynamic analysis.

3.2 Analytical Method of Disc brake

Engine type: 4-stroke, DTS-i, air cooled, single cylinder. Kerbweight (kg) =144 and Diameter of the disc=240mm are the specifications of the brake system considered.

Speed of the vehicle=54kmph

$=54\times\frac{5}{18}$

$=15$m/sec

Velocity V= u+at (Final velocity = 0)

0=15+a (4)

Acceleration (a) $=3.75$ m/s^2;

Distance (x) $= ut+\frac{1}{2}at^2$

Distance (x) $= 15\times4+\frac{1}{2}\times(-3.75)\times4^2$

Distance (x) = 30m;

Kinetic energy $=\frac{1}{2}mv^2$

$=\frac{1}{2}\times200\times15^2$

= 22,500 J

Rubbing area $=2\pi r^2$

$=2\times3.14\times(115^2-89^2)$

$=0.0333m^2$

Drag force $F_D=\frac{1}{2}u^2\rho\, C_D\, A$

$=\frac{1}{2}\times15^2\times1.2\times0.5\times(0.45\times1.866)$

=56.6797N

Friction force $F_N=\mu w$

$=0.65\times9.81\times100$

=637.65N

Total Heat Generated = Kinetic energy – (Drag force F_D ×Distance)-(Friction force ×Distance)

= 22500 - (56.679×30) - (637.65×30)

= 1670.13 w

The analysis is done by taking the Brake Efficiency as 15% and hence distribution between the front and the rear wheel axle is 15:85.

Thus, Total Heat Generated = 1670.13×0.15 = 250.5195 w

$$\text{Heat flux } q = \frac{\text{Heat Generated}}{\text{time}\times\text{rubbing area}}$$

$$=\frac{250.5195}{4\times0.0333} = 1880.7770 \text{w/m}^2$$

$$= 0.001880 \text{ w/mm}^2$$

Single stop temperature rise is

$$T_{max} = \frac{0.527\times q\times\sqrt{t}}{\sqrt{\rho.\, c.\, k}} + T_{amb}$$

Where, $=49.37^0$c

T_{max}	=	maximum disc temperature (^{0}C)
q	=	heat flux (Watts/m^2)
t	=	break on time (sec)
ρ	=	density of disc material (Kg/m^3)
c	=	brake disc specific heat capacity (J/Kg/K)
k	=	brake disc thermal conductivity (W/ (m.K))
T_{amb}	=	ambient temperature (^{0}C)

The thermal stresses 'σ 'developed in the surface of a disc from sudden temperature increases is

$$\sigma = \frac{E}{1-V}\times\alpha\times\Delta T$$

=153.348 MPa

Temperature Rise

The temperature rise after repeated stopping can also be approximated, although so many variables exist it is suggested this is only used for basic optimization work.

$$\Delta T = \frac{P.\, t}{\rho.\, c.\, V}$$

Where

ΔT

= average temperature increase per stop (^0C)
P = average power (watts)
t = brake on time (sec)

ρ

= density of disc material (kg/m^3)
c =brake disc specific heat capacity (J/kg/^0C)
V = volume of the disc (m^3)

Different materials are considered for selecting the optimized design and the properties are detailed in Table 3.1

Material	**Gray cast iron (FG15)**	**Stainless steel (304 AISI)**	**Structural steel**	**Aluminium alloy (5083-H116)**
Thermal conductivity(K), (W/m.K)	52.5	16.27	60.5	117
Density(ρ), (Kg/m^3)	7200	8030	7850	2660
Specific heat(c), (J/Kg ^0C)	265	500	434	900
Elastic modulus(E), (GPa)	100	193	200	71
Poisson's Ratio(υ)	0.26	0.29	0.3	0.33
Thermal expansion coefficient α ($10^{-6}/^0C$)	11.0	17.3	12	23.4

Table. 3.1 Technical specifications of Different materials

3.3 Coupled field analysis with different materials

The results shown below are of Ventilated disc brakes made of Stainless steel, Aluminium alloy, Gray cast iron and structural steel. These results are obtained after applying the thermal and structural boundary conditions and performing the Coupled Field Analysis. The maximum values of Temperature, Total Heat Flux, Total Deformation, Equivalent (von-Mises) Stress are interpreted in the form of colours such as blue being the minimum, green being the intermediate temperature and red being the maximum.

IV. RESULTS & DISCUSSIONS

4.1 Stainless Steel Original Model

4.1.1 Thermal Analysis

The below figures 4.1, 4.2 displays the geometry and boundary condition of Thermal analysis.

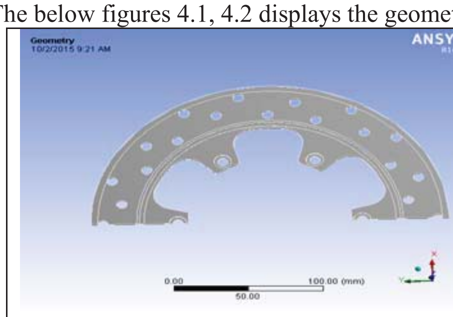

Fig 4.1 Geometry

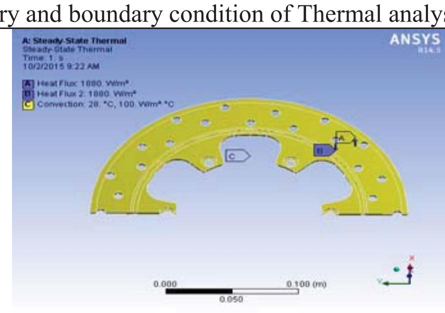

Fig 4.2 Boundary condition

The below figures 4.3, 4.4 displays the Temperature and Total heat flux of Stainless Steel Original Model. As it is evident from the figures, the maximum temperature and the maximum total heat flux are represented by red colour.

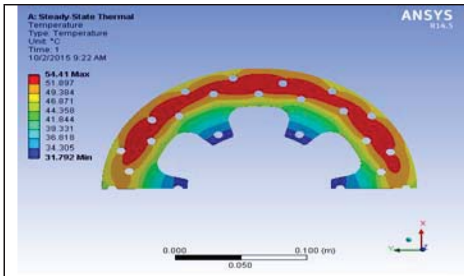

Fig 4.3 Temperature

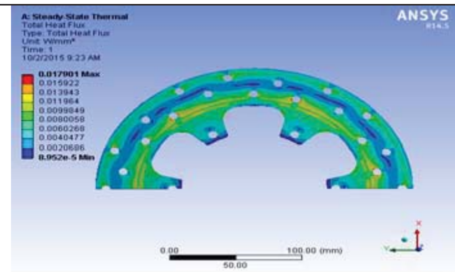

Fig 4.4 Heat flux

4.1.2 Stress Analysis

The below figure 4.5 displays the boundary condition for Stress analysis.

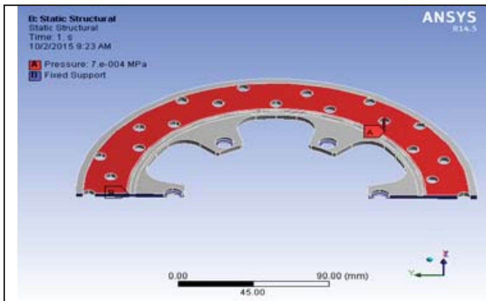

Fig 4.5 Boundary condition

The below figures 4.6, 4.7 displays the Total deformation and Equivalent (von-Mises) stress of Stainless Steel Original Model. As it is evident from the figures, the maximum total deformation and equivalent (von-Mises) stress are represented by red colour . The max temparatures in analytical and simulated values are 49.37^0 C and 48.43^0 c and vonmisses stresses are 153.34MPa and 160.46MPa.Comparing the max. temparature and vonmisses stress with analytical values and are understood the values are very closed .hence the simulated values are validated for adequency.The output parameters for different materials after analysis is tabulated in Table 4.1

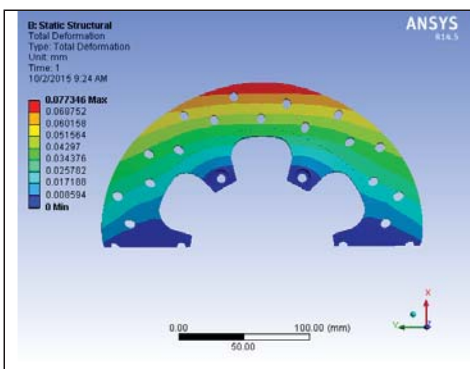

Fig 4.6 Total deformation

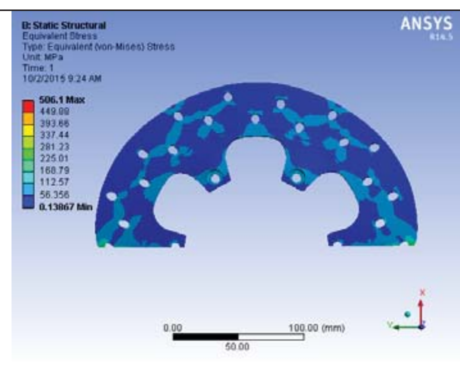

Fig 4.7 Equivalent stress

Table 4.1 Comparison of output parameter for different materials of existing model

Materials	**Stainless steel**	**Aluminum alloy (5083-H116)**	**Gray cast iron**	**Structural steel**
Temp max^{o}c	54.41	45.773	48.432	47.929
Total deformation(mm)	0.077346	0.087712	0.04432	0.047926

Equivalent stress(MPa)	506.1	198.47	160.46	311.59
Factor of safety	0.42482	1.1488	1.4956	0.80234

The results of the four materials: Stainless steel, Aluminium alloy, Gray cast iron &Structural steel for original model. Comparing the results for these materials, Stress and deformation are less in Gray cast iron than the existing material.

4.2 Gray Cast Iron Modified 30 Holes Disc Model

4.2.1 Thermal Analysis

The below figures 4.8, 4.9 displays the Temperature and Total heat flux of Gray Cast Iron Modified 30 Holes Disc Model. As it is evident from the figures, the maximum temperature andthe maximum total heat flux are represented by red colour.

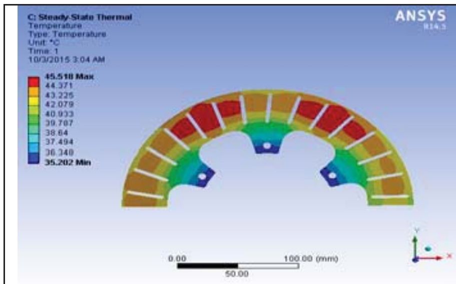

Fig 4.8Temperature

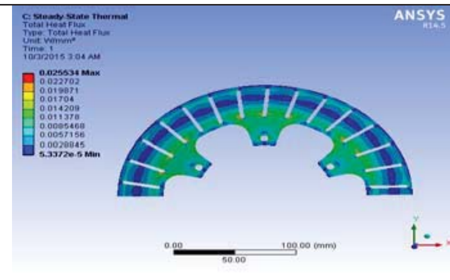

Fig 4.9 Heat flux

4.2.2 Stress Analysis

The below figures 4.10, 4.11 displays the Total deformation and Equivalent (von-Mises) stress of Gray Cast Iron Modified 30 Holes Disc Model. As it is evident from the figures, the maximum total deformation and equivalent (von-Mises) stress are represented by red colour.

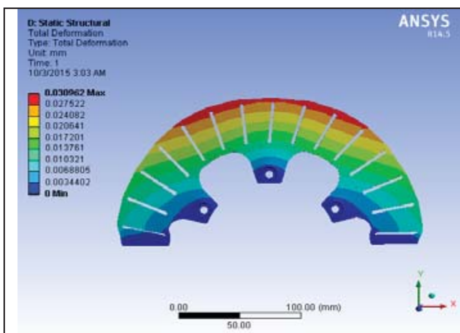

Fig 4.10 Total deformation

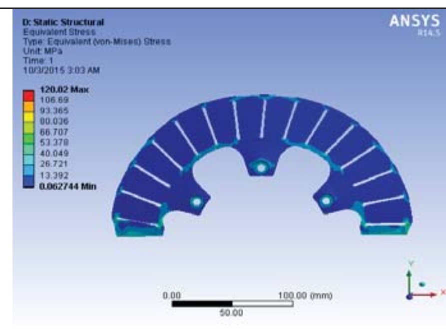

Fig 4.11 Equivalent stress

Table 4.2 Comparison of output parameter for different materials of modified 30 Holes disc model

Materials	**Stainless steel**	**Aluminum alloy (5083-H116)**	**Gray cast iron**	**Structural steel**
Temp max^{o}c	49.815	43.249	45.581	45.113
Total deformation(mm)	0.047499	0.065204	0.030962	0.033895
Equivalent stress(MPa)	346.63	156.55	120.02	236.51
Factor of safety	0.62025	1.4564	1.9996	1.0571

Table 4.2 shows the results of the four materials: Stainless steel, Aluminium alloy, Gray cast iron &Structural steel for Modified 30 Holes Disc Model. Comparing the results for these materials, Stress and deformation are less in Gray cast iron than the existing material.

4.3 Aluminum Alloy Modified 36 Holes Disc Model

4.3.1 Thermal Analysis

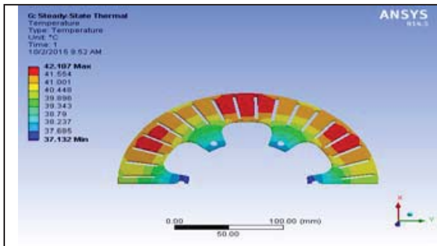

Fig 4.12 Temperature

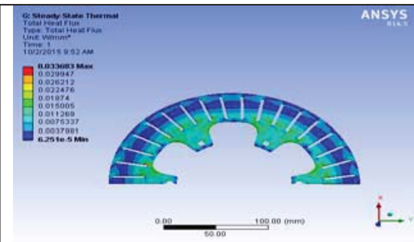

Fig 4.13 Heat flux

The below figures 4.12, 4.13 displays the Temperature and Total heat flux of Aluminum Alloy Modified 36 Holes Disc Model. As it is evident from the figures, the maximum temperature and the maximum total heat flux are represented by red colour.

4.3.2 Stress Analysis

The below figures 4.14, 4.15 displays the Total deformation and Equivalent (von-Mises) stress of Aluminum Alloy Modified 36 Holes Disc Model. As it is evident from the figures, the maximum total deformation and equivalent (von-Mises) stress are represented by red colour.

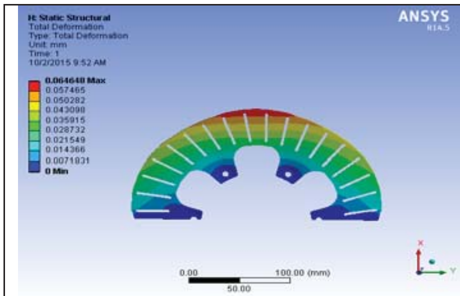

Fig 4.14 Total deformation

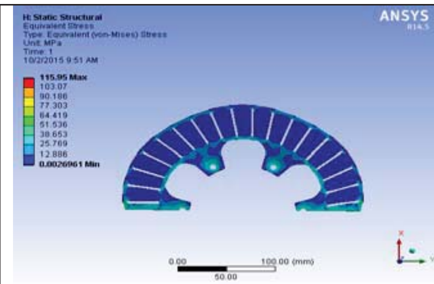

Fig 4.15 Equivalent stress

Table 4.3 Comparison of output parameter for different materials of modified 36 holes Disc model

Materials	**Stainless steel**	**Aluminum alloy (5083-H116)**	**Gray cast iron**	**Structural steel**
Temp max^{o}c	47.926	47.107	44.16	43.779
Total deformation(mm)	0.046426	0.064648	0.030558	0.03349
Equivalent stress(MPa)	265.02	115.95	90.617	177.76
Factor of safety	0.81125	1.9663	2.6485	1.4064

Table 4.3 shows the results of the four materials: Stainless steel, Aluminium alloy, Gray cast iron &Structural steel for Modified 36 Holes Disc Model. Comparing the results for these materials, Stress and deformation are less in Gray cast iron than the existing material.

4.4 Stainless Steel Modified 42 Holes Disc Model

4.4.1 Thermal Analysis

The below figures 4.16, 4.17 displays the Temperature and Total heat flux of Stainless Steel Modified 42 Holes Disc Model. As it is evident from the figures, the maximum temperature and the maximum total heat flux are represented by red colour.

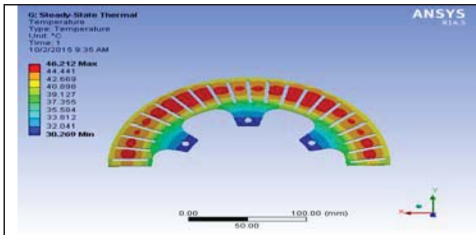	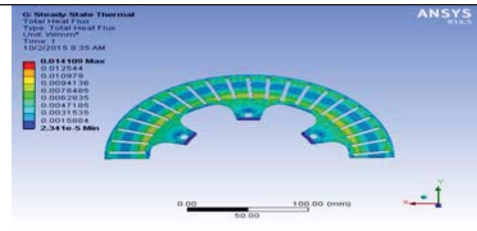
Fig 4.16Temperature	Fig 4.17 Heat flux

4.4.2 Stress Analysis

The below figures 4.18, 4.19 displays the Total deformation and Equivalent (von-Mises) stress of Stainless Steel Modified 42 Holes Disc Model. As it is evident from the figures, the maximum total deformation and equivalent (von-Mises) stress are represented by red colour.

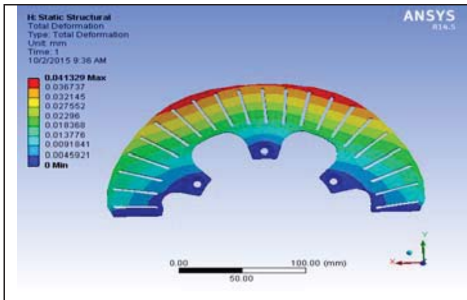	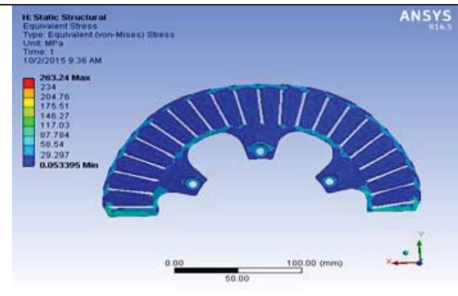
Fig 4.18 Total deformation	Fig 4.19 Equivalent stress

Table 4.4 Comparison of output parameter for different materials of modified 42 Holes disc model

Materials	**Stainless steel**	**Aluminum alloy (5083-H116)**	**Gray cast iron**	**Structural steel**
Temp max^{o}c	46.212	41.004	42.868	42.544
Total deformation(mm)	0.041329	0.05811	0.027429	0.030046
Equivalent stress(MPa)	263.24	121.8	92.928	183.37
Factor of safety	0.81673	1.8719	2.5826	1.3634

Table 4.4 shows the results of the four materials: Stainless steel, Aluminium alloy, Gray cast iron &Structural steel for Modified 42 Holes Disc Model. Comparing the results for these materials, Stress and deformation are less in Gray cast iron than the existing material.

4.5 Gray Cast Iron Modified Ventilated Disc Model

4.5.1Thermal Analysis

The below figures 4.20, 4.21 displays the Temperature and Total heat flux of Gray Cast Iron Modified Ventilated Disc Model. As it is evident from the figures, the maximum temperature and the maximum total heat flux are represented by red colour.

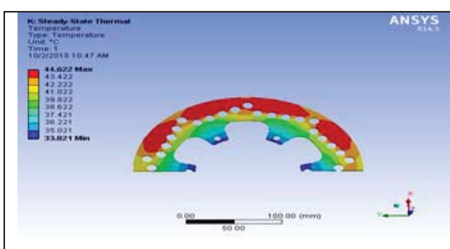	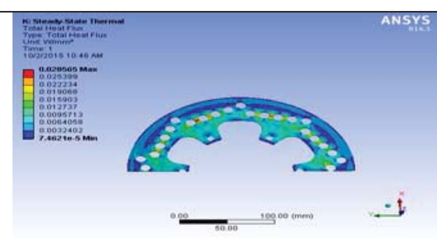
Fig 4.20 Temperature	Fig 4.21 Heat flux

4.5.2 Stress Analysis

The below figures 4.22, 4.23 displays the Total deformation and Equivalent (von-Mises) stress of Gray Cast Iron Modified Ventilated Disc Model. As it is evident from the figures, the maximum total deformation and equivalent (von-Mises) stress are represented by red colour.

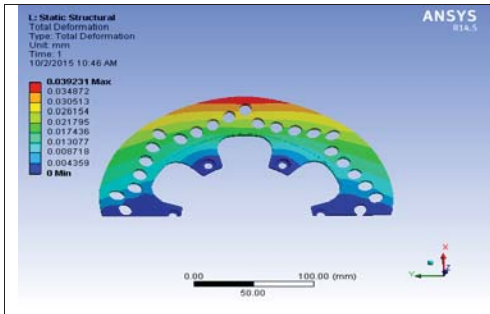

Fig 4.22 Total deformation

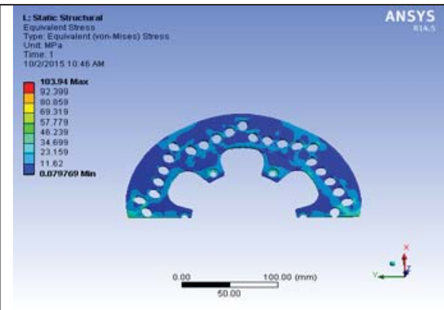

Fig 4.23 Equivalent stress

Table 4.5 Comparison of output parameter for different materials of modified ventilated disc model

Materials	**Stainless steel**	**Aluminum alloy (5083-H116)**	**Gray cast iron**	**Structural steel**
Temp max^{o}c	50.137	42.055	44.622	44.144
Total deformation(mm)	0.066132	0.078629	0.039231	0.042584
Equivalent stress(MPa)	307.43	129.35	103.94	202.48
Factor of safety	0.69934	1.7627	2.3090	1.2347

Table 4.5 shows the results of the four materials: Stainless steel, Aluminium alloy, Gray cast iron &Structural steel for Modified Ventilated Disc Model. Comparing the results for these materials, Stress and deformation are less in Gray cast iron than the existing material.

V. CONCLUSIONS

The attempt has been made in finding a new material with the modification of ventilated holes for the existing disc brake was successfully done using simulated software. Comparing the different results of temperature rise and vonmisses stresses of original disc brake was done using analytical and software. The results are validated for its adequacy. Among the other materials Grey cast iron offers less stress, therfore it is best material for disc brake. Similarly in ventilated version 36 holes gives the better results. As a whole grey cast-iron with 36 holes is the optimized state of disc brake. **Future scope of work**: Transient analysis can also carried for the same application.

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