Modelling and Thermal-Static Coupled Field Analysis of Ventilated Disc Brake

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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. 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. The aim of the paper is to design, ventilated model of a disc brake. Disc brake model is done by CATIA and analysis is done by using ANSYS workbench. The main purpose of this project is to study the thermal and structural analysis of the Materials for the Stainless Steel, Aluminum and Grey Cast Iron. A Comparison is made between three different materials used for ventilated disc brakes and the best material for making disc brake and type of disc brake have been suggested based on the magnitude of von-Mises stresses, temperature distribution and deformation.*

Keywords - ANSYS, CATIA, Ventilated Disc, Couple Field, Analysis

I. INTRODUCTION

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. Brake fade can be significantly reduced by appropriate equipment and materials design and selection, as well as good cooling. 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 became a standard feature in front brakes for most vehicles.

II. LITERATURE REVIEW

An extensive literature review on disc brakes was performed by Gnanesh, P et al [1] 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. Disc brakes are exposed to large thermal stresses during routine braking and extraordinary thermal stresses during hard braking. In the present work actual disc brake rotor has no holes; design is changed by giving holes in the disc brake rotor for more heat dissipation.

P.K.Zaware et al [2] investigated on "Design modification & optimization in stress, deformation & weight of Disc brake rotor", which studies about on disc brake rotor by modelling & 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.

Praveena S et al [3] aims to study the Thermal analysis of the Materials. A comparison between the four materials for the Thermal values and material properties obtained from the Thermal analysis low thermal gradient material is preferred. Hence best suitable design, low thermal gradient material Grey cast iron is preferred for the Disc Brakes for better performance.

Blot [4] defined several numerical procedures for the temperature analysis of brake discs and revealed that the FE technique was the fastest and most accurate for the investigation of brake disc performance. Furthermore, the time and cost of prototype manufacture and test could be significantly reduced.

Medonos [5] investigated the mechanical and elastic thermal stresses using the FE technique with temperature dependent properties. A full three dimensional model was necessary in order to take the braking drag load and the circumferential variation of thermal stresses into account. The results revealed that

the effect of mechanical stresses due to the braking pressure load, deceleration forces and centrifugal forces were minor and could be neglected. However, the friction braking drag load induced significant shear stress in the disc.

Praveena S et al [6] aims to study the Thermal analysis of the Materials. A comparison between the four materials for the Thermal values and material properties obtained from the Thermal analysis low thermal gradient material is preferred. Hence best suitable design, low thermal gradient material Grey cast iron is preferred for the Disc Brakes for better performance.

From the above literature, it is understood that various researchers considered different parameters to study the effect of stress distribution. But obtaining weight reduction on different materials with desirable life of disc brake is a challenging task.

Hence, in this work the author have chosen different materials for analysis of thermal and structural 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.

III. CATIA

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.

A. Part Design Workbench

Part design workbench is used to create solid models of the sketches drawn in the sketcher workbench. Apart from creating models, the Part Design workbench is also used for advanced modelling of solid models, such as creating a hole, pocket, fillet, and adding rectangular as well as circular patterns. Moreover, the Part Design workbench is also used to modify the structure of a solid model by inserting an additional body into a solid model.

The part design application makes it possible to design 3D mechanical parts with an intuitive and flexible user interface, from sketching in an assembly context to iterative detailed design. Part Design application will enables to accommodate design requirements for parts of various complexities, from single to advance. This application, which combines the power of the feature-based, parametric design with

flexibility of a Boolean approach, offers a highly productive.

B. Different Models of Disc Brakes

Designing different models including existing model in CATIA part modelling which are further imported to ANSYS work bench. The original model prepared in CATIA is shown in Fig 3.1. The modified models for different number of ventilated holes are reported in the Figs.3.2 to 3.4.
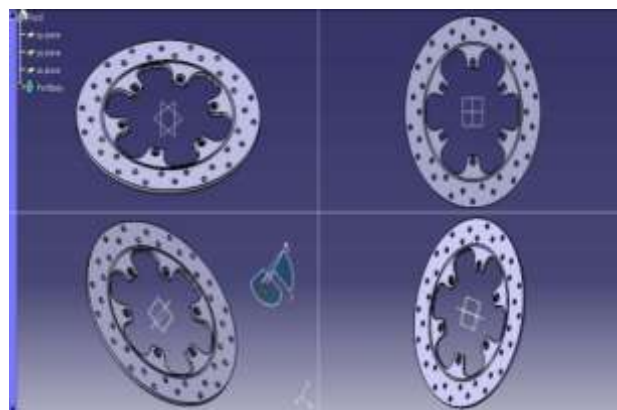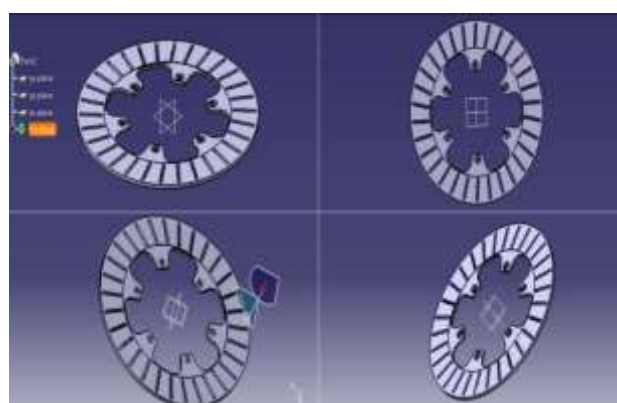

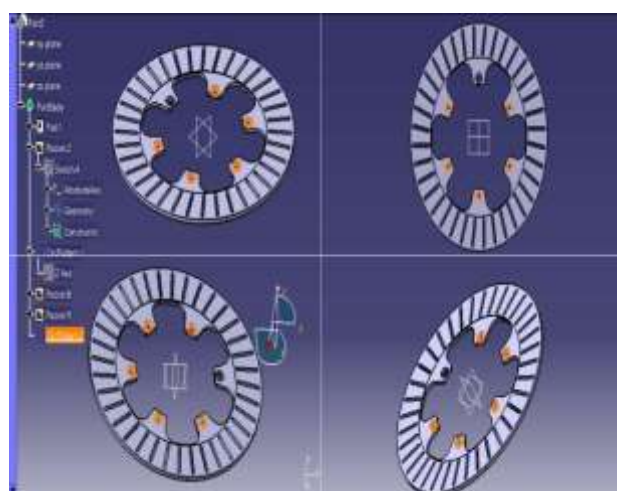Fig 3.1 Original Model

Fig 3.2 Modified 30 Holes Disc Model

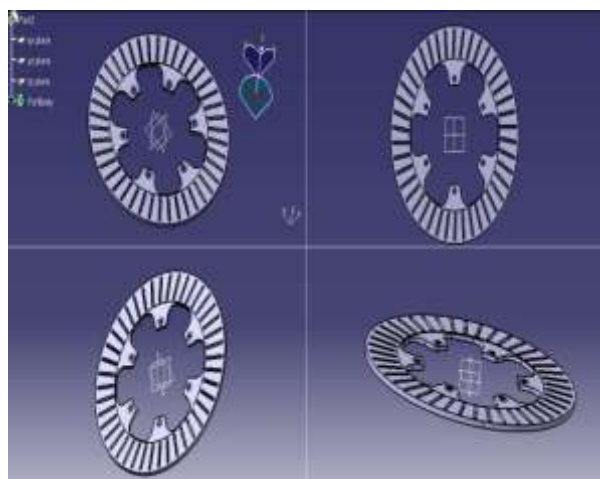Fig 3.3 Modified 36 Holes Disc Model

Fig 3.4 Modified 42 Holes Disc Model

IV. Theoretical Calculations

A. Specifications of Engine 150cc Pulsar

Engine type   : 4-stroke, DTS-i, air cooled single

cylinder

Displacement   : 149cc

Maximum power   : 15.06 @ 9000 (Ps @ RPM)

Maximum torque   : 12.5 @ 6500 (Nm @ RPM)

Length (mm)   : 2055

Width (mm)   : 755

Height (mm)   : 1060

Ground clearance (mm) : 165

Wheelbase (mm)   : 1320

Kerb weight (kg)   : 144

Front   : 240mm Disc

Rear   : 130mm Drum

B. Calculations

Speed of the vehicle=54kmph

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

$$=15 \text{m/sec}$$

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

    $0 \quad = 15 + a\,(4)$

    $a \quad = -3.75 \text{ m/s}^2;$

Distance $x = u\,t + \frac{1}{2}at^2$

Distance x $= 15 \times 4 + \frac{1}{2} \times (-3.75) \times 4^2$

Distance x $= 30 \text{m};$

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

$$= \frac{1}{2} \times 200 \times 15^2$$

$$= 22{,}500 \text{ J}$$

Rubbing area $= 2\pi r^2$

$$= 2 \times 3.14 \times (115^2 - 89^2)$$

$$= 0.0333 m^2$$

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

$$= \frac{1}{2} \times 15^2 \times 1.2 \times 0.5 \times (0.45 \times 1.866)$$

$$= 56.6797 N$$

Friction force $F_N = \mu w$

$$= 0.65 \times 9.81 \times 100$$

$$= 637.65 N$$

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 carried by taking the Brake Efficiency as 15% for the calculation of Heat flux .

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

Heat flux $\emptyset = \dfrac{\text{Heat Generated}}{\text{time} \times \text{rubbing area}} = \dfrac{250.5195}{4 \times 0.0333}$

$$= 1880.7770 \text{ w/m}^2 = 0.001880 \text{ w/mm}^2$$

V. ANSYS

     The finite element method is numerical analysis technique for obtaining approximate solutions to a wide variety of engineering problems. Because of its diversity and flexibility as an analysis tool, it is receiving much attention in engineering colleges and industries.

A. Coupled Field Analysis of Ventilated Disc Brake with Different Materials

     The coupled field Analysis is a combination of both Steady State Thermal and Static Structural

Analysis, which is carried out for a ventilated disc brake which is made of Stainless steel, Aluminium alloy and Gray cast iron.

Initially, the Heat flux and convection are given at desired boundary conditions at a particular time there by the total heat flux and temperature are determined for the given amount of heat generated.

In the second phase, these output results which are obtained during the thermal analysis are taken as input parameters along with pressure and fixed support boundary conditions

and the total Deformation and Equivalent (von-Mises) Stress are obtained as output parameters. The minimum and 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.

1) Thermal and Structural Analysis for Stainless Steel Original Model
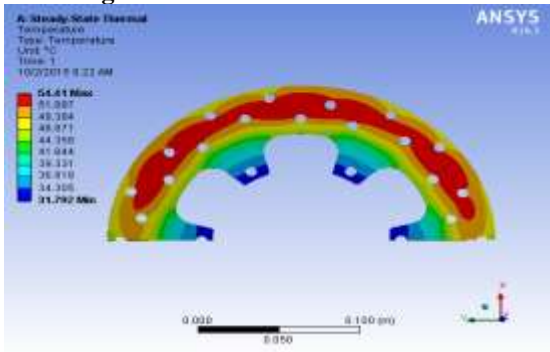
Fig 5.1 Temperature
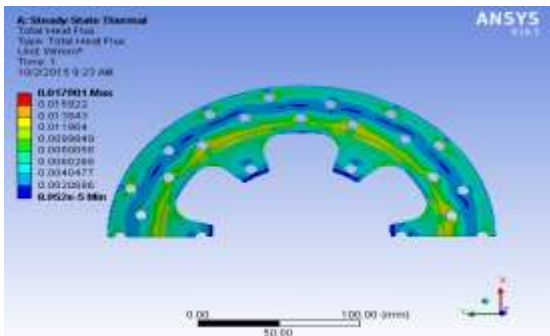
Fig 5.2 Heat Flux

The Fig 5.1 and 5.2 shows 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.
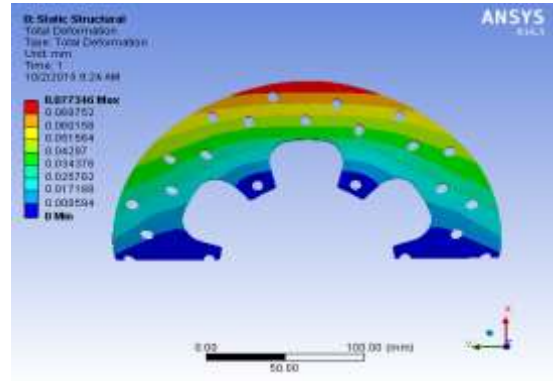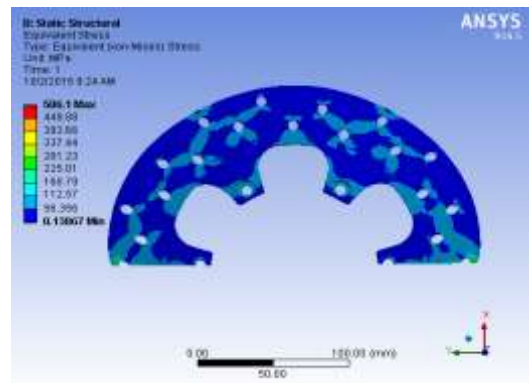

Fig 5.3 Total Deformation

Fig 5.4 Equivalent Stress

The Fig 5.3 and 5.4 shows 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.

2) Thermal and Structural Analysis for Gray Cast Iron   Original Model
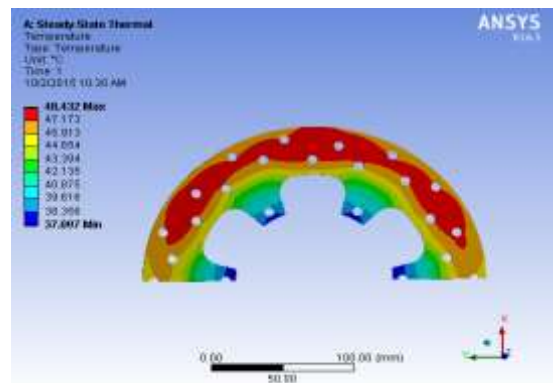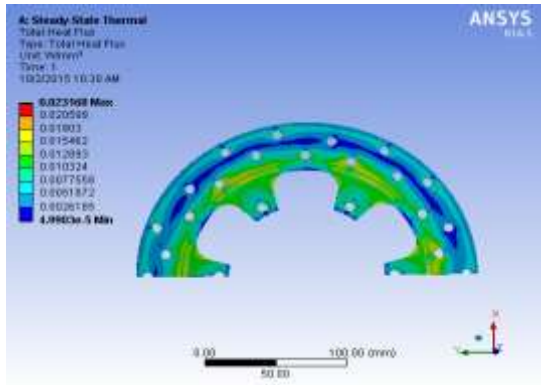

Fig 5.5 Temperature

Fig 5.6 Heat Flux

The Fig 5.5 and 5.6 shows the Temperature and Total heat flux of Gray cast iron Original Model. As it is evident from the figures, the maximum temperature and the maximum total heat flux are represented by red colour.
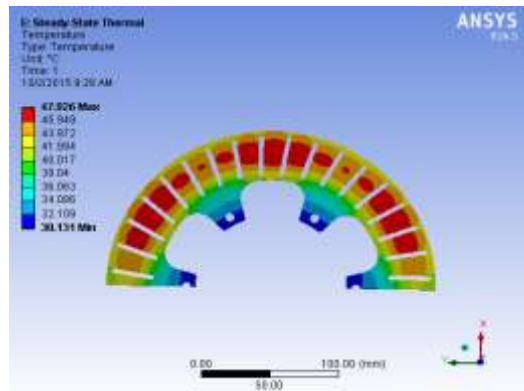

Fig 5.7 Total deformation

Fig 5.8 Equivalent stress

The Fig 5.7 and 5.8 shows the Total deformation and Equivalent (Von-Mises) stress of Gray cast iron Original Model. As it is evident from the figures, the maximum total deformation and equivalent(Von-Mises) stress are represented by red colour.

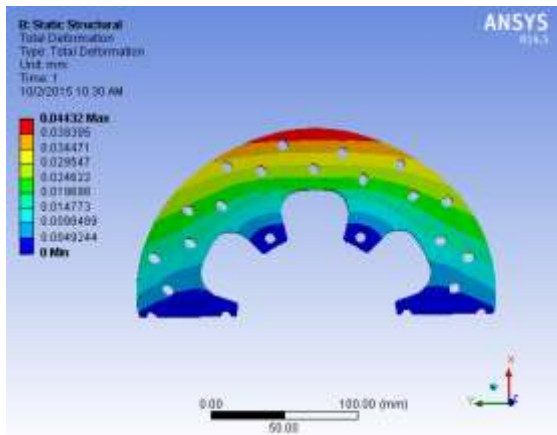3) Thermal and Structural analysis for Stainless Steel

Modified 36 Holes Disc Model
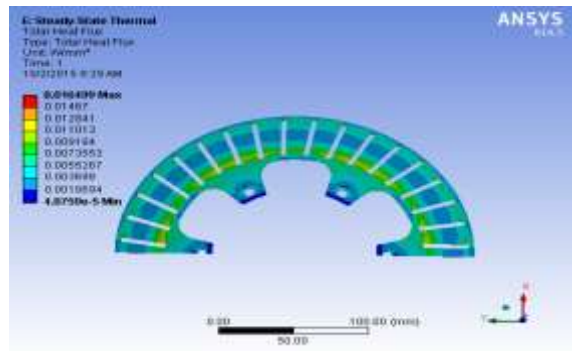

Fig 5.9 Temperature

Fig 5.10 Heat Flux

The Fig 5.9 and 5.10 shows the Temperature and Total heat flux of Stainless Steel 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.
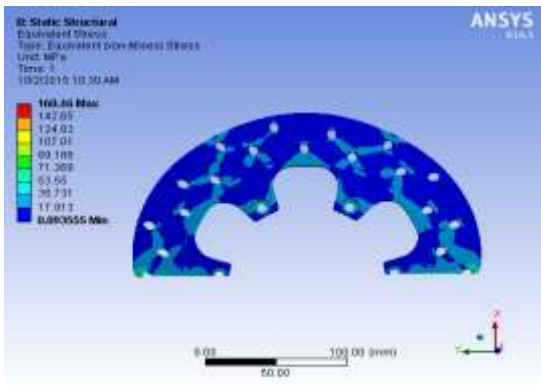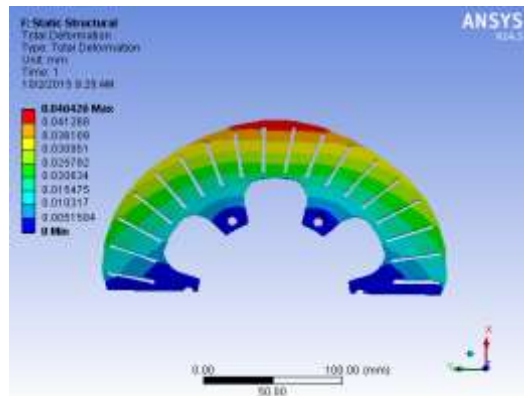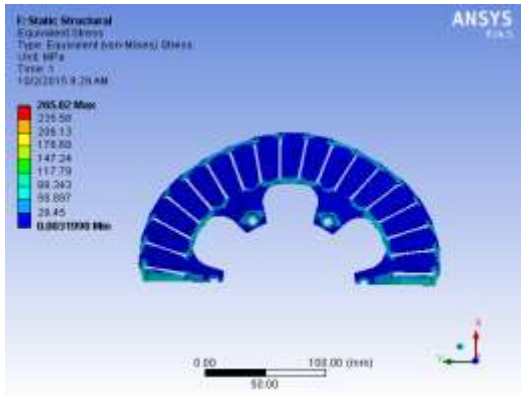

Fig 5.11 Total Deformation

Fig 5.12 Equivalent Stress

The Fig 5.11 and 5.12 shows the Total deformation and Equivalent (Von-Mises) stress of Ventilated disc brake made 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.
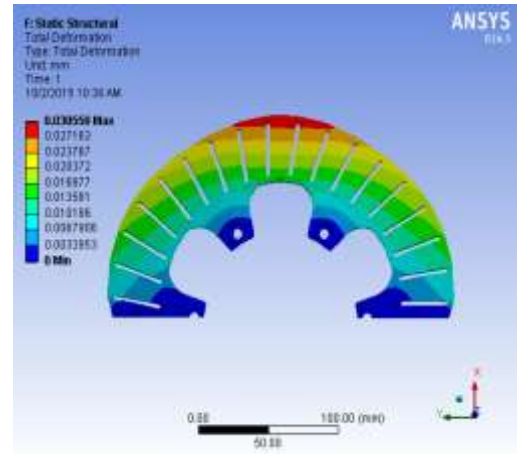
4) Thermal and Structural analysis for Gray cast iron Modified 36 Holes Disc Model

Fig 5.13 Temperature

Fig 5.14 Heat Flux

The Fig 5.13 and 5.14 shows the Temperature and Total heat flux of Ventilated 36 Holes Disc Model disc brake made of Gray Cast Iron. As it is evident from the figures, the maximum

temperature and the maximum total heat flux are represented by red colour.

Fig 5.15 Total deformation
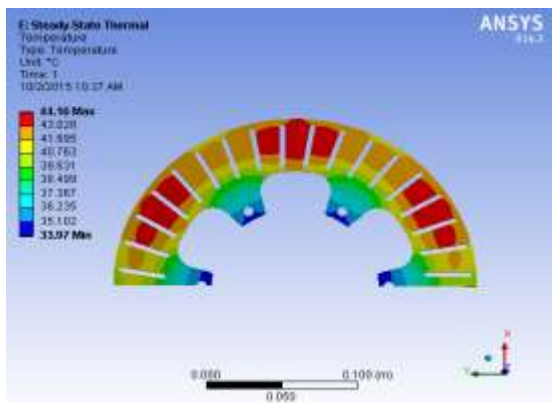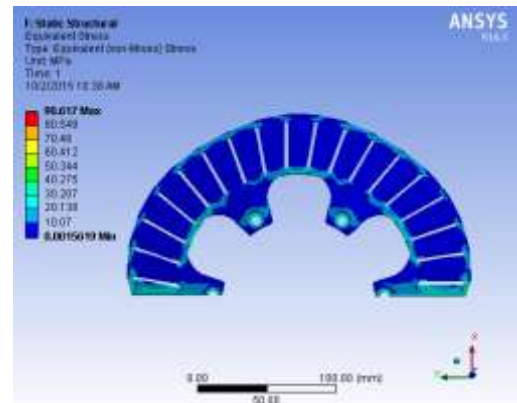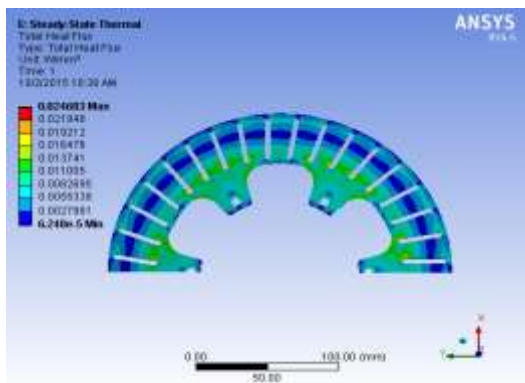

Fig 5.16 Equivalent Stress

The Fig 5.15 and 5.16 shows the Total deformation and Equivalent (Von-Mises) stress of Gray Cast Iron 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.

The above process is repeated for models made up of aluminium to know the Heat flux, temperature, total deformation and equivalent stresses. The same analysis was carried out for different number of ventilated holes such as 30 and 42.

A comparative analysis was carried out for original model along with modified ventilated disc brake models. The Table 5.1 and 5.2 gives the results of compartives anlysis of different materials namely Stainless steel, Aluminium alloy and Gray cast iron.The results for these materials shows that equivalent (Von-Mises) stress and deformation are found to be less in Gray cast iron in comparison with remaining models of Stainless steel and Aluminium alloy.

Materials	Stainless Steel	Aluminum Alloy 5083-H116	Gray Cast Iron
Temp min ^{o}c	30.131	37.132	33.97
Temp max ^{o}c	47.926	47.107	44.16
Heat flux (w/mm^2)	0.016499	0.033683	0.024683
Total deformation(mm)	0.046426	0.064648	0.030558
Equivalent stress(MPa)	265.02	115.95	90.617
Factor of safety	0.81125	1.9663	2.6485
Weight(kg)	0.82624	0.27472	0.74362

Table 5.1 Original Model

Materials	Stainless steel	Aluminium alloy 5083-H116	Gray cast iron
Temp min ^{o}c	31.792	40.857	37.097
Temp max ^{o}c	54.41	45.773	48.432
Heat flux (w/mm^2)	0.017901	0.026521	0.023168
Total deformation(mm)	0.077346	0.087712	0.04432
Equivalent stress(MPa)	506.1	198.47	160.46
Factor of safety	0.42482	1.1488	1.4956
Weight(kg)	0.9452	0.31428	0.85068

Table 5.2 Modified 36 Holes Disc Model

VI. CONCLUSIONS

An attempt has been made in finding a new material with the modification of ventilated holes for the existing disc brake. The following conclusions were drawn.

(i) The gray cast iron material disc brake exhibits more heat flux and capacity to with stand for high thermal stresses with good factor of safety.

(ii) The couple field analysis of different material shows that the gray cast iron gives reliable results as it has good cooling rate efficiency when compared with the stainless steel.

(iii) It was inferred from the results obtained from different materials and with different number of ventilated holes, a modified 36 ventilated holes disc model with Gray cast iron is having better results than the existing material.

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