Fatigue and Static Thermal Analysis of Brake Disc for SAE Based Cars

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Abstract – *The disc brake is a mechanism used for stopping or slowing the rotation of a rotating element. During each braking event the kinetic energy of the rotating element is converted into heat. Hence it becomes important to carry out static as well as thermal analysis of the disk brake. This work aims at evaluating the fatigue life of the two wheeler disc brake at a particular static and thermal load conditions. The disk brake was modelled using CATIA V5 modelling software and the thermo-mechanical analysis was carried out using ANSYS workbench 14.5. Coupled thermal – structural analysis was used to analyse the Fatigue life, Damage, stress concentration, structural deformation and thermal gradient of disc brake at a particular thermal and structural loading condition. It is found that the total heat flux and temperature is maximum at the contact region of brake disc and brake pads. The maximum value of the stress is found to be occurring at the at the hole regions. This is because the hole regions act as stress concentrators. While rest of the brake region experiences a minimal value of stress. Also it is clear that the crack initiation takes place at the junction of the holes. This is because of the low contact cross section area between the holes where the maximum stress is found to be occurring. The minimum cycle for failure is 8722.2 while the maximum cycle or the design life is 1x109 cycles.*

Key Words: Disc brake, Thermal analysis, Fatigue life, Heat flux, ANSYS workbench.

1. INTRODUCTION

Newton's first law of motion which states that an object remains in its state of rest or in motion until and unless acted upon by an external force is the basic foundation for the development of braking system. Developing an automobile vehicle not only requires the power source but also the efficient braking system as higher the horse power higher will be the brake force required to stop or de accelerate that vehicle. The brake is a mechanism used for stopping or slowing the rotation of a rotating element. A brake is a mechanism used to restrict the motion of machine or a vehicle. The kinetic energy absorbed by the brakes is dissipated as heat energy. Brake systems must serve the following purpose:

- In case of emergency or when needed vehicle must stop at a minimum distance.

- It should possess anti wear properties.

- With prolonged application the braking properties must not faint away.

The conversion of kinetic energy into heat energy is a function of frictional force generated by the frictional contact between brake shoes and moving drum or disc of a braking system. Disc brake is an important component of vehicle retardation system. It is the type of brake that uses callipers to squeeze pairs of pads against a disc to create friction. That friction slows the rotation of a shaft (vehicle axle) to hold it stationary or slow its rotational speed. Disc brake is usually made of cast iron or ceramic composite such as carbon, aluminium, and silica. Friction material known as brake pad is made to engage on both side of disc either mechanically or pneumatically. This friction material causes disc to slowdown or stop. The disc brake is sandwiched between two pads activated by a cylinder backed in a calliper mounted on the stud shaft. At the point where the brake lever is pressed, pressurized hydraulic pressed fluid is constrained in the chamber pushing the contradicting cylinders and brake parts. When the pad is pressed against the disc, the brake absorbs kinetic energy of the vehicle and it is transferred into heat which is mainly absorbed by rotor and brake pad. This heat is dissipated into the surrounding atmosphere. Due to the generation of frictional heat on the interface of the disc and pad, there is rise in temperature. When this temperature exceeds the critical value of the given material, it leads to catastrophic events such as brake fail, premature wear, and failure of bearing, thermal crack or vaporization of brake fluid. Furthermore, due to heat generation at the disc pad interface, global deformation occurs in disc and pad. Some common deformations are coning and buckling. Besides this, macro cracks may appear on the disc brake in radial direction after some brake cycles. Thus life and performance of the disc brake is affected. Mainly three types of mechanical stress is subjected on disc brake.

- Traction force, caused by centrifugal effect and it occurs when wheel is rotating and no brake force is applied to the disc.

- Compressive force, when the brake is applied due to action of the force exerted by pressing the pad perpendicular onto the surface of the disc.

- Due to braking action caused by rubbing on the brake pad against the surface of the disc. It acts in opposite direction of the disc rotation.

Fig -1: Disk Brake

1.1 Necessity of a Braking System

In an automobile vehicle braking system is needed

- To de accelerate the moving vehicle.

- To stop the moving vehicle.

- As a precaution for accidents.

- For stable parking of a vehicle either on a flat surface or on aslope.

- To prevent the vehicle from any damage due to road conditions.

2. OBJECTIVE

The objective is to design a Disc brake using CATIA V5 and carry out the finite element analysis (FEA) and thermal analysis on the prepared model using ANSYS 14.5. Thus obtain the values of Fatigue life, Damage, shear stress, total deformation, total heat flux and temperature distribution on disc brake.

3. METHODOLOGY

A Structural analysis calculates deformations, stresses, and strains on model in response to specified constraints. A static analysis gives certain information about model. For example, a static analysis tells us if the material in our model will stand stress and if the part will break (stress analysis), where the part will break (strain analysis), and how much the shape of the model changes (deformation analysis). In these work,

- The disk break is designed by using CatiaV5 software with specified dimension.

- The 3D disc model is important to the Ansys workbench.

- The analysis is carried out with by specifying material property and meshing.

- Application of boundary conditions for steady state thermal model.

- Application of boundary conditions for static structural model.

- Interpretation of solution and results.

3.1 Finite Element Analysis

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 almost every industry. In more and more engineering situations today, we find that it is necessary to obtain approximate solutions to problem rather than exact closed form solution. It is not possible to obtain analytical mathematical solutions for many engineering problems. In this step it defines the analysis type and options, apply loads and initiate the finite element solution. This involves three phases.

- Pre-processor phase

- Solution phase

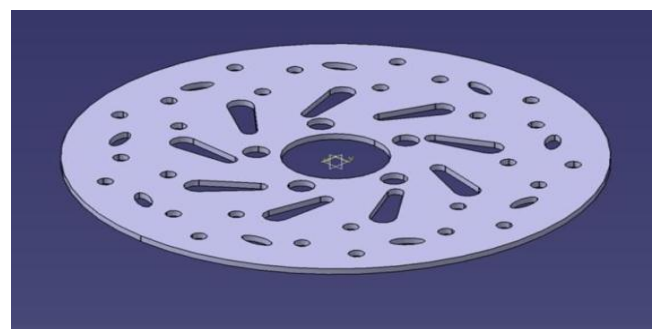- Post-processor phase

4. DESIGN AND ANALYSIS OF THE DISC BRAKE

Fig -2: Disk Brake

3D model of the brake disc was modeled using CATIA V5 modeling software. The dimensions of the brake disc are listed below.

Inner diameter – 40 mm

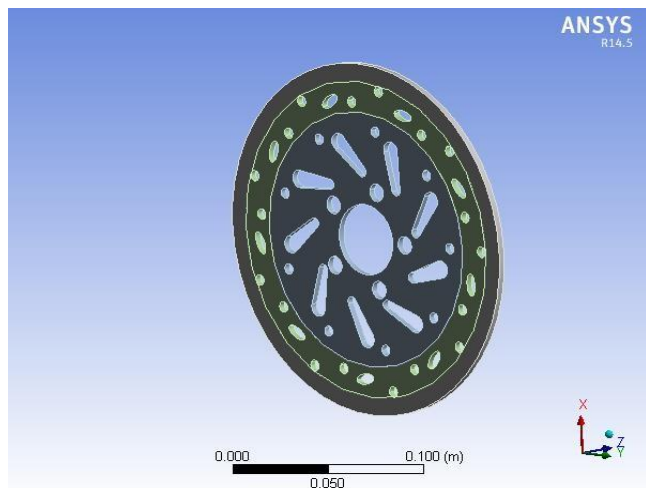Outer diameter – 200 mm

Hole diameter – 6 m

Fig -3: ANSYS Geometric Model Divided Into 3 Regions

The 3D disk model was imported to ANSYS workbench in STP format. The imported model was divided into three regions, for the application of different boundary conditions.

The 3D disc model was meshed in ANSYS meshing software. Meshing was carried out automatically containing 1487358 and 739062 elements. The maximum size was 0.9997072 mm and the minimum size was set to 6.561198 x 10^{-02} mm. The transition between the elements was set slow and smoothing was set high.

4.1. Brake Disc Material Data

Table -1: Brake Disc Material Data

Sl. No	Parameter	Value
1	Material	Structural steel
2	Density	7852 kg m^{-3}
3	Specific heat	434 J kg^{-1} C^{-1}
4	Thermal conductivity	60.5 W m^{-1} C^{-1}
5	Resistivity	1.7 e^{-007} ohm m

5. APPLICATION OF BOUNDARY CONDITIONS FOR STEADY STATE THERMAL MODEL

The heat generated while braking due to the contact between the brake pads and the brake disc was simulated by applying heat flux boundary condition at the contact region as shown in the figure 4. Since the heat dissipates from the entire surface of the brake disc, convection and radiation boundary conditions were applied to the entire surface of the disc brake as shown in figure 5 and 6 respectively. The values of the same is shown in the below table 2.
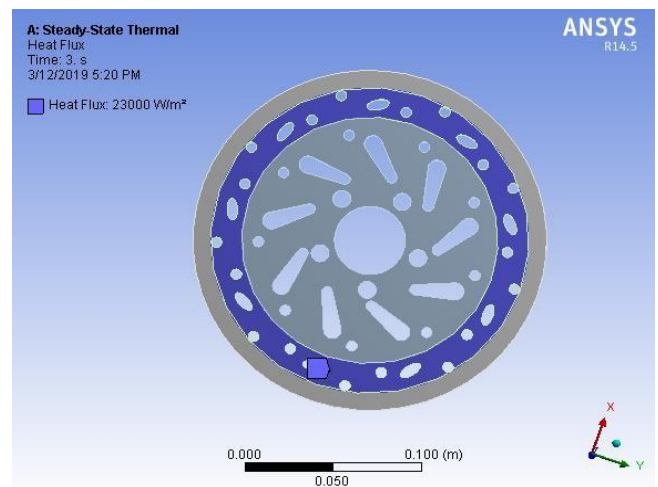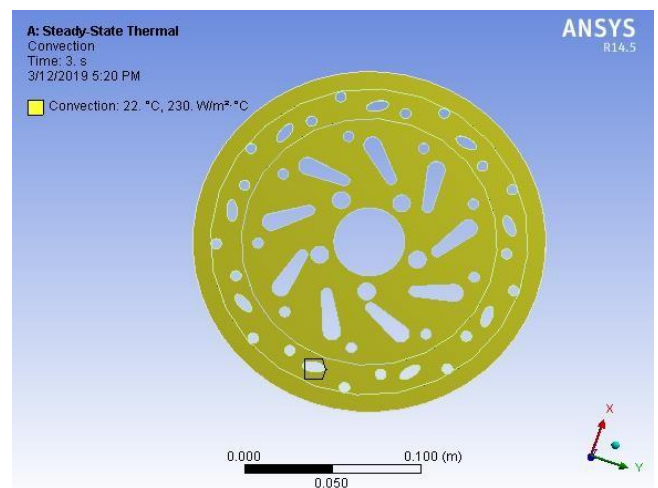

Fig -4 Heat flux boundary condition
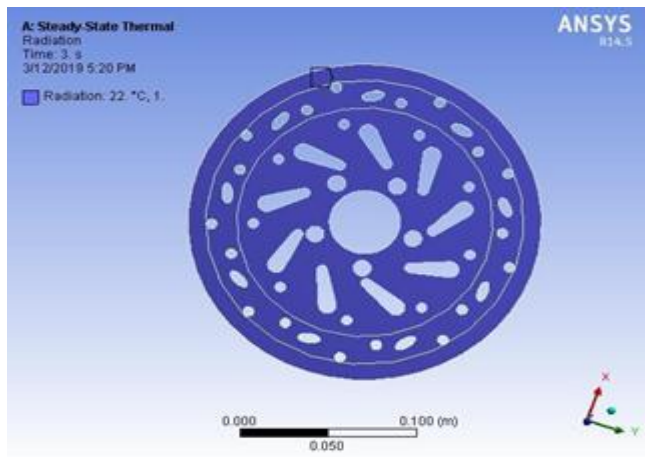

Fig -5: Convection boundary condition

Fig -6: Radiation boundary condition

Table -2: Thermal Boundary Conditions

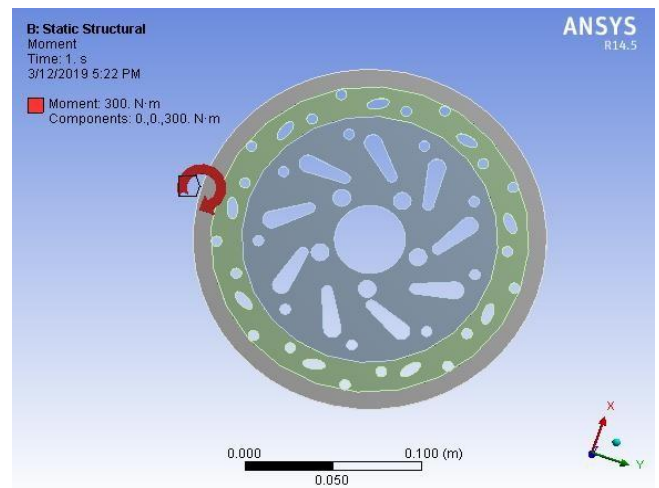| Sl. No	Boundary condition	Value
1	Heat flux	23000 W m^{-2}
2	Convention	230 W m^{-2} C^{-2}
3	Radiation	22 ^{o}C

5.1 Application of Boundary Conditions for Static Structural Model.

Force of 300 N and the Moment of 300 N-m was applied to simulate the rotational effects of the brake. The solutions of the thermal analysis are coupled to static structural analysis and further analysis was carried out.
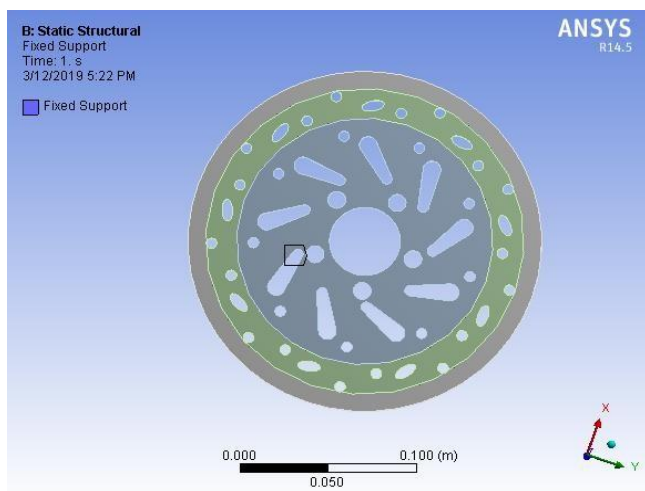
Fig -7: Fixed support boundary condition

Fig -8: Force boundary condition

Fig -9: Moment boundary condition

6. RESULTS AND DISCUSSIONS

During each braking event the kinetic energy of the rotating element is converted into heat. The maximum heat flux is found to be 1.07×10^{5} W/m^{2} and is found to occur at the contact region of brake disc and brake pad. The minimum heat flux is found to be 6.7299 W/m^{2} at the center of the disc. The maximum temperature is found to be 63.062^{o}C at the contact region of the disc and the brake pads due to frictional heat decapitated. The stress acting on the brake disk at a load of 300 N. The maximum value of the stress is found to be occurring at the at the hole regions. This is because the hole regions act as stress concentrators. While rest of the brake region experiences a minimal value of stress. The total deformation of the brake disk during braking action. The deformation is found to be progressing from center at a minimum value of 0 to the maximum value of 4.4478×10^{-5} at the outer edge of the disc. The fatigue life and damage of the brake disc at a load of 300 N. It is

clear that the crack initiation takes place at the junction of the holes. This is because of the low contact cross section area between the holes where the maximum stress is found to be occurring.
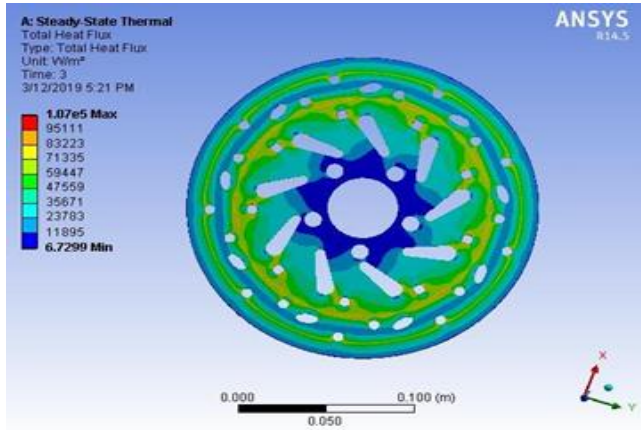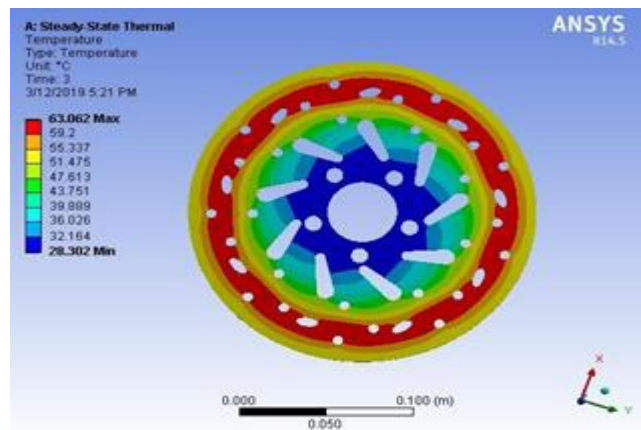

Fig -10: Total Heat Flux

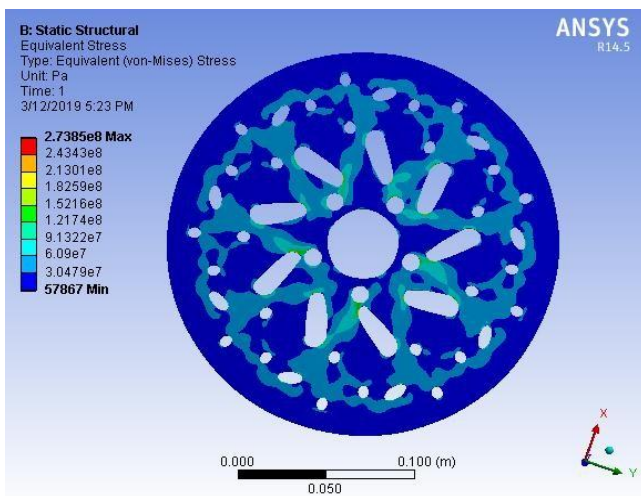
Fig -11: Temperature Distribution

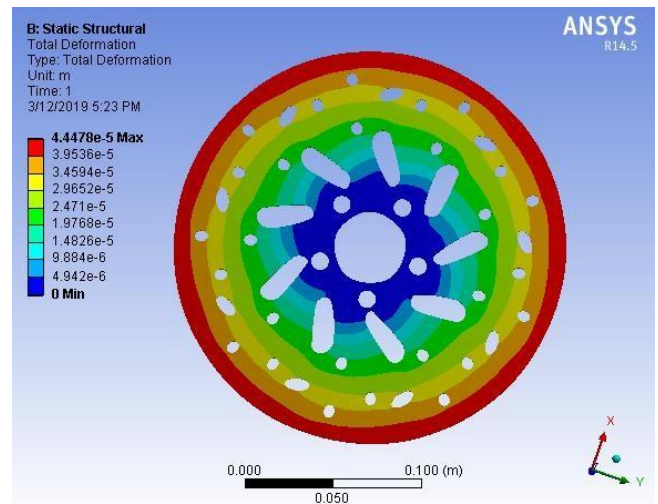**Fig -12**: Stress acting on brake Disc
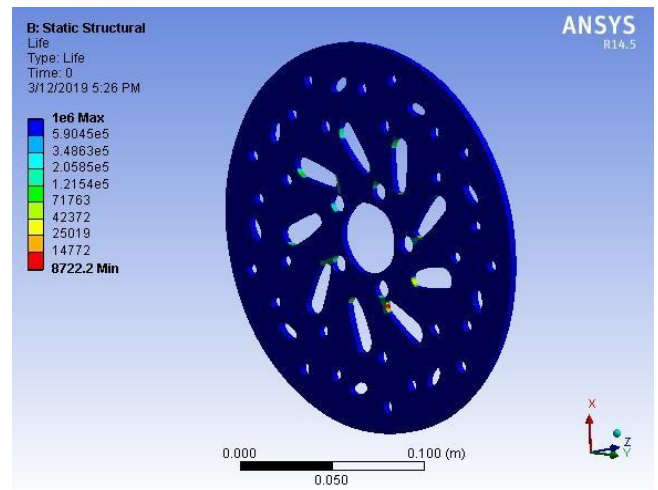

Fig -13: Total Deformation

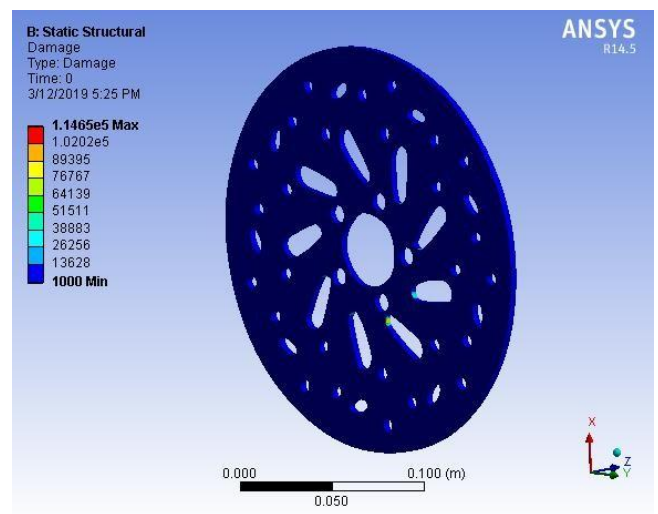
Fig -14: Fatigue Life Analysis

Fig -15: Damage Analysis

7. CONCLUSIONS

- Coupled thermal – structural analysis was used to analyze the Fatigue life, Damage, stress concentration, structural deformation and thermal gradient of disc brake at a particular thermal and structural loading condition.

- It is found that the total heat flux and temperature is maximum at the contact region of brake disc and brake pads.

- The maximum value of the stress is found to be occurring at the at the hole regions. This is because the hole regions act as stress concentrators.

- While rest of the brake region experiences a minimal value of stress.

- It is clear that the crack initiation takes place at the junction of the holes.

- The low contact cross section area between the holes where the maximum stress is found to be occurring.

- The minimum cycle for failure is 8722.2 while the maximum cycle or the design life is $1\text{x}10^9$ cycles.

REFERENCES

[1] Venkataramana R, kumaraburaban S, Venukumar C, Shivakumar S, Design and analysis of Disk Brake Rotor,Research gate, V.10,Nunber19(2015)

[2] Manjunath T V. Dr. Suresh P M, Structural and Thermal Analysis of Rotor disk of Disk Brake,Vol1.Issue12,December2013

[3] Mahmood Hasan Dakhil, Dr. A. K. Rai, Dr. P. Ravinder Reddy & Ahmed Abdul Hussein Jabbar, 'Structural Design and Analysis of Disc brake in Automobiles', Research gate/publication/274373222, January 2014.

[4] Jayaram A S, Effect of Stress Concentration Factor For Maximum Stress for A Rectangular Plate With Cutout, Subjected to Tensile Load, International Journal of Innovative Science and Research Technology Volume2, Issue9, September-2017

[5] S A Mahesh, H S Manjunath, Viyaj kumar V, Design and Optimization of Display unit Suporting Structural Under Static and Sprectrum Loads Using FEA, International Research Journal of Engineering and Technology (IRJET) Volume 4- Issue 10 - October 2017

[6] Er. N. B. Shinde, Prof. B.R. Borkar, 'CAD. and FEM Analysis of Disc Brake System', Volume 4, Issue3 March 2015, Page NO-10697-10706

[7] K, Sowjanya, S Suresh, ' Structural Analisys of Disc Brake Rotor', International Journal of Computer Treads And Technology (IJETT)-Volume 4 Issue 7 -july 2013

[8] Preetham Raj V, Chandan R, Doddanna K, Stress Analysis and Fatigue Failure of Typical Compressor Impeller, International Research Journal of Engineering and Technology (IRJET) Volume 05- Issue 10 - October 2018