Static structural and thermal analysis of disc brake pad model

Yashvardhan singh Chouhan1, Sudhir Tiwari2
1,2Department of Mechanical Engineering, SGSITS, 23, Park Road, Indore, 452003, M.P., India
1ysinghchouhan810@gmail.com, 2sudhir2609@gmail.com

Abstract. This paper attempts to present a study of the automotive disk brake’s thermo-mechanical behaviour during the braking period using the Static Structural and Transient Thermal analysis for vehicle disk brake pad system using finite elemental analysis. In this work Thermal and static analysis was performed on solid and ventilated disc for two configurations of pads using ANSYS 15. Two pad Profiles with pure and single slot along with both discs have been studied. The analysis is conducted on the model that lacks thermal properties first. It is predicted for structural performance such as deformation and von-mises stress. After that, with the introduction of heat flux, convection and adiabetic components, thermo-mechanical analysis is performed on the same model. The estimate results of temperature distribution, total deformation and von-mises stress are presented. The software tools CATIA and ANSYS Workbench have been selected for modelling and analysis. CATIA is a widely used 3D modelling technology in the design process. ANSYS is a software package for general purpose finite element analysis (FEA). The outcome of this investigation assists brake engineers in choosing appropriate research to determine the disk brake assembly in structural and contact behaviour.

Keywords. Ventilated Disc, Brake Pads, Structural Analysis, Thermo-mechanical Coupling, Catia, Ansys.

1. Introduction
A vehicles used in a transportation sector are being developed to be able to transport a passengers and products at higher speeds and higher capacities to achieve a desired high performance. This requires absorbing more kinetic energy during stopping or slowing down of vehicles. Thus, brake system is required in a vehicle to stop & adjust a speed in altering conditions of street and rush-hour traffic. A brake is functioned with a help of caliper through which frictional resistance occurs on wheel in order to slow down or break a motion of a vehicle. In general we find two types of a frictional brake namely disc brake & drum brakes. Disc brake in comparison with drum brake cools sooner because of larger cleared range & comparatively high acquaintance of air stream & also shows self-cleaning skill because of centrifugal force.

A hydraulic braking system was invented over 100 years ago (Newcomb & Spur 1989) and has been universally used in passenger cars for over 60 years. A hydraulic braking system relies upon a ‘muscular’ energy of a driver, which may be amplified by a suitable ‘booster’. A basic principle is that incompressible ‘brake fluid’ is pressurised by a ‘master cylinder’ piston connected to a brake pedal & a pressure generated creates an actuation force from a ‘slave cylinder’ piston, which actuates a brake shoe or pad. In the disc brake, a rotating disc is pressed against by pads and heat is generated because
of friction at the interface of disc and pad. The frictional heat is transferred directly to the environment and the disc becomes cool. A disc brake assembly is shown in Figure 1.

Figure 1. A simplified disc brake assembly

Brake disc is placed secure to axle, so that it exchanges with an equivalent speed as a wheel. Brake disc generally are of two types:

1. Solid brake disc
2. Ventilated brake disc

The simplest structure involving a single strong plate is known as Solid disc. While in the ventilated disc vanes separate two partitions of disc and stretch a way for the mid-air to pass or stream. It also performs faster cooling and subsequently, outcomes low outside temperature. Disc brakes now become critical safety components whose functionality depends on the working members. Rashid [1] presents a review paper which depicts various geometries of parts and materials used in disc handling systems. Despite an extensive number of improvements, there are until now many working issues for different systems which need to be understood. Vehicle safety is becoming more concerning subject nowadays in the automobile industry. Using a finite element approach to define and predict structural quality of the disk brake is becoming very popular in the research community. Belhocine et al. [2] presents research of a thermal and mechanical manner of a car disc brake while braking stage is being introduced. Likewise, a basic execution between a two breaks down (mechanical & thermo mechanical) was additionally analyzed. Talati and Jalalifer [3] presented the heat equation for pad and disc in the form of transient heat equations.

In the work performed by Kumar et al. [4] a selective material for brake pads & rotor is proposed. Two unique materials, S2 glass fiber & carbon fiber, are picked as cushion materials and aluminium alloy & grey cast iron are picked for a rotor material. Warm investigation performed in solid & ventilated disc for different materials of pad utilizing ANSYS 15. Diverse pad profiles along with solid, single slot & two slots have been examined by fluctuating material properties of pad. Parab et al. [5] depicts a designing of brake disc using CATIA. Basic & thermal investigation is performed on disc brakes utilizing 3 different materials. Reddy et al. [6] carried out research in a solid and ventilated disc using Pro-E and ANSYS. He performed a couple analyses done on both disc to predict strength of disc brake. Comparisons can be made among three materials to get best material for FSAE car. Babukant and Teja [7] performed transient thermal analysis using ANSYS for distribution of temperature and heat flux on each friction surface of contacting bodies. Hwang and Wu [8] investigate the thermal stress and temperature in ventilated disc pad model. The work is done using thermo-mechanical multi body technique and it is validated with experimental results. Yildiz and Duzgun [9] presents three diverse ventilated brake disc and braking power examinations were researched tentatively together with a solid disc. In the work performed by Kumar and Bijwe [10] copper as filler material is investigated for a brake pad.
The finite element modelling is the main research method used in this project. The model is prepared in the CATIA software based on the assumptions raised in the literature survey then; the model is implemented to analysis software in ANSYS where it is being introduced with basic theories of structural and thermo-mechanical analysis. The basic equations such as heat transfer equations, frictional heat flux and convection were implemented in thermo-mechanical analysis.

2. Modelling of disc brake-pad model

CATIA is multi stage 3D programming created by Dassault Systems, including CAD, CAM and CAE. CATIA is a solid modeling tool displaying pictures that joins 3D parametric highlights with 2D devices & furthermore addresses each structure to-assembling process. CATIA likewise gives creating orthographic, projections, isometric or point by point 2D drawing perspectives. It also produces model measurements & makes reference measurements in a drawing. Table 1 shows dimension of parts and figure 2 (a-d) shows catia model of parts.

| Parameter Name | Disc(mm) | Pad(mm) |
|----------------|----------|---------|
| Outer diameter | 221      | 220     |
| Inner diameter | 133      | 137     |
| Thickness      | 10       | 12      |

![Table 1. Dimension of disc-pad model](image)

Figure 2. Different parts of disc and pad

3. Introduction of FEA

A FEA is a simulation technique of physical problem through numerical method which is also known as FEM. Experts tried to decrease an amount of hard models, optimize by redesign parts in their structure stage to enhance effectively things, quickly. FEA is a numerical procedure used for prediction of how an area or assembly together acts under given conditions. FEA method has transformed into a favoured system in performing thermal assessment on a brake assembly together recently. It is communicated that thermal examination is generally performed using a finite part method, as this procedure has transformed into an outstanding resource for a numerical game plans of a wide extent of structure problems.

3.1. ANSYS

Dr. John Swanson built up ANSYS in 1970 with an idea to advertise a possibility of computer mirrored structure, setting up himself as one of pioneers of Finite Element Analysis (FEA). ANSYS is all around valuable finite element assessment (FEA) programming group. ANSYS 15 is totally used to reproduce assistant deformation, temperature, stresses and pressure distribution in brake applications. In the present work, a 3-D FE model includes a solid disc & two pads are utilized. The material of a disc is grey cast iron & brake pads have an isotropic behavior whose mechanical features of two portions are given in table 2.
Table 2. Properties of disc and pad

| Properties          | Grey Cast Iron (Disc) | Isotropic Material (Pad) |
|---------------------|-----------------------|--------------------------|
| Density, $\rho$     | 7000 kg/m$^3$         | 2.31 g/cc                |
| Young Modulus $(E)$ | 100 Gpa               | 2.30 Gpa                 |
| Thermal Conductivity, $k$ | 54 W/m.k       | 2.41 W/m.k               |
| Specific heat, $C_p$| 586 J/kg.k            | 1076 J/kg.k              |
| Poisson ratio, $\mu$| 0.28                  | 0.25                     |

3.2. Meshed model
Cross section includes division of a whole model into little pieces called elements. Elements utilized for a coincided model are tetrahedral 3D components. A limited component model of a rotor was completed to such an extent that a subsequent components came to 10325 elements with an aggregate of 19843 nodes. Cross section of disc pad model is appeared in figure 3 and meshed properties in table 3. Working force to the brake pad is 2785.24 N. The pressure applied externally between the disc and pad is 1 N/mm$^2$. The rotational speed of the disc is 123.44 rad/s.

Table 3. Finite elements meshed properties

| Description | Nodes | Elements |
|-------------|-------|----------|
| Disc        | 12402 | 6836     |
| Pad 1       | 1803  | 884      |
| Pad 2       | 1840  | 913      |

Figure 3. Meshed model of disc-pad assembly

3.3. Boundary condition and loading
In the present model, boundary conditions are shown in figure 4 for pressure applied on single side of pad. The disk is fixed tightly in all directions at the bolt holes except in its direction of rotation and pads are fixed at the edges in all degree of freedom excluding in the normal direction. So the pad moves up and down and makes contact with the disc surface.

Figure 4. Boundary condition

Figure 5. Thermal boundary condition
3.4. Thermal boundary condition
Thermal boundary conditions as appeared in figure 5 are applied in the model for expressing heat transfer. At the boundary between the disc & brake pad, heat is created because of friction which is appeared in blue lines. For uncovered region of disc & brake pad, it is accepted that heat is traded with surrounding over convection. In this way, convection limit condition is functional there. At outside of a back plate, adiabatic boundary condition is utilized.

4. Result and discussion

4.1. Disc-pad deformation without thermal effects

4.1.1 Total deformation
Figure 6 (a-d), presents the disc deformations in contrast to braking time. From the figures, it is seen that large deformations mostly found at discs outer radius that are in contact with the pads. Ventilated disc deform more compare to the solid disc through both configurations of pads. The highest deformation is 29μm for ventilated disc with single slot pad. As for the pads, deformations occur at the outer radius of the pads. Table 4 shows total deformation in a model.

![Figure 6. Total deformation in both discs along with pads](image)

**Table 4.** Total deformation

| Configurations                        | Total deformation(μm) |
|---------------------------------------|-----------------------|
| Solid disc-solid pad (a)              | 26.351                |
| Solid disc-single slot (a)            | 26.729                |
| Ventilated disc-solid pad (c)         | 28.881                |
| Ventilated disc-single slot (d)       | 29.269                |

4.1.2 Stress distribution
Figure 7 (a-d) shows the von-mises stress distribution of the disc-pad model. The maximum stress generates in the single slot-solid disc model of the order of 25Mpa. The stresses are maximum at the bowl of the disc. Table 5 shows stress values in different configuration of model.

**Table 5.** Von-mises stress

| Configurations                        | Von-mises stress (Mpa) |
|---------------------------------------|------------------------|
| Solid disc-solid pad (a)              | 16.331                 |
| Solid disc-single slot pad (b)        | 25.082                 |
| Ventilated disc-solid pad (c)         | 14.384                 |
| Ventilated disc-single slot pad(d)    | 21.136                 |
4.2. Disc-pad deformation with thermal effects

4.3. Solid disc with solid pad

Figure 8. Thermo-mechanical analysis of solid disc with pad

Figure 9. Thermo-mechanical analysis of ventilated disc with pad

Based on the table 6, it shows that total deformation is maximum in solid disc but stress generation is maximum in ventilated disc. On the basis of temperature distribution ventilated disc is suited best for temperature distribution.
Table 6. Thermo-mechanical results of solid and ventilated disc

|                         | Solid disc |                      | Ventilated disc |                      |
|-------------------------|------------|----------------------|-----------------|----------------------|
|                         | Maximum    | Minimum              | Maximum         | Minimum              |
| Total deformation, µm (a)| 249.28     | 0                    | 249.28          | 0                   |
| Von-mises stress, Mpa (b)| 164.29     | 0                    | 191.34          | 2.7555e-9           |
| Temperature distribution, ºc (c) | 227.79     | 23.707               | 226.55          | 11.436              |

5. Conclusion
The Work attempted studies in static structural and transient thermal analysis of disc brake pad model using mechanical and thermo-mechanical approaches. Deformation, von mises stresses and temperature distribution of disc-pad model has been carries out in order for improving the braking effectiveness and provides good strength to the vehicle in the design stage. From the results it can deducted that:

- The outer radius of the disc deforms more.
- When dealing with without thermal effects, large stresses generated at the bowl of the disc. Based on total deformation solid disc-solid pad is best and based on von-mises stress ventilated disc with pure profile pad is taken as the best.
- Von-mises stress and total deformation of disc pad model increase in noticeable way in thermo-mechanical analysis.
- Large deformations are found in solid disc compare to ventilated disc but stresses are reduced in solid disc.
- Ventilated disc provide good temperature distribution effect compare to solid disc to dissipate heat to the surroundings.

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