DESIGN AND ANALYSIS OF BRAKE ROTOR FOR FORMULA STUDENT VEHICLE

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Abstract - *The braking system plays a crucial role in controlling and stabilizing the race car. This work contains the Design and Analysis of Brake Disc/Rotor for FSAE/SAE SUPRA. The disc is designed by considering all the standard parameters for a Formula Student Vehicle like weight, speed, wheelbase, tire size, etc. Selection of Brake disc type is made from 4 standard profiles: - Solid, Drilled, Slotted, Combination (Drilled and slotted). The selecting parameters are based on Heat Flux, the mass of a disc, stress-induced, and deformation in the disc on a standard Engineering material. A comparative study of Rotor is showed by varying a list of predetermined engineering materials as follows: EN-19, SS-321, Al-7075, Carbon fiber-reinforced composite.*

Key Words: FSAE, Standard parameters, Brake Efficiency, Structural Analysis, Thermal Analysis, Comparative result & Composite Material.

1. INTRODUCTION

Moving vehicles possess kinetic energy whose value depends on the mass and velocity of the vehicle. Without the ability to slow and stop our vehicles, we cannot hold control of it, and ultimately accidents would occur. So, to control the kinetic energy of a vehicle or to reduce the speed of the vehicle we need a brake system that will stop the vehicle. It is the braking system that converts the kinetic energy of the moving vehicle into heat energy via friction. The dissipation of the heat produced on the disc surface is essential to maintain braking efficiency when a driver applies brakes. In general, there are three main functions of a brake system, i.e., to maintain a vehicle's speed when driving downhill, to reduce a vehicle's speed when necessary, and to hold a vehicle when in parking. To achieve this, we have to verify the design of the braking system based on calculation. The main criteria are taken into consideration while designing the brake system is that the the torque generated in braking should be greater than the required. The braking system is made up of five main components, when the driver inputs a force, it is transmitted directly through the pedal assembly, which magnifies the driver force using simple leverage. Then, this force created is split using a bias or balance bar, which allows for different amounts of force to be directed to the front and rear brakes. The balance bar is connected on either end to a master cylinder, one which controls the front brakes and the other controlling the rear brakes. The master cylinders operate on hydraulic pressure as they are filled with brake fluid fed by a reservoir. The pressure created in the master cylinder is fed through hydraulic lines to the calipers, which physically grip the brake rotors at each of the four wheels. Although this system is closed and has a fairly simple mode of operation, there are many variables to consider when properly designing a braking system. Below you can see the exploded view of brake assembly it consists of the brake rotor, brake caliper, and master cylinder. The detailed function of each component has been explained in 1.1 component details.

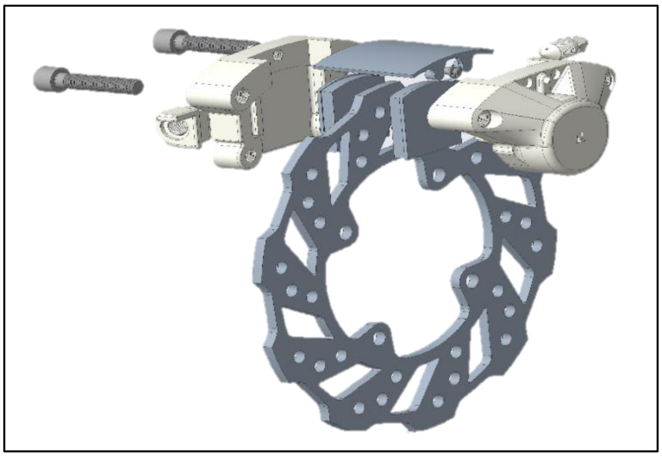


Fig – 1. Brake assembly exploded view

1.1 Component Details

I. Brake rotor: The brake rotor or brake disk is the main rotating part of the disk brake assembly. The brake caliper clamps the Disc with braking force, results in increased friction force between the disc and brake pads. The disc is mounted on the wheel hub which in turn helps to stop the wheel rotation. The rotor is hard to wear and resists high temperatures that occur during braking.
The brake rotor is further classified as- 1. Plane Disc Rotor, 2. Drilled Disc Rotor, 3. Slotted Disc Rotor, 4. Slotted Drilled Disc Rotor.

II. Brake caliper: The brake caliper acts as an assembly for brake pads and pistons. Caliper is used to slow or reduce the speed of rotating discs via friction which leads to dissipation of heat. The brake caliper acts as a clamping mechanism for the brake disc to stop the wheel from rotating when brakes are applied. Inside each caliper is a pair of metal plates known as brake pads. When the brake pedal is pressed, brake fluid creates pressure on pistons in the brake caliper via the Master cylinder, forcing the pads against the rotating brake rotor, reducing the speed of the rotor and eventually wheels.
The disc caliper is further classified as 1. Floating caliper, 2. Fixed caliper.

III. Master cylinder: Master cylinder in an automobile braking system component. It acts as a hydraulic device in which a cylinder and one or two pistons are arranged. The Master cylinder converts the manual force applied on the brake pedal into the hydraulic pressure via a piston-cylinder arrangement which then is supplied to the brake caliper for braking.
The master cylinder is further classified as 1. Single circuit master cylinder, 2. Tandem master cylinder.

1.2 Project Overview

The main objective of this research is as follows: -

- Design a braking system that is balanced, reliable, cost-effective which meets the standards of the FSAE vehicle.
- To design a custom brake rotor for a wheel radius of 10".
- Performing static structural & thermal analysis of designed disc profiles.
- Study and select four engineering materials on their properties.

2. LITERATURE REVIEW

Most of the research work in the automobile sector concentrates on building up an efficient braking system, a lot of research concentration is still going on in providing the efficacy profile of the braking system, with disc rotor and caliper being the most important part.

There has been significant progress in the area of the design of brake rotors. **(Patel, Raval, & Patel, 2016)** has undergone research to analyze the thermomechanical behavior of the brake disc during the braking phase. Analytical values were compared with FEA obtained results and all the outcomes were within the allowable limits. So, by undergoing the research they were able to select the disc on the parameters like e performance, strength, and rigidity.

When we apply the force on the rotor during braking lot of stress is produced so the analysis of the developed stress on the rotor **(Hanamant & Rajesh, 2017**) has been researched to find the stress developed in the rotor during the contact of pad and rotor. The analysis was performed for contact stress distributions at the disc-pad interfaces using a detailed 3-dimensional finite element model of a real car disc brake. A general-purpose commercial software package (Hypermesh 9.0 and Ansys 12.0) has been utilized and assessed. A study was carried by modifying the different geometry and different materials for the brake disc to obtain a more uniform contact stress distribution. It is supposed to prevent excessive wear on brake pads and in turn, increase the life of the pads.

To improve the brake performance of disc brake system operating temperature also an important aspect **(Hugar & Kadabadi, 2017)** has researched to minimize the temperature of disc brake with the help of thermal analysis by giving different shapes of slots to reduce the weight of the disc and for good thermal conductivity. In this study, thermal analysis is conducted on a real model of the disc brake rotor of Bajaj Pulsar 220.

For better efficiency of a vehicle, the brake should be as light in weight as possible to get better performance. So, to reduce the weight we do optimization in the system **(Naikwadi, Wadageri, & Bidari, 2017)** has analyzed to optimize and find out the effective design of disk with minimum weight by reducing raw material cost without affecting function and investigate the effect of load on stress, displacement, and model analysis through finite element analysis.

3. METHODOLOGY

The Possible approaches to research design are mixed approaches. There are three different categories of scientific research that mainly focus on Deduction, Induction, and Abduction. According to the author, the deduction is where theory is falsified or verified induction is where the theory is generated and built and abduction is where theory is generated or modified based on the existing theories.

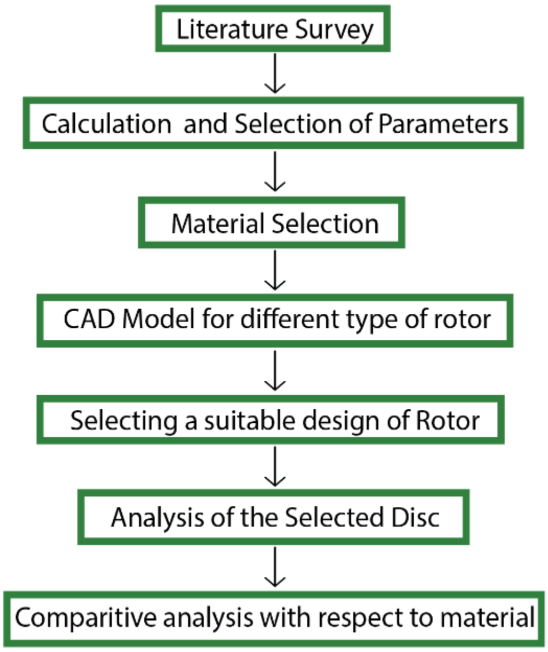


Fig – 2: Research approach

4. BRAKE CALCULATIONS

4.1 Considered values

Mass of car, m = 300 kg
C.G height, cgh = 0.203 m
Wheelbase, wb = 1.6 m
Weight distribution = 40:60
Coefficient of friction (road and tire) = 0.8
Coefficient of friction (disc and brake pad) = 0.4
Wheel Radius = 0.2286 m
Area of Master Cylinder = 197.93 mm^2
Area of caliper = 706.85 mm^2
Vehicle speed = 60 km/hr or 16.67 m/s
Wheel diameter = 0.4572 m

I. Static Weight (Front and Rear)

As the weight distribution for a vehicle is 40:60.
Static Weight Front = 1177.2 N.
Static Weight Rear = 1765.8 N.

II. Dynamic Weight (Front and Rear)

So, to calculate the dynamic weight of the vehicle we need longitudinal weight transfer of a vehicle.

Longitudinal weight transfer = $\frac{M*a*cgh}{Wb}$
= 30.45 kg.
= 298.71 N

where,
a = deceleration of the vehicle.

Dynamic weight front (Fdw) = 120 + 30.45
= 150.45 kg
= 1475.91 N

Dynamic weight rear (Rdw) = 180 – 30.45
= 149.55 kg
= 1467.08 N

Percentage of dynamic weight distribution is
50.15 / 49.85 % .... (1)

III. Required braking torque

For front, Tf = μ*Fdw*Rw
= 269.91 Nm

For rear, Tr = μ*Rdw*Rw
= 268.29 Nm

where,
Fdw = Dynamic weight front
Rdw = Dynamic weight rear
Rw = Wheel radius

IV. To calculate the braking force applied by the caliper on the disc

The pedal ratio is 5:1
The pedal force applied by driver = 250 N
Force at balance bar = 250*5 = 1250 N

4.2 For the front wheel

Force at front MC = 1250*0.5015 .... from (1)
= 626.87 N

Pressure generated in MC = 626.87/197.93
= 3.16 N/mm^2

Force applied by caliper = $3.16*10^6*0.000706$
= 2230.96 N

Clamping force = 2230.96*2
= 4461.92 N

Friction force applied by brake pad = 4461.92*0.4

= 1784.76 N

Torque produced = Brake force * effective radius (Reff)

$\frac{269.91}{2}$ = 1784.76*Reff

Reff. = 0.0756 m = 75 mm

As our brake pad width is 40 mm therefore,

Ro = Reff+20
= 75+20 =95 mm

Ri = Reff-20
= 75-20 = 55mm

4.3 For rear wheel

Force at front MC = 1250*0.4985
= 623.12 N

Pressure generated in MC = 623.12/197.93
= 3.14 N/mm2

Force applied by caliper = $3.14*10^{6}*0.000706$
= 2216.84 N

Clamping force = 2216.84*2
= 4433.68 N

Friction force applied by brake pad = 4433.68*0.4
= 1773.47 N

Torque produced = Brake force * Reff.

$\frac{268.29}{2}$ = 1773.47*Reff

Reff. = 0.0756 m = 75 mm

As our brake pad width is 40 mm therefore,

Ro = Reff+20
= 75+20 =95 mm

Ri = Reff-20
= 75-20 = 55mm

So, after the calculation, the diameter for the front and rear disc came as 190 mm.

4.4 Temperature calculation for heat flux.

The heat generated by applying braking = K.E.

Hg = K.E. = 41683.35 J

Heat generation (Hg) = md × Cp × Δt

41683.35 = 0.42932*473*Δt

Δt = 205.26°C

where,

md – Mass of the disc (Kg)

Cp – specific heat (J/Kg. K)

Δt – temperature difference (°C)

Δt = (tf – ti)

205.26 = (tf-40) tf
= 245.26 °C

Therefore, the outer surface temperature was calculated as 245.26. For heat flux, we have given the input as temperature and the output we get as heat flux from the software.

5. DESIGN SELECTION

There are four different kinds of brake rotor profiles i.e., solid, drilled, slotted, drilled, and slotted. So, to choose an efficient profile amongst these, we used one common material EN19 for all of the designs to examine how the discs differed for the same inputs. First, we used Ansys 19.0 to perform a static structural analysis and obtain output findings such as equivalent stress, total deformation total stress.

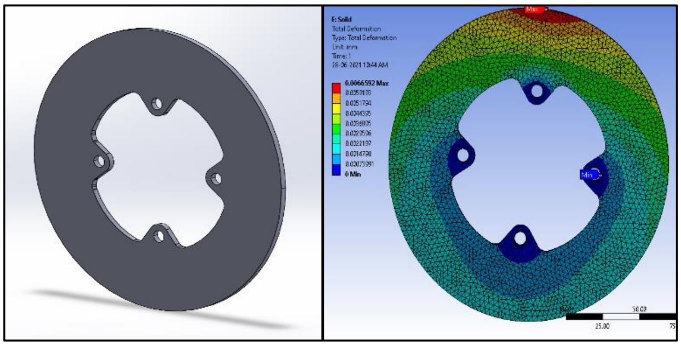


Fig – 3: Design and analysis of solid profile

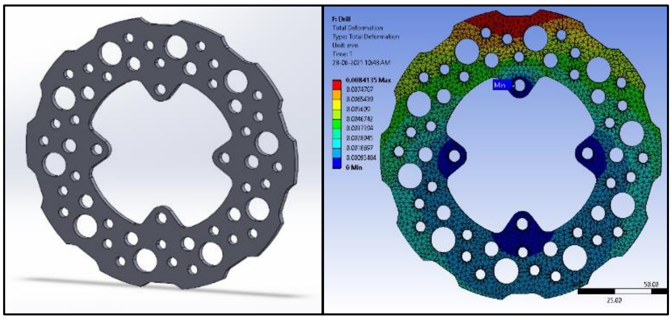


Fig – 4: Design and analysis of drilled profile

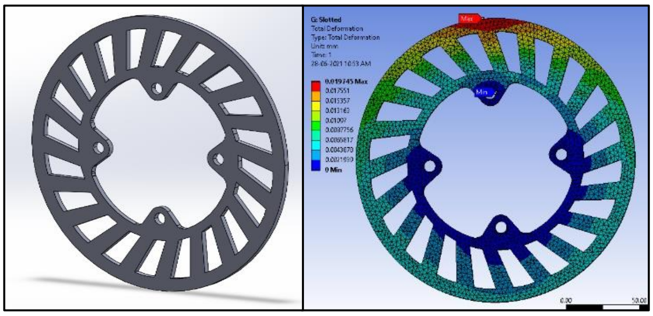


Fig – 5: Design and analysis of slotted profile

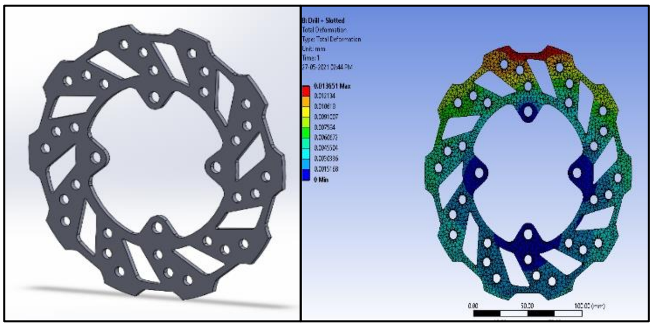


Fig – 6: Design and analysis of drilled-slotted profile

The same analysis has been done on the other designs and the output values of all the designs are shown in the table below.

Table -1: Design selection result for all design

Design type	Stress (MPa)	Deformation (mm)	Heat flux (w/mm^2)	Mass (kg)
Solid	72.213	0.0066592	0.29192	0.65632
Drilled	91.774	0.00841	0.41268	0.48457
Slotted	101.6	0.01975	0.5713	0.45012
Slotted And drilled	109.4	0.0136	0.96302	0.42932

We can see from the above that the slotted drilled disc produces greater heat flux than the others and can withstand the force applied to it because it is within the allowed limits and has a smaller mass than the others. As a result, the slotted drilled disc was chosen to conduct the test and obtain the findings for the various materials.

5.1 Ansys Result for Various Materials

All the output results from Ansys for different material on the selected design of disc has been collected. Below is the analysis result for EN-19 material,

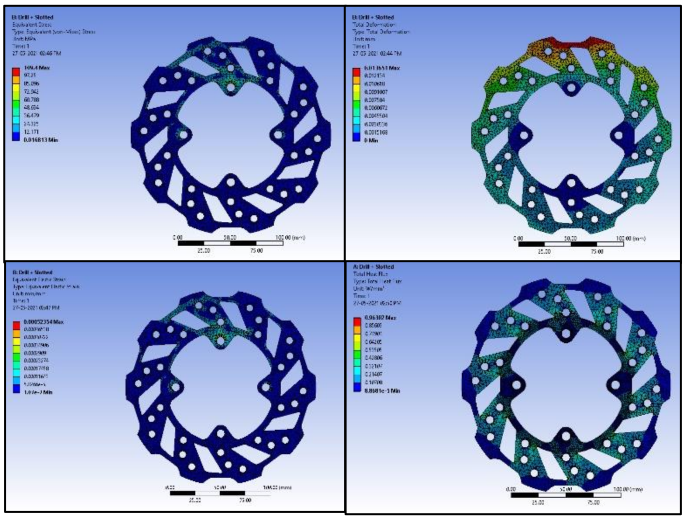


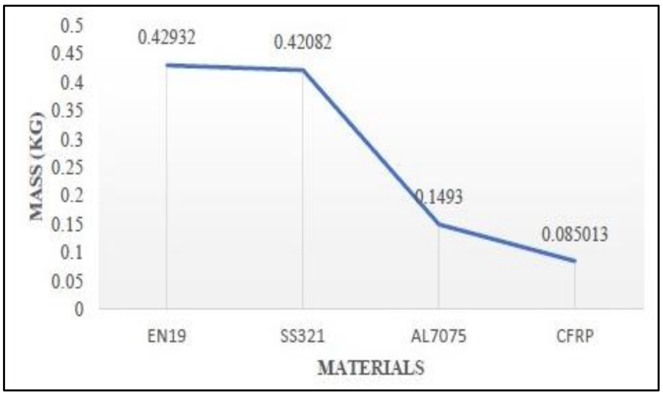
Fig – 7: Analysis on EN-19

The outcome values of analysis for other materials are arranged in the tabular form by which we can easily compare the materials with each other according to their values for stress, deformation, mass, and heat flux.

Material	Heat flux (W/mm^2)	Stress (MPa)	Deformation (mm)	Mass (kg)
EN19	0.96302	109.4	0.013642	0.42932
SS321	0.34085	110.18	0.014722	0.42082
AL7075	4.2024	108.55	0.040005	0.1493
CFRP	3.7581	114.98	0.038315	0.085013

Table -2: Output result for different material

From all the output values for four materials, we can see that the selected design of disc with an outer diameter of 190 mm and thickness as 4 mm can be used for a vehicle as it can sustain the forces coming on the disc during the application of braking.



Graph – 1: Relationship between Mass & Material.

The mass of the disc changes from material to material, as shown in the graph. The mass of the vehicle is essential since more weight impacts the vehicle's performance.

6. CONCLUSION

The major goal of this study was to observe the changes in the disc's parameters such as heat flux, stress, deformation, and mass when the material was altered. We chose the brake disc materials based on qualities such as strength, thermal conductivity, Poisson's ratio, density, elastic modulus, and so on. EN19, SS-321, AL7075, and CFRP are the materials chosen for the disc. In general, there are four types of discs so for that, we have designed these four types of the disc to select which design will better suit our vehicle. We chose drilled and slotted disc after evaluating the outcomes for the designed disc.

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