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Analysis of Ventilated Disc Brake using Ansys with Computer Aided Manufacturing

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ABSTRACT

Safety is the most important parameter while developing a modern vehicle. A vehicle capable of high acceleration must decelerate quickly as well. Disc brakes are used in modern vehicles to reduce stopping distance. On application of brakes, the disc is subjected to thermal & structural stresses. The brakes fail to slow down or stop the vehicle if they become too hot. In this study, we attempt to understand the existing disc brake rotors in use in the automobile industry and improve on their design in order to enhance heat dissipation. The currently used disc brakes are studied to understand their design. This knowledge is further used to design a useful disc brake. The aim of this paper is to improve heat transfer rate by designing disc rotors and selecting suitable material.

Keywords: *Ansys; Solidworks; Thermal Analysis; Ventilated Disc Brake.*

1.0 Introduction

Brake is the component of an automobile that majorly contributes to reducing its speed by converting frictional energy into heat energy. Multiple types of brakes have been in use in the industry since the start of vehicles. The most frequently used brakes are frictional brakes, which consists of a moving part and a stationary part, which wears out the moving part in order to stop the vehicle. Hence, the kinetic energy (KE) of the automobile is converted into frictional energy to stop the vehicle. A subtype of this type of brakes is the Disc brake. Disc braking system comprises a rotating disc that is attached to the axle or wheel-hub of the vehicle. Thus, it moves with the wheels. Attached to this disc is a brake caliper.

This caliper holds the disc in between 2 rubber calipers, making sure that they do not touch the disc in ideal operation. When the driver presses the brake pedal, these calipers are pushed forward through the means of the braking fluid to grip the disc plate from both sides and hence bring it to a stop. Since the disc is connected to the vehicle, it brings the vehicle to a stop too. The disc plates are used in vehicles to absorb high amounts of heat generated through friction in order to stop the vehicle. Hence, their design becomes an important factor in order to determine the safety and usefulness of a vehicle. Disc brakes are subjected to a lot of forces and pressure.

The material should be chosen carefully such that it should bear mechanical stresses, centrifugal forces, thermal loads & tensile forces. Generally, cast iron and ceramic composites are used for the manufacturing of disc brakes because their mechanical & thermal properties are able to withstand the required loads. In this research paper, we will be using gray cast iron, aluminium alloy & stainless steel. In this paper we will be studying the Disc brake system made of the three materials.

2.0 Material used

2.1 Stainless steel

Stainless steel contains steel and about 10-30% chromium is present. Chromium aids in resistance from corrosion and heat. Stainless steel is majorly classified into ferritic, austenitic, duplex, martensitic, and precipitation-hardening.

Properties of stainless steel are"

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2.1.1 Melting point

Stainless steel has high melting points - 1400°C - 1530°C. This makes Stainless steel a good choice for brake rotors.

2.1.2 Corrosion

Corrosion resistance for stainless steel can be increased by increasing chromium content to more than 11%, adding a minimum of 8% nickel, and molybdenum addition.

2.1.3 Wear

Stainless steel is prone to galling. This can result in breaking or complete seizure of the moving components. It can be prevented by using stainless steel with dissimilar materials like bronze.

Present study used SS-410 as it is a martensite stainless steel. It hardens on heat treatment and has high chromium content which results in good corrosion resistance properties.

2.2 Grey cast iron

Graphitic microstructure is present in this type of cast iron. Due to the presence of graphite, it forms a gray-coloured fracture and is thereby named Gray CI. It has high specific heat capacity and high thermal conductivity and thereby it is used in making Disc brake rotors.

It is composed of 2.5 to 4% carbon by weight, 6 to 10% graphite by volume, and 1 to 3% silicon by weight.

Properties of Gray Cast Iron are:

- Gailing and wear resistance: Gray Cast Iron self lubricates and thereby provides good gailing and wear resistance.
- Heat Dissipation: Due to its excellent damping capacity, energy is absorbed and further converted into heat.
- Corrosion Resistance: Good corrosion resistance is provided by silicon present in the Gray Cast Iron.

2.3 Aluminum alloy

Aluminum is the dominant metal across all aluminum alloys. Typically magnesium, copper, tin, nickel, zinc, and silicon are the alloying elements. Alloys containing cerium are being developed for high-temperature automotive applications, for eg rotor discs.

Properties of Aluminum alloys are:

- Corrosion Resistance: Good corrosion resistance is provided by silicon present in the Aluminum alloys.
- Heat Dissipation: Aluminum is a good heat reflector and heat conductor and is therefore an excellent choice for heat exchanger applications.
- Wear Resistance: Hard ceramic particles can be added on aluminum base to improve wear resistance.

We have used Aluminium alloy with SiC particles which forms a metal-matrix composite.

3.0 Types of Disc Brake

3.1 Flat disc brake

It is a flat disc design and has surface area for brake pad to press on. It does the required job of braking but has a short life compared to other types. This type is not used much in present vehicles but in the past was used in smaller vehicles.

3.2 Ventilated disc brake

This type of disc is used in almost all modern vehicles. These can withstand more load and can provide more braking power. This type of disc brake has a vented design for better heat dissipation while braking. This increases the life of the disc brake and also increases the structural strength.

4.0 Type of Grooves/Slots

4.1 Drilled disc

Holes are drilled in the disc plate to increase surface area which helps in better heat dissipation. This also results in reducing the weight of the disc brake.

4.2 Slotted disc

Instead of drilling holes, slots are made in the disc for heat dissipation. Advantage of creating slots is that it does not affect the heat resistance of the disc. Sometimes a combination of both drilled and slotted is used. For the purpose of this research study, we have used a combination of drilled and grooved design.

5.0 Literature Review

Lemi Abebe presented a paper on thermal analysis of disc brake made of multiple materials – Cast Iron(CI), E-Glass Fiber, Maraging Steel, and

AL-MMC. By comparing the FEA results and analytical results, values were found to be similar and were not much different. In both cases, it was observed that the pattern of variation of temperature is the same. [1]

Manjunath TV compared the result of temperature rise, deflection and stress field by analyzing ventilated and solid disc rotors. It showed that in the ventilated CI disc, deformation was 8% less, reduction in temperature was 31.47% higher, and stresses were 22.5% lower than the solid disc. [2]

V. Naveen evaluated braking performance of multiple disc rotors. It was concluded that braking performance is completely dependent on the material of construction and geometry of the rotor.

Ali Belhocine presented a paper on thermal analysis of a full and ventilated disc. Analysis of three types of CI was conducted, namely (AL-FG 25, FG 20, FG 15). Thermal behavior of disc brakes influenced by braking mode was studied. It showed that in cooling of the disc rotor, radial ventilation plays an important role and thereby affects braking performance [3].

Sumeet Satope conducted research on thermal analysis of disc brakes and it was concluded that maximum temperature rise for stainless steel is much higher than cast iron.

It was thereby concluded that cast iron is best suited for making disc brake rotor. It suffers a drawback of getting corroded when it comes in contact with moisture and thereby cannot be used in two wheelers [4].

Shah Alam compared two types of rotors (i) without holes and (ii)perforated on the basis of heat dissipation. The perforated disc turned out to be more efficient as maximum temperature after 50 sec is less than that of a simple disc [5].

Yashwardhan Chouhan in a study on static thermal and structural performance of disc brakes mentioned that disc deforms more at the outer radius and huge stresses are generated on the disc bowl. Deformations were found to be greater in the solid disc as compared to the ventilated disc.

Ventilated disc also provides a better distribution of temperature than a solid disc. [6].

Dr. Swastik Pradhan concluded that structural steel has less strain followed by stainless steel, grey cast iron, titanium, copper, and aluminum alloy. Aluminum alloy has the lowest stress followed by grey cast iron and stainless steel. Stainless steel and grey cast iron maintained their average values in most of the conditions. It was found that rotor discs reach temperatures of upto 300°C [7].

Y Chandna used AlSiC Composite Disc Brake to perform transient thermal analysis. It was concluded that under repeated braking conditions, a ventilated cast iron disc has worse performance than a ventilated composite disc [8].

Durgesh Kaiwart worked to reduce brake disc rotor weight. AlNiCo alloy and titanium alloys were used for the analysis. Total stress, strain, and deformation was in control limits [9-15].

Rolan Siregar conducted a study on maximum temperature reached on disc rotors.

The maximum difference between the front and rear brake temperatures was found to be 49 °C [16-20]. A. Phaneendra compared carbon ceramic, cast iron, and aluminum alloy disc brake rotors. Cast iron attained lowest maximum and is widely available, thereby preferred for regular automobiles.

Carbon ceramic attained the highest maximum temperature but dissipated maximum heat and it was lighter as compared to the others. AM Ismael compared solid, vented and vented and drilled disc brake rotors on the basis of heat distribution. Vented and drilled disc performed better than the other two discs.

C. Radhakrishnan compared gray cast iron (CI) and Ti550 alloy on thermal efficiency measures. It was concluded that Ti 550 was better of the two [21]. MD Rajkamal compared Vanadium Disc with SS disc, CC composite disc and CI disc. It was found that the vanadium disc performed better in terms of overall structural strength [22-23].

5.1 Motivation

With over 4 Lakh road accidents resulting in over 1.73 lakh deaths annually in India, brake failure comes out to be one of the major reasons for the same. The safety of passengers of faulty vehicles along with safety of by passers on the road, motivated us to perform this study on Disc Brake analysis.

There has been very little study on the ventilated disc brakes. With the advancements in the automotive world, we have more refined engines, power figures are on steady rise and new fuel sources are coming up but the braking part is seen to be ignored in this process.

An automobile capable of achieving high speeds must be capable of coming to a stop in a short distance. Getting an opportunity to study Mechanical with specialization in Automotive Engineering from prestigious Delhi Technological University, we wanted to do our part for the industry and focus our research on Braking System of Automobiles.

6.0 Research gap

A ventilated disc rotor is more efficient than a solid disc rotor. Earlier research focused on traditional disc brakes and did not cover the scope of more useful ventilated disc brakes in a detailed comparison. Scope of improvement for research was found in ventilated disc brakes by testing various possible materials for manufacturing the disc brake. Such an analysis and comparison would help the academia and industry by providing further study material and building trust in the new technology for actual use.

7.0 Methodology

7.1 Computer-aided manufacturing and automated testing programs

Computer-aided or computer-integrated manufacturing is a method of manufacturing which uses computer software and machinery operated by computer. It helps in the manufacturing part by optimizing the manufacturing process effectively. It also involves computer-aided design which is a method that helps in designing the part using computer softwares.

It helps in identifying the errors and reduces wastage in manufacturing processes. Nowadays, CAM/CAD are used in numerous industries as it aids in visualizing & manufacturing of the final part. Various automated testing programs are also used in present times to meet the customer requirements with respect to quality because these methods are more efficient and accurate. They help in testing the part without performing the test manually and also saves time and resources.

7.2 Modeling

The CAD modeling of the disc brake rotor is done on Solidworks 2020. The dimensions of the disc are according to standard manufactured disc rotor (add reference). We have compared three different designs as part of this research study. All the designs have different pillar ventilation systems.

All these designs have been analyzed with three different materials to find the best possible combination for use in the industry. The heat dissipation of a disc brake system is dependent on the design of the disc.

All parameters like diameter, thickness, surface area etc. of the disc are of crucial importance. In a ventilated disc, the pillar system or vanes of the disc can be of varied lengths or at some angle. According to research by S.Sarkar et al [37], angled or radial vanes affects the airflow inside the ventilated disc, hence, improving the heat dissipation.

Figure 1 shows the dimensions of the disc. Figure 2,3 & 4 shows the three pillar designs in 3d models.

Figure 1: Dimensions of Ventilated Disc Brake

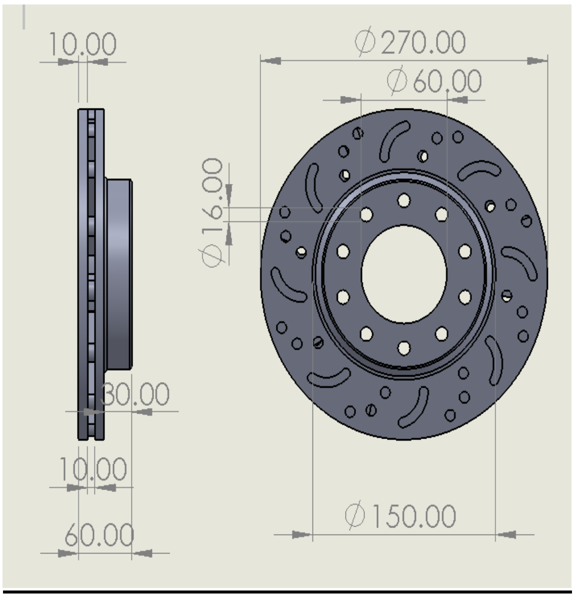


Figure 2: Section View of Straight Pillar Disc Brake

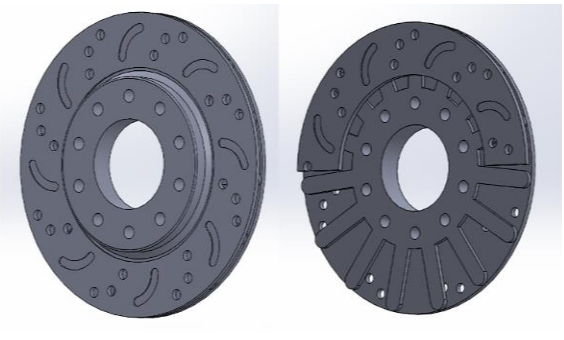


Figure 3: Section View of Radial Pillar Disc Brake

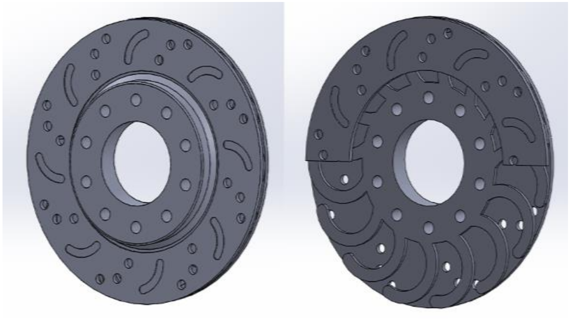
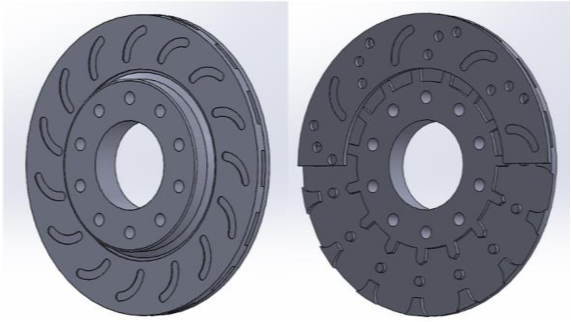


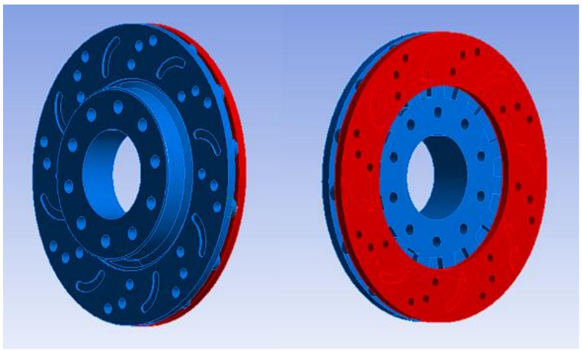
Figure 4: Section View of Segmented Pillar Disc Brake



7.3 Geometry

CAD Models of the disc brake are designed on SolidWorks-2020 and the model is imported in Ansys workbench for steady-state thermal analysis. The disc brake assembly consists of two plates in contact with each other.

Fig 5: Components of Disc Brake



In each assembly, the plate consisting of the hub (blue plate) has different pillar design. Therefore, the mass of the disc rotors are different. Table 1 contains the mass property information for all pillar design and material of brake disc rotor.

Table 1: Mass of Disc (in Kg)

Material	Aluminium Alloy	Gray Cast Iron	Stainless Steel
Straight Pillar	1.12	2.91	3.13
Radial Pillar	1.13	2.93	3.16
Segmented Pillar	1.08	2.8	3.01

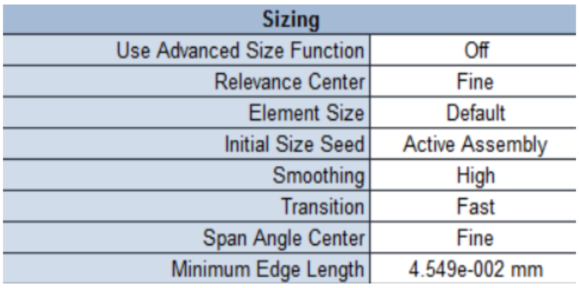
7.4 Meshing

Meshing is a process which breaks the geometry model into smaller parts and each part represents a finite element. We have used fine meshing on the model to get accurate results. Fine meshing takes more time and memory compared to coarse meshing but is better for precise results because in finer mesh the elements are smaller and they can capture the stress or temperature gradients across the model. The mesh is generated automatically. Table 2 shows the number of nodes & elements and Table 3 shows the mesh sizing.

Table 2: Number of Nodes in Each Disc

Disc Type	No. of Nodes	No. of Elements
Straight Pillar	188462	107259
Radial Pillar	190896	111340
Segmented Pillar	170442	96154

Table 3: Mesh Sizing Properties Used



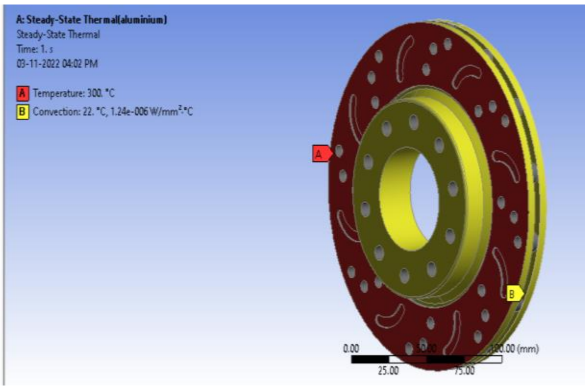
Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	High
Transition	Fast
Span Angle Center	Fine
Minimum Edge Length	4.549e-002 mm

7.5 Boundary conditions

The initial and boundary conditions for thermal analysis are added in the steady-state thermal module in Ansys Workbench 16.0. Figure 3 below shows the areas where the boundary conditions are applied. The boundary conditions are responsible for the results obtained during the analysis. Same boundary conditions are used for all designs and materials. The initial temperature of the disc is taken as 22°C. Table 3 shows the step controls for the analysis. The maximum temperature of the disc is assumed to be

300°C. Convection boundary condition is also applied on the geometry surface having 22°C ambient temperature and stagnant air data is used for the film coefficient because it is exposed to the atmosphere for heat dissipation. [49]

Figure 6: Boundary Condition Application Area

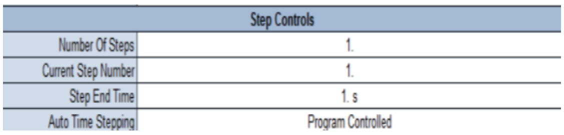


8.0 Results

8.1 Design-1 (Straight Pillars)

8.1.1 Aluminium Alloy

Table 3: Step Control



Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled

Figure 7: Temperature Distribution

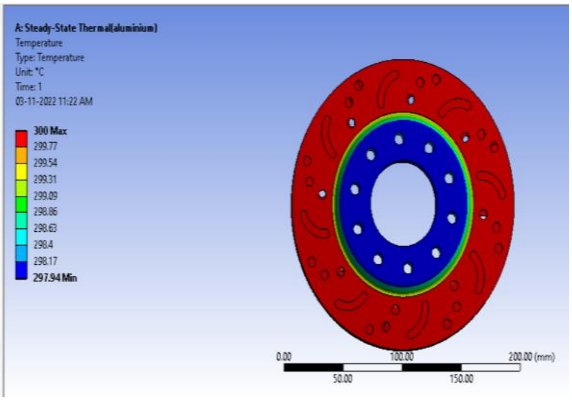
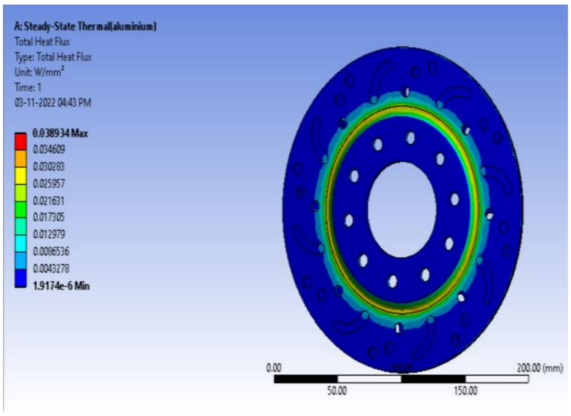


Figure 8: Total Heat Flux



8.1.2 Gray cast iron

Figure 9: Temperature Distribution

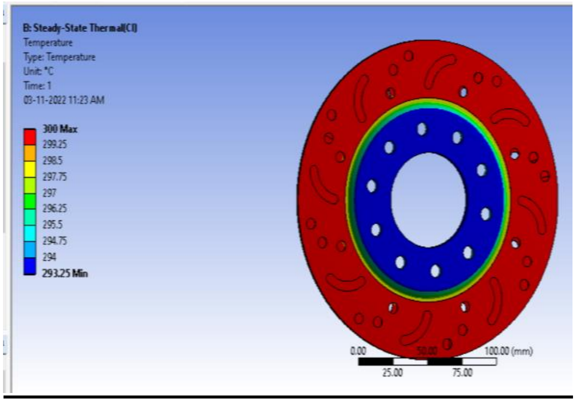
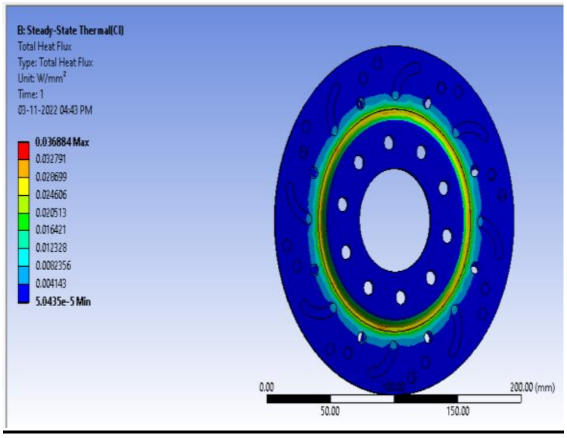


Figure 10: Total Heat Flux



8.1.3 Stainless steel

Figure 11: Temperature Distribution

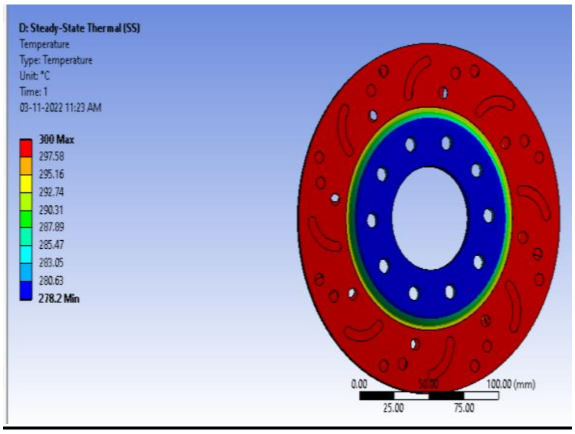
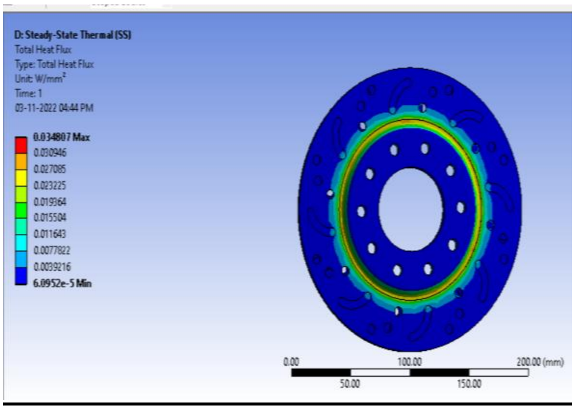


Figure 12: Total Heat Flux



8.2 Design-2 (Radial Pillars)

8.2.1 Aluminium Alloy

Figure 13: Temperature Distribution

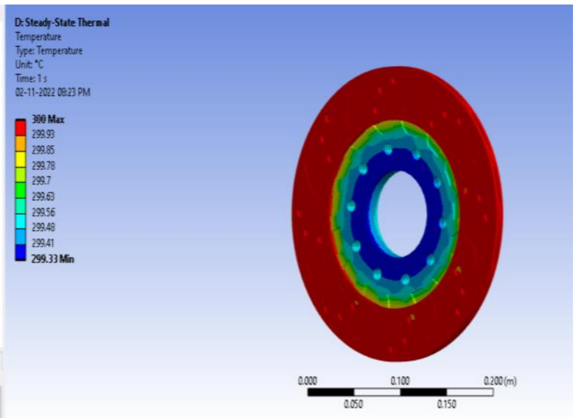
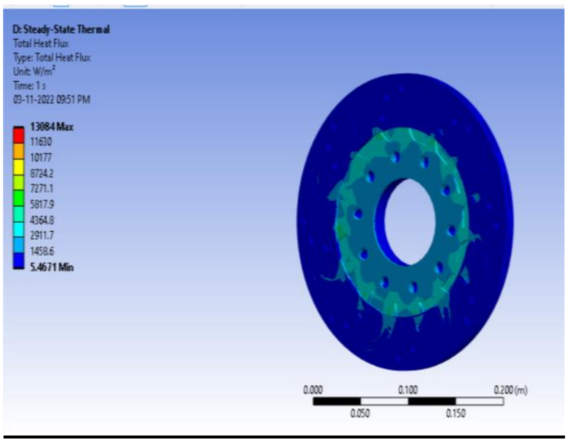


Figure 14: Total Heat Flux



8.2.2 Gray Cast Iron

Figure 15: Temperature Distribution

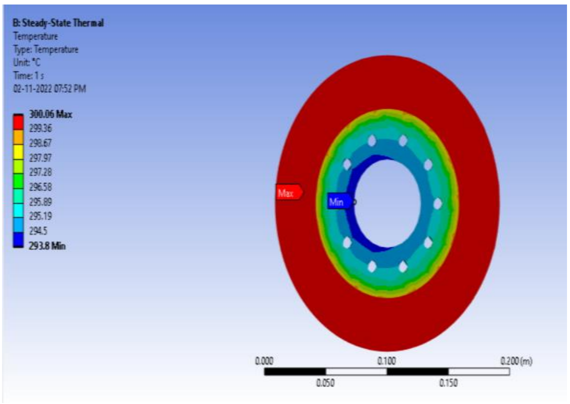
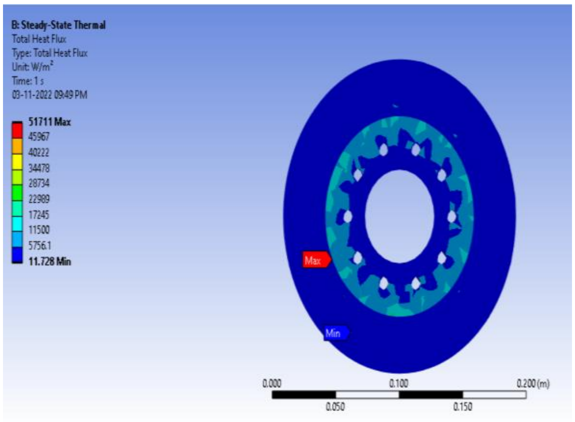


Figure 16: Total Heat Flux



8.2.3 Stainless Steel

Figure 17: Temperature Distribution

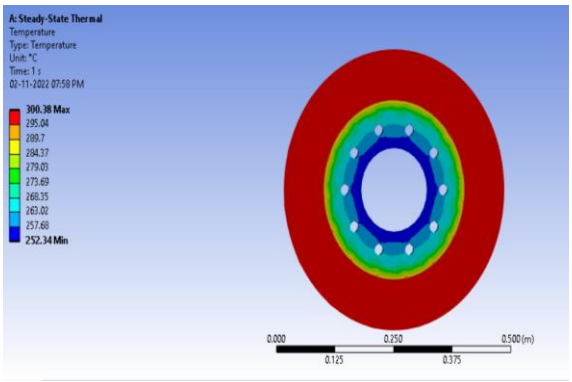
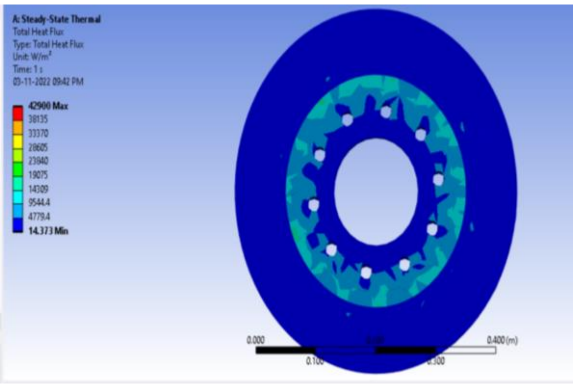


Figure 18: Total Heat Flux



8.3 Design-3 (Segmented Pillars)

8.3.1 Aluminium Alloy

Figure 19: Temperature Distribution

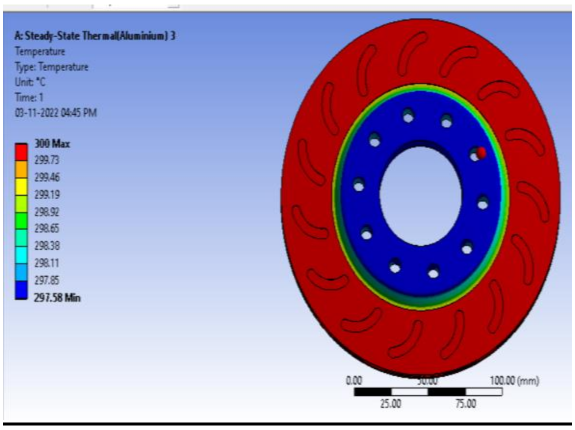
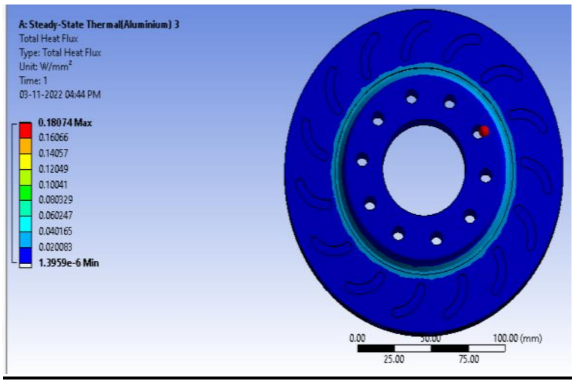


Figure 20: Total Heat Flux



8.3.2 Gray Cast Iron

Figure 21: Temperature Distribution

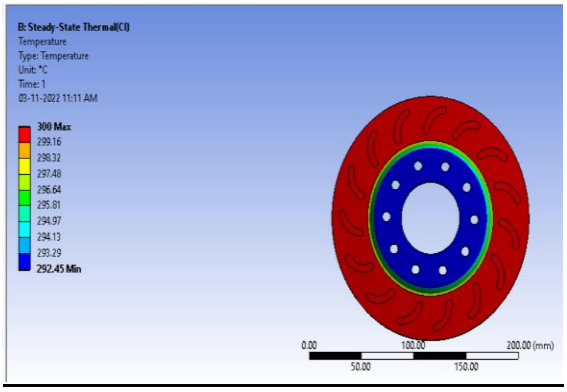
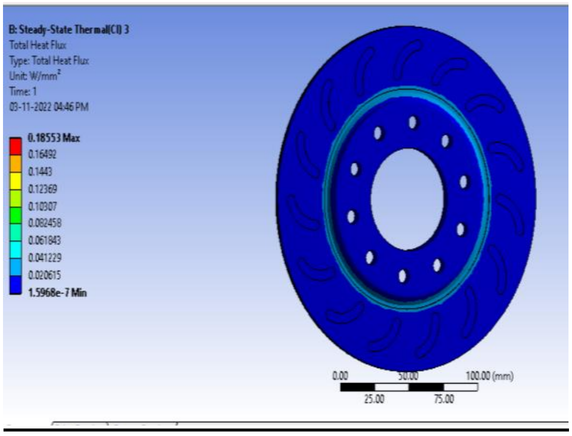


Figure 22: Total Heat Flux



8.3.3 Stainless steel

Figure 23: Temperature Distribution

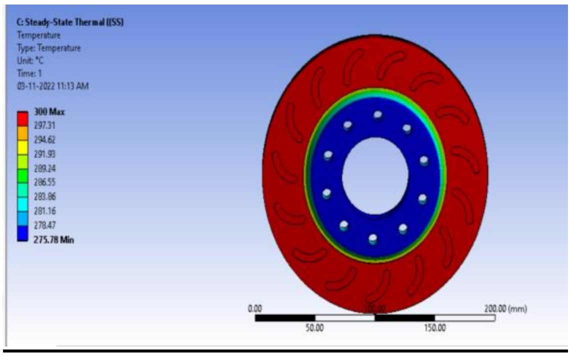


Figure 24: Total Heat Flux

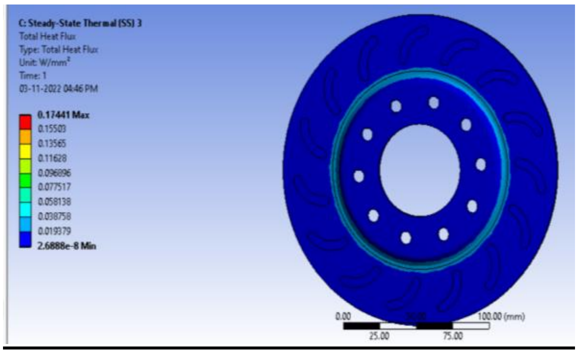


Table 4: Analysis Results of Temperature and Heat Flux

Disc Type	Material	Min. Temperature (°C)	Heat Flux (W/mm^2)	
			Min	Max
Straight Pillar	Aluminium Alloy	297.94	1.92E-06	0.038934
	Gray Cast Iron	293.25	5.04E-05	0.036884
	Stainless Steel	278.2	6.10E-05	0.034807
Radial Pillar	Aluminium Alloy	252.34	0.54E-05	0.013084
	Gray Cast Iron	293.8	1.17E-05	0.051711
	Stainless Steel	299.33	1.43E-05	0.042900
Segmented Pillar	Aluminium Alloy	297.58	1.40E-06	0.18074
	Gray Cast Iron	292.45	1.60E-07	0.18553
	Stainless Steel	275.78	2.69E-08	0.17441

9.0 Conclusions

The results of steady-state thermal analysis are shown in Table 4. It is found that in the radial pillar design the minimum temperature possible while braking is 252.34°C. Maximum reduction of temperature is found in the radial pillar design of disc brake rotor. When the pillars are formed at an angle the length increases which leads to an increase in the surface area. Therefore, in radial pillars maximum surface area is available for heat dissipation resulting in minimum temperature.

The heat flux is found maximum(51711 W/m2) in the ventilated disc of gray cast iron with the design of radial pillars and the average of heat flux for different materials is found maximum in straight pillar design. Heat flux is directly proportional to the surface area available for heat transfer and thus heat dissipation will be more and heat generated will be less. Out of all the materials studied, Aluminium Alloy turned out to be the best performer, achieving the least minimum temperature in the radial pillar design (252°C).

The objective of this research paper is to establish the difference generated in distribution of temperature in a ventilated disc by the design as well as the material used. We have been able to compare the aforementioned designs and materials based on the detailed analysis carried out. However, due to a constraint of time, we have not gone further into researching more related issues.

There is future scope for delving deeper into the aerodynamics of the disc and understanding how the flow of air around the disc affects its performance. Further, there is scope for analyzing the effect on the life of the disc due to change in material, braking behavior and design of the disc.

This can also be used to recommend an optimal braking behavior that can help vehicle owners improve the life of brake discs and help automobile companies in reducing the maintenance costs for the owners.

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