# EFFECT OF MATERIALS ON THERMO-MECHANICAL CHARACTERISTICS OF AN AUTOMOTIVE BRAKE DISC

**A DESIGN PROJECT III REPORT (EME51803)**

***Submitted by***


| | |
|---|---|
| **A NAGA MANOJ KUMAR** | **(22124009)** |
| **MOHAMMAD RAYAN SHIEK** | **(22124013)** |
| **K BHARATH** | **(22124023)** |


***Under the Guidance***

***Of***

**Dr. Hariram V**

*In partial fulfillment for the award of the degree*

***Of***

**BACHELOR OF TECHNOLOGY**

**In**

**MECHANICAL ENGINEERING**


**DEPARTMENT OF MECHANICAL ENGINEERING**

**HINDUSTAN INSTITUTE OF TECHNOLOGY AND SCIENCE,**

**PADUR, CHENNAI - 603 103**


**NOV -2024**

**HINDUSTAN INSTITUTE OF TECHNOLOGY AND SCIENCE**

**PADUR, CHENNAI - 603 103**

## BONAFIDE CERTIFICATE

Certified that this project report titled “EFFECT OF MATERIALS ON THERMO-MECHANICAL CHARACTERISTICS OF AN AUTOMOTIVE BRAKE DISC” is bonafide work of “A NAGA MANOJ KUMAR (22124009), MOHAMMAD RAYAN SHIEK (22124013), K BHARATH (22124023)” who carried out the project work under my supervision. Certified further that to the best of my knowledge the work reported here does not form part of any other project / research work on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

| **HEAD OF THE DEPARTMENT** | **SUPERVISOR** |
| --- | --- |
| Dr. Vijayabalan P, | Dr. Hariram V, |
| Professor and Head | Professor |
| Department of Mechanical Engineering | Department of Mechanical Engineering |
| Hindustan Institute of Technology and Science, Padur | Hindustan Institute of Technology and Science, Padur |

| **INTERNAL EXAMINER** | **EXTERNAL EXAMINER** |
| --- | --- |
| Name:______________________ | Name:_____________________ |
| Designation:_________________ | Designation:_________________ |

The Design Project Viva-Voice Examination is held on 05-11-2024

## ACKNOWLEDGEMENT

First  and foremost, I would like to thank the Lord Almighty for His presence and immenseblessings throughout the project work.

I would like to thank my guide Dr. V. Hariram, Professor, Department of Mechanical Engineering for continually guiding and actively participating in my project, giving valuable  suggestions  to  complete the project work.

I wish to express my heartfelt gratitude to Dr. Vijayabalan P, Head, Department of Mechanical Engineering for much of his valuable support encouragement in carrying out this work.

It’s a matter of pride and privilege for me to express my deep gratitude to  the managementof  HITS for  providing me the  necessary  facilities  and support.

I would like to thank all the technical and teaching staff of the Mechanical Engineering Department, who extended directly or indirectly all support.

Last, but not the least, I am deeply indebted to my parents who have been the greatest

**BHARATH K**
**MOHAMMAD RAYAN SHIEK**
**NAGA MANOJ KUMAR A**

# ABSTRACT

The kinetic energy of the vehicle is converted into mechanical energy while retarding which leads to heat dispersal and temperature rise of the disc and the disc- pads. The aim of this experiment is to study the rise in temperature of an automotive disc brake at the time of retardation and its effect on disc durability using finite element method. operation of a specified braking torque on the rotor led to generation of heat flux. The heat flux and heat transfer coefficient are numerically calculated and the max lower temperature obtained by brake disc are observed. various materials are applied to check the performance of the brake disc, likely using grey cast iron, Titanium alloy, Aluminum alloy and carbon ceramics comparison to disc were studied and their effect on maximum temperature rise and slice continuity has been observed by modelling and conducting FEM techniques in Solid works and ANSYS respectively.

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## Department of Mechanical Engineering

## EME51803 – Design Project and Viva Voce (5th Mech)

**Project Batch No** : 08

**Title of the Project** : Effect of Materials on Thermo-Mechanical Characteristics of An Automotive Brake Disc

**No of students in the Batch** : 03

***Student's Individual contribution***

**Name of the student** : A Naga Manoj Kumar

**Register No** : 22124009

**Mention your individual contribution briefly**

NAGA MANOJ KUMAR, I have done the report work by referring various journals and research paper which helped our team to complete this project and done the materials and methods part in the presentation and report with the help of team and helped in the literature review and analysis part in this project, I coordinated effectively with the rest of the team in report and presentation.

A NAGA MANOJ KUMAR
(Name of the student with Signature)

HINDUSTAN
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(DEEMED TO BE UNIVERSITY)

## Department of Mechanical Engineering

## EME51803 – Design Project and Viva Voce (5th Mech)

**Project Batch No** **:** 08

**Title of the Project** **:** Effect of Materials on Thermo-Mechanical Characteristics of An Automotive Brake Disc

**No of students in the Batch** : 03

***Student's Individual contribution***

**Name of the student** **:** Mohammad Rayan Shiek

**Register No** **:** 22124013

**Mention your individual contribution briefly**

MOHAMMAD RAYAN SHIEK, I have done the analysis part and then coordinated in calculation part, I have gathered the required information from various sources to complete the report. I have also played my key role in communicating the project status with guide and communicated the same with team members. I have shared my knowledge and ideas in this project to make sure that the project is completed soon on time.

MOHAMMAD RAYAN SHIEK
(Name of the student with Signature)

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(DEEMED TO BE UNIVERSITY)

## Department of Mechanical Engineering

## EME51803 – Design Project and Viva Voce (5th Mech)

| | |
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| **Project Batch No** | **:**08 |
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| **No of students in the Batch** | **:**03 |

***Student's Individual contribution***

| | |
|---|---|
| **Name of the student** | **:** Bharath K |
| **Register No** | **:** 22124023 |

**Mention your individual contribution briefly**

K BHARATH, I have contributed my presence in project idea, design modeling, and analysis part, I have participated in shortlisting of journals, Model verification, and checking of analysis results, creating motion simulations, etc. the major part of the project. I have also guided and encouraged the team to make sure in completion of project on time.

BHARATH K
(Name of the student with Signature)

# CHAPTER 1

# INTRODUCTION

## 1.1 INTRODUCTION

The thermal analysis is a primordial organize in the study of the brake systems, since the temperature determines thermomechanical behavior of the structure. In the braking stage, temperatures and thermal gradients are exceptionally high. This produces stress and deformations whose results are showed by the appearance and the complement of cracks. It is then imperative to determine with exactness the temperature field of the brake disc.

During the stop braking, the temperature does not have time to be stabilized in the disc. A study state thermal analysis is required. It is moreover essential to assess the thermal gradients, where at requires a three-dimensional modelling of the problem. The thermal loading is represented by a heat flux entering the disc through the brake pads. The large amount of heat produced at the pad/disc interface during emergency braking indisputably brings out non-uniform temperature dispersions in the space of the rotor, while the pad component is always heated during mutual sliding. The study state thermal examination to determine the temperature distributions on the contact surface of a disc brake is performed. The issue of non-uniform frictional heating impacts of shared slipping of a disc over fixed pads is tested using FE models with the several possible to happen in car application heat transfer coefficients. To have a possibility of comparison of the temperature dispersions of a disc during cyclic brake application, the energy transformed during time of each analyzed case of braking process and the subsequent discharge periods was equal. The time-stepping method is utilized to create moving heat source as the boundary heat flux acting interchangeably with the convective cooling terms. In this study, we will display a numerical modelling to examine the thermal behavior of the ventilated disc brake utilizing diverse materials.

## 1.2 OVERVIEW OF DISC BRAKE:

The purpose of this component is to develop a brake disc made of gray cast iron, titanium, aluminum, and carbon composite materials that can withstand harsh operating conditions of high temperatures and heavy wear while keeping the weight in check. This is usually achieved by utilizing gray cast iron, which is strong and has great heat sink capabilities despite being heavy. This is where titanium and aluminum alloys help by providing weight savings, however they do not possess proper heat transfer capabilities like that of a cast iron. On the other hand, carbon composites are very lightweight and have great heat resistance which reduces brake fade under high performance applications, though these come at a high price and tend to wear out faster under certain circumstances. In this context, using different combinations of different materials can help build hybrid brake disc that achieves optimum strength, thermal resistance and weight efficiency, which involves using grey cast iron for strength, titanium and aluminum to reduce weight and carbon composites for thermal resistance in high-performance and racing applications.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 LITERATURE REVIEW

- Ali Belhocine, et al (2012), conducted a study in Thermal analysis of a solid brake disc. He conducted the transient thermal analysis on the full and ventilated brake rotor to analyse the thermal behavior of the disc when the calculated heat flux is entering through the disc. This study is conducted using the numerical modelling code in Ansys11. The formula used in this paper to find the heat flux entering into the disc is efficient. The modelling is created using Ansys CFX.

- Ashish kumar Shrivastava, et al (2021) conducted a study Thermal analysis on car brake rotor using cast iron material with different geometries. he performed a study state thermal analysis on the three different geometries of brake disc, i.e., solid rotor, drilled rotor and slotted rotor using cast iron material and they observed and stated that the drilled and slotted rotor geometry has very high value of heat flux compared to other rotor geometries. The design is modelled using catia V5 R20, and the analysis is done using the Ansys R20.

- Daanvir Karan Dhir, (2016) study the Thermo-mechanical performance of automotive disc brakes, he conducted the experiment on three different geometry brake discs by modelling it in SolidWorks, he understood that studying of thermo-mechanical behavior of the brake disc can determine the braking efficiency and performance of the braking system of the vehicle. He explained the micro deformation and fractures occurs when the disc reaches extreme temperature during braking this may cause brake fade, premature wear, brake fluid vaporization, thermal cracking and thermal excited vibrations. He stated the amount of energy dissipated in the form of heat can generate rises in temperature from 300°C to 800°C. and found the significant difference in different rotor geometries after analysis. His study suggests and justifies the application of disc flange rotors in areas of heavy braking where a larger braking force is required. Discs with geometric patterns (holes and air foil vents) can be used where faster cooling and lightness in weight is preferable, as desired in the racing automobiles.

- Challa Balaji Naga Sai Abhishikt, et al (2020), studied the thermos-mechanical performance of ventilated disc rotor and drilled contour disc rotor with three different materials of grey cast iron basic material, Ti-6Al-4V (Grade 5), and Chromium-Vanadium steel, and applied a force of around 2000 N and he stated that the Titanium alloy (Ti-6Al-4V), has the high maximum temperature difference between two designs discs of around 500°C. whereas the temperature difference between the ventilated and drilled contour disc was found to be roughly 100°C for the grey cast iron and Chromium- Vanadium steel materials.
- S. Mithlesh, et al (2021) conducted study on drilled hole ventilated disc, he identified that increasing the drilled holes size of ventilated disc can significantly increase the amount of heat dissipation and increase the thermal efficiency, so he conducted the Ansys thermos-mechanical analysis on the brake disc by changing the drilled holes for three sizes and concluded that increasing hole size can reduce the disc weight and increase the stress properties, deformation and life span of the disc using single stainless steel material.
- Pragya Mahajan, et al (2021), conducted experiment on FSAE brake disc, where they calculated and designed a slotted brake disc based on requirements and calculations, they stated that optimizing the geometry of brake disc can significantly increase the braking efficiency, similarly they conducted the static structural and study state thermal using Stainless steel 420 material and suggested a cheap and best manufacturing process for fabricating the brake rotor, they further tested the rotor on race tracks and got the compatible to their requirements based on the driver feedback and technologies measurements.
- Ali Belhoncine, et al (2012), has conducted a study on the thermal behavior of the full and ventilated brake discs of the vehicles using computing code ANSYS. He conducted this experiment for a total simulation time of 45s. He designed the brake disc and brake pad using the mathematical equations, in Ansys CFX, further he applied the boundary conditions for the simulation. He conducted this thermos-mechanical study using three different types of iron materials namely FG25 Al, FG

20, and FG 15. He observed for the two types of discs and noticed that starting from the first step of time one has a fast raise of temperature, he quickly noticed that for a ventilated disc out of cast iron FG15, the temperature increases until Tmax of 345°C at the moment t = 1.85s, then decreases rapidly in the course of time. He concluded that the geometric design of the disc is an essential factor in the improvement of the cooling process.

- Habtamu Dubale et al (2021), his study focuses on friction brakes that are exposed to high mechanical and thermal stresses. He investigated and analyzed the thermomechanical behavior of three selected disc brake profiles analytically and numerically. He concluded by the comparison between the analytical and numerical analysis for the three types of disc profiles performance. In solid-type, drilled-type and grooved-type disc profiles, He finalized by stating that as the number of holes increases, the disc brake’s heat transfer efficiency increases.
- Iacopo Bianchi et al (2023), he conducted the research study on the Life Cycle Assessment on the Ceramic Matrix composites and prepreg of Ceramic Matrix composites recovered disc and compared among them. His aim is that he claims that using of CMC brakes have several environmental impacts from the starting production till its life time, as CMC brakes manufacturing impacts environment in several conditions like Global warming potential, cumulative Energy Deman etc. So, he studied the manufacturing and recycling process in all three scenarios and concluded that from the production concerns, the cast iron brake disc is most sustainable alternative, resulting between 15% and 21% of the impacts of the composite components.
- Yanjun Zhang et al (2024), research aims to investigate the impact of thermal expansion and wear on the temperature and stress of the railway disc-pad system. He conducted a thermos-mechanical coupled on FEM model, the experiment is done on three different cases, where, in first case does not consider, thermal expansion and wear on the brake pad, the second consider thermal expansion but ignores wear, the last considers both. He concluded through his observations that the average temperature difference of brake discs with/without thermal expansion and wear is around 10%. And the maximum temperature of railway brake discs, can reach a 257%

difference. In his analysis he observed the equivalent stress difference can reach 3500%, which is higher than the effects on the maximum temperature difference.

- Mohammad Taiviqirrahman et al (2022), in his study he conducted the thermal analysis of disc brake with variation in drill hole angles and grove hole angle and stated that changing the geometry of the brake disc will increase the braking efficiency. He conducted this experiment with three different materials, namely gray cast iron, carbon ceramic and stainless steel. He observed that the ventilation hole angle and groove angle of 0° with grey cast iron given the smallest maximum temperature, and gives the best performance.

- Haizhou Wang et al (2024), conducted experiment on structural optimization design of friction pair wet brakes for a hydraulic machine motor. He optimized the existing friction pair by changing the number of oil vent holes and conducted the thermal analysis to check the max temperature withstand. In this study, he observed the temperature raise of wet brake in non-braking state with the optimized fit clearance between multiple friction pairs if 0.06 mm in theoretical model. He concluded that his optimized design needs to further verified in future work before getting into the application.

- Rahim Jafari et al (2021), he conducted a comprehensive investigation into the overall cooling performance of the ventilated brake disc. He did a mathematical modelling of ventilated brake disc by using Taguchi L16 design parameters, and conducted a CFD analysis and observed the temperature difference in the airflow around the surface of the disc which changed from 400°C to 100°C in 334s. He also checked the geometry optimization performance by changing the angle of internal vanes and increasing the ventilation gap and reducing the number of vanes and angle of twist will significantly improves the cooling performance. He observed by changing the geometry parameters he enhanced the reduce the cooling time by 10%, an d21% by increasing the ventilation gap from 8 mm to 14 mm.

- Federico Bonini et al (2024), his research touches upon the enhancement of thermographic assessments of carbon disc brakes installed on the motorcycles of MotoGP racing. In a race, carbon brakes are outfitted as they are light, have great friction force and good thermal conductivity thus performing better than steel brakes.

On the other hand, air composite brakes require a strict management of temperature because it is only the best in operation around a certain optimal temperature range. Heuristic Methods using a hybrid approach of the Unscented Kalman Filter (UKF) and simplified one-dimensional thermodynamic models were employed to estimate the temperature distribution of brake discs. The UKF model aids in modifying temperature predictions in relation to factors that were not incorporated in the basic model such as, uneven pressure application and external conditions during a race event. The analysis successfully determined the convection heat transfer coefficient, which has been shown to be an important governing factor in accurate temperature forecasts. It was able to prove that the integration of predictions made by statistical models with the actual data of thermographs increases accuracy many times over traditional methods. This construction enables speedy computation of disc temperatures which is vital for racing applications. Disadvantages posed by the UKF based method were minimal in this respect while gaining new insights into the effects of disc temperatures on the performance of the braking system and the tires which are fundamental to the adjustment of racing motorcycles.

- Fabien Formosa (2024), he conducted a thermal study on the solid bike disc with no holes and with different materials individually, different materials are modified and new in motor cycle industry, he conducted the experimentation on the plain stainless steel, plain aluminum, multilayered aluminum, multilayered ceramic, multilayered carbon. Then he conducted the experiment in uniform velocity condition, where the rotation of the disc is kept constant, and the supplied external heat to the surface of the disc. An analytical model is prepared for the thermal analysis and results are observed. He observed that multi layered aluminum stainless steel structured rotor disc performed better, due to its light weight and mechanical properties, further studies are conducted to understand the best performance material for the disc1

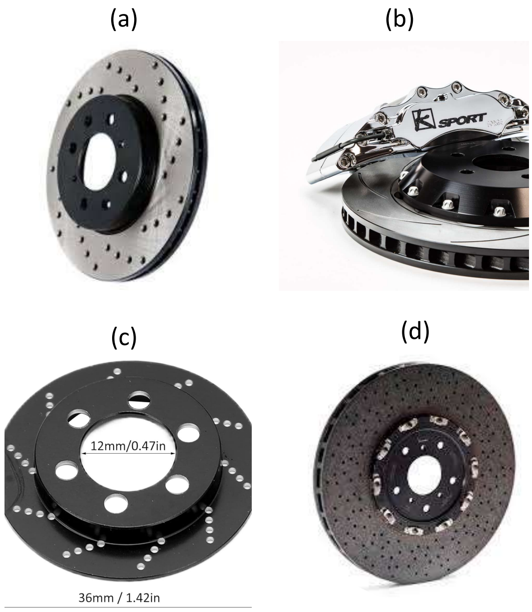


**Fig. 2.1: Brake disc with different materials (a) Grey Cast Iron, (b)Ti-6Al-4V, (c) Al6061-T6, (d) C/SiC.**

## 2.2 OBJECTIVE:

- This study deals with the complete thermo- mechanical properties of ventilated brake disc used in passenger cars, with four different materials and comparing the results with the traditional cast iron disc brake.
- Materials we choose to apply are traditional grey cast iron, compared with the Titanium alloy (Ti-6Al-4V), aluminum alloy (Al6061-T6), and Carbon ceramic matrix composite (CFR silicon carbide composite).
- This study explains the importance of lower maximum temperature of the brake rotor indicates the high heat dissipation rate (heat flux) for the given materials

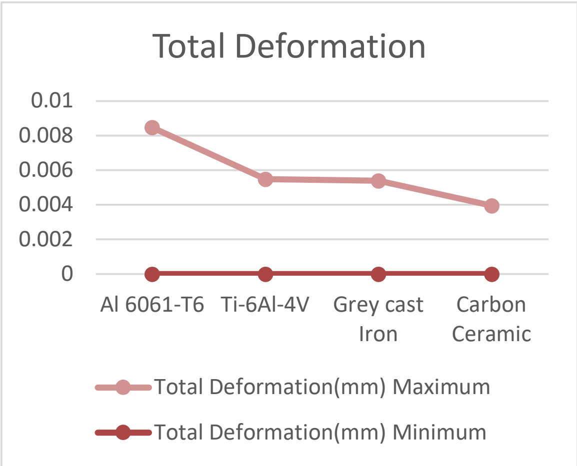


**Fig.2.2: Total deformation graph**

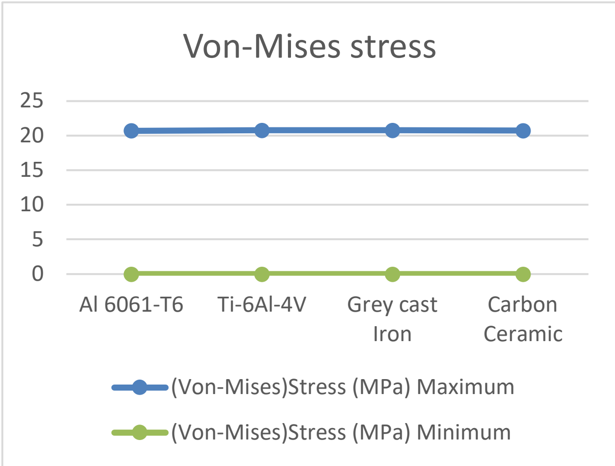


**Fig.2.3: Von-Mises Stress Graph**

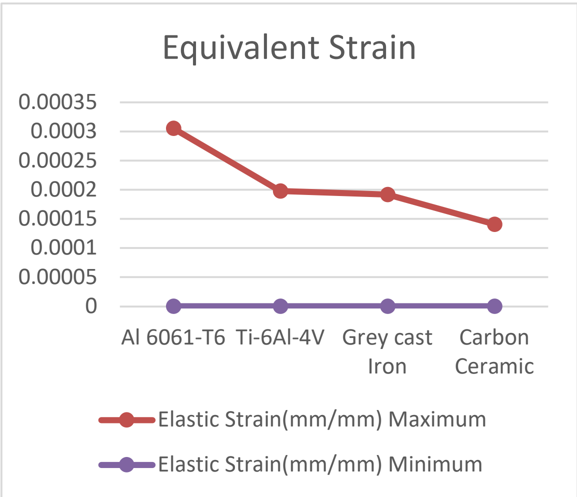


**Fig.2.4: Equivalent Strain graph**

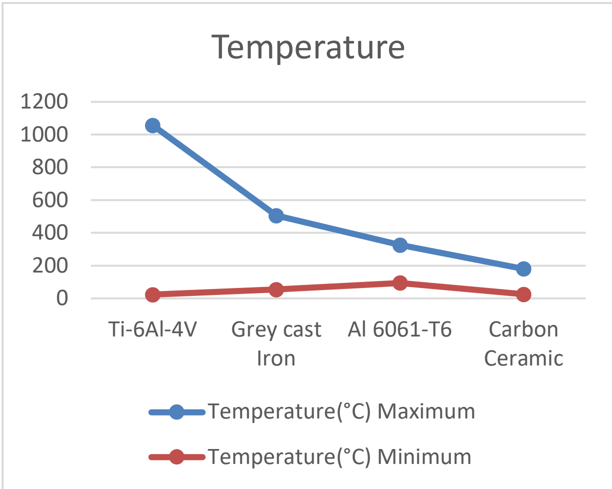


**Fig.2.5: Temperature Graph**

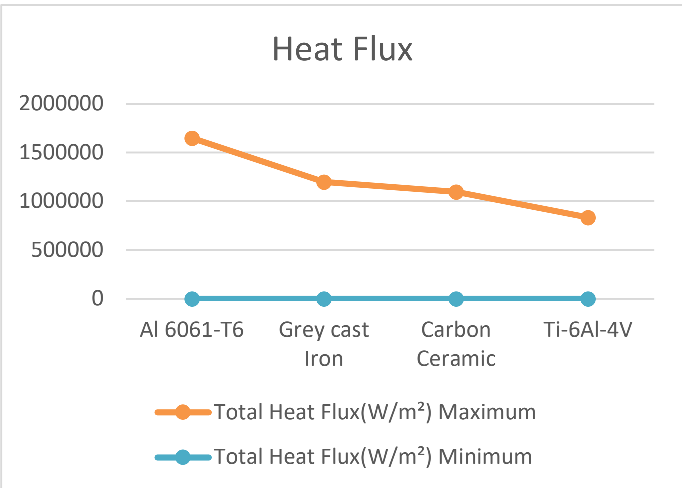


**Fig.2.6: Heat Flux Graph**

## 2.3 RESEARCH GAP:

- Brake discs are one of the important parts of automobile system, these brake discs subjected to various kinds of loads and stresses during the braking operation, may reach up to extreme conditions (depending on the usage). These condition leads to the formation and raise of temperature and internal thermal stresses and micro-deformation will deplete the performance, efficiency and life time of the disc.
- We understood that the factors subjected to braking can be increased by multiple factors like disc geometry, material composition, and type of heat treatment process, etc.
- A research study in the field of materials is conducted to improve the braking efficiency and understanding of braking effect for a period of time by changing the various materials.
- In this study, we came to know that grey cast iron is the most used material for manufacturing of brake disc due to their exceptional thermal and mechanical abilities but those are heavy, and highly dense.

# CHAPTER 3

# MATERIALS AND METHODS

## 3.1 DESCRIPTION OF VARIOUS MATERIALS:

### 3.1.1 GREY CAST IRON:

Grey cast iron has an excellent tensile strength of 240 MPa and high compressive strength. It has good resistance to oxidation, prevents from getting corroded, 115 GPa of Young's modulus. Its fatigue resistance is 110 MPa. The hardness is ranging from 179 to 202. Good heat conductivity of 52 W/m °C. Grey Cast Iron has a low melting point of around 1140°C to 1200°C. Grey cast iron with carbon contents varying from 3.65% to 2.7%, silicon from 2.5% to 1.35%, phosphorus from 0.5% to 0.09% and manganese around 0.6% depending upon the grade.

The cast iron discs are produced by means of traditional sand casting; a versatile process suitable for the manufacturing of complex shaped parts. In a sand-casting process, the metal is molten and poured into the cavity of a sand mold. The metal cools down and solidifies inside the mold before the cast part is extracted. Machining operations are then required to reach the design dimensions and tolerances (i.e. turning and drilling). The production process of the cast iron disc ends with the application of protective paint.

### 3.1.2 TITANIUM ALLOY:

Titanium Ti-6Al-4V (Grade 5), Annealed has an ultimate tensile strength of 918 MPa, yield tensile strength of 845 MPa, 36 Rockwell C hardness. The modulus of elasticity is 111.2 GPa. Density of 4.43 g/cc. Thermal conductivity of 7.187 W/m°C. Its melting point is around 1604 to 1660 °C. Fatigue strength of 240 MPa. Due to the inferior surface wear properties, it seizes to slide during its contact with other metals. Surface treatment with nitriding and oxidizing would enhance the surface wear to improve its surface wear resistance property. The alloy composition consists of Aluminum of 6%, Iron of maximum 0.25%, Oxygen of maximum 0.2%, Titanium of 90%, and Vanadium of 4%.

First, the Ti-6Al-4V alloy is selected for its combination of titanium with Aluminum and vanadium, offering high strength and durability. The material is typically forged or cast into the rough shape of the brake disc due to titanium's challenging machining characteristics. Forging is preferred for its ability to enhance the alloy's mechanical properties through grain refinement under high pressure. Next, the brake disc undergoes heat treatment, including solution treatment and aging, to improve its strength and hardness. This process tailors the alloy's microstructure to enhance its performance under extreme braking conditions. Once heat-treated, the disc is CNC-machined to its precise final dimensions, including features such as mounting holes and any necessary surface patterns for improved braking performance and heat dissipation. Titanium's hardness requires specialized tools and machining techniques to achieve the desired precision and surface finish. Surface treatments like shot peening or coating may be applied to further improve fatigue resistance and protect against wear. These treatments are essential in ensuring the brake disc's longevity and reliability under high stress.

### 3.1.3 ALUMINUM ALLOY:

Aluminum Al6061-T6, tempered has an ultimate tensile strength of 310 MPa, yield tensile strength of 270 MPa, 60 Rockwell B hardness. The modulus of elasticity is 68.9 GPa. Density of 2.7 g/cc. Thermal conductivity of 152 W/m K. Its melting point is around 582 to 652 °C. Its specific hear capacity is of 0.896 J/g-°C. Excellent joining characteristics, good acceptance of applied coatings. Combines relatively high strength, good workability, and high resistance to corrosion; widely available. The alloy composition consists of Al of 95.8%- 98.6%, Cr of 0.04%-0.35%, Cu of 0.15%-0.4%, Iron of maximum 0.7%, Mg of 0.8%-1.2%, Mn of maximum 0.15%, Si ranges from 0.4%-0.8%, Ti of maximum 0.15%, Zn of maximum 0.25%.

The manufacturing of Al6061-T6 brake discs starts with selecting the alloy for its strength, light weight, and corrosion resistance. The alloy is shaped through casting or forging, followed by heat treatment (solution treatment, quenching, and aging) to achieve the T6 temper for maximum strength. Next, the disc is CNC-machined to precise dimensions, including features like mounting holes and heat dissipation slots. Surface treatments, such as anodizing, improve corrosion resistance, and balancing ensures smooth operation.

### 3.1.4 CARBON FIBER REINFORCED SILICON CARBIDE COMPOSITE:

Carbon fiber reinforced silicon carbide composite, has an ultimate tensile strength of 200-600 MPa, yield tensile strength of 270 MPa. The modulus of elasticity is 150 GPa. Its flexural strength is often in the range of 300-500 MPa. Density of 2.6 g/cc. Its Vickers hardness is typically in the range of 20-30 GPa. Thermal conductivity of 152 W/m K. C/SiC doesn't have true melting point because of the melting point of carbon fiber and silicon carbide are different. Silicon carbide has a very high melting point of around 2730°C, and carbon fibers will sublimate at around 3500°C in inert temperature. However, in the presence of oxygen, carbon fibers will oxidize at much lower temperatures of around 400- 600°C. Its specific heat capacity is of 600 J/kg-K. It has high friction coefficient, the hardness of silicon carbide gives the brake disc excellent wear resistance, can withstand extremely high temperatures without significant loss of strength or deformation, low density of carbon fibers makes the composite much lighter than traditional cast iron brake discs, which reduced the vehicle weight and improved fuel efficiency. The composite material composition consists of carbon fibers of 10%-30% by volume of the composite and silicon carbide of 60%-80% by volume of the composite.

The first phase of the production process is the manufacture of a CFRP preform (the green part); chopped virgin carbon fibers are mixed with powdered phenolic resin and additives and are placed inside an aluminum mold. Then, a compression molding (or warm pressing) process is carried out to cure and consolidate the composite part by means of the combined effects of pressure and temperature. The aluminum tools are coated with a release agent before the molding process to facilitate the extraction of the cured part.

After that, a pyrolytic decomposition of the green part is performed in an oven at a temperature above 900 ◦C and ambient pressure. This causes a mass loss of about 40% due to the transformation of the polymer matrix and a porous Carbon Fiber/Carbon (Cf/C) preform is obtained.

Metallurgical grade raw silicon powder is infiltrated into the porosity of the preform to produce the carbon ceramic composite Cf/C–SiC part. This is done by heating and melting the metal powder at about 1650 ◦C in an oven and applying light suction to facilitate the infiltration. In this way, ceramic brake disc with a density of about 2.6 g/cm3 are produced. Sanding operations are finally carried out to reach the required dimensions and finishing.

**Fig.3.1: Section View**

## 3.2 MODELING OF BRAKE DISC:

The 3D model of brake disc is designed in SolidWorks. The diameter of brake disc is decided according to the rim constrains which is 305 mm (0.305 m) for outer diameter and the thickness is decided to be 16 mm according to the caliper specifications.

Brake Disc is ventilated disc with pitch circle diameter 0.2525 m and a disc pad swept area of 0.019238 m² at 0.024 m from the disc centre. The thickness of disc is 0.0016 m and the disc when grey cast iron material is applied weighs around 6.1935 kg. when applied with Titanium alloy it weighs around 3.8099 kg, when analysed with Aluminum alloy it reaches around 2.3251 kg, and finally when it is checked with C/SiC ceramic composite material it was around 2.2365 kg respectively. The details are mentioned in table 1 below.

| Material | Weight(kgs) |
|---|---|
| Grey cast Iron | 6.1935 |
| Ti-6Al-4V | 3.8099 |
| Al6061-T6 | 2.3251 |
| C/SiC | 2.2365 |

**Table 3.1: Disc weight according to various materials**.

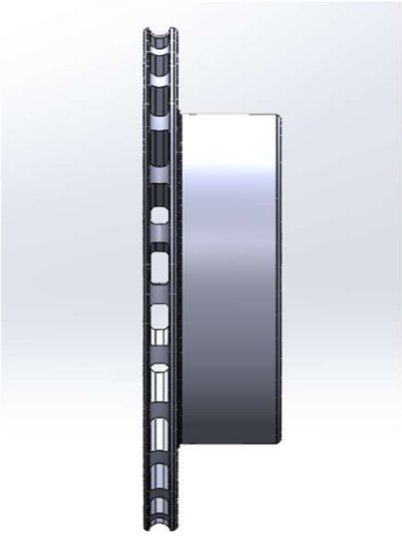

**Fig 3.2: Side View**

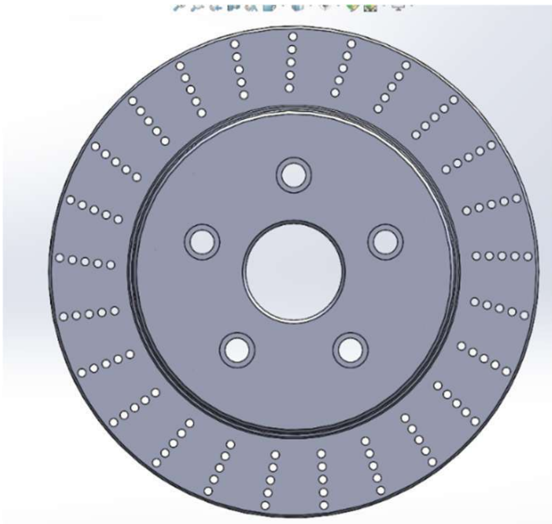

**Fig 3.3: Front View**

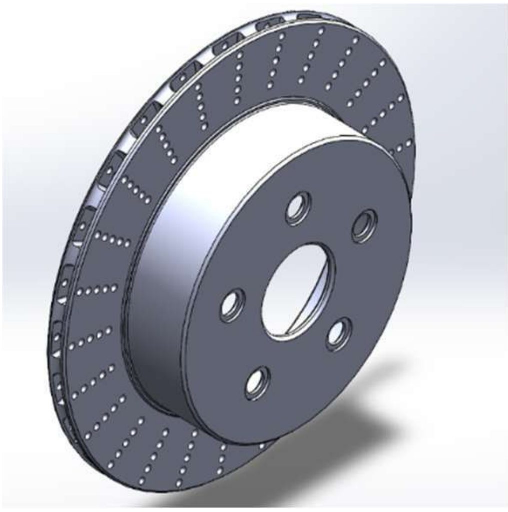

**Fig 3.4: Isometric View**

## 3.3 DISCRATIZATION OF THE DISC (MESHING):

The aim of meshing in Workbench is to convey robust, simple to utilize meshing apparatuses that will abbreviate the mesh generation method. The model utilized must be fragmented into a number of little pieces recognized as finite elements. In the meantime, the model is partitioned into a number of discrete parts, in basic terms, a numerical net or "mesh" is required to carry out a finite element examination. A finite element mesh model created. The mesh results are as shown in table 2 below. The type of mesh utilized in the analysis is tetrahedral three-dimensional triangular elements with 10 nodes. The meshing relevance Centre was kept medium and the smoothing process was maintained at a least pace. The average surface area of the meshing is around 200.35 $mm^2$. The meshing of disc is appeared in Fig 4 below.

| Meshing Details | |
|---|---|
| Number of nodes | 122727 |
| Number of elements | 65251 |

**Table 3.2: Meshing Details**

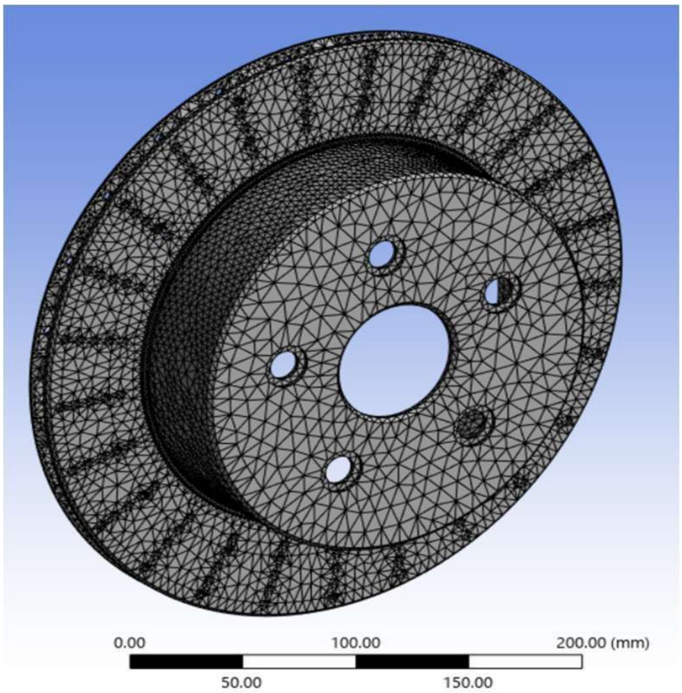


**Fig.3.5 Meshing Detail.**

### 3.4 Input Parameters and Constraints:

Input parameters like pressure, heat flux, film coefficient, heat flow are calculated from the assumed vehicle parameters. The weight of the vehicle is assumed as 1385 kg, at a initial speed of 28kmph, which is around 7.7m/s or 441.1rad/s, pressure applied on the brake disc from the brake booster to caliper, a pressure is applied on the brake pad swept area. The stopping distance and stopping time are around 3.7 m and 0.9625s. Heat flux generated on brake disc calculated by dividing braking power and Area of rubbing surface or pad swept area, the heat flux generated by calculation.

- Total time of simulation = 45 (s).
- Increment of initial time =0.25 (s).
- Increment of minimal initial time= 0.125 (s).

- Increment of maximal initial time= 0.5 (s).
- Initial Temperature of the disc= 60 (°C).
- Materials: Grey cast iron, Al 6061-T6, Ti-6Al-4V, C/SiC composite.

| **Item** | **Values** |
|---|---|
| Inner disc diameter, mm | 200 |
| Outer disc diameter, mm | 305 |
| Disc thickness, mm | 16 |
| Disc Height, mm | 66 |
| Vehicle mass m, kg | 1385 |
| Initial speed, km/h | 28 |
| Deceleration, m/s² | 8 |
| Effective outer rotor radius, mm | 145 |
| Effective inner rotor radius, mm | 120 |
| Rate distribution of the braking forces, % | 20 |
| Factor of charge distribution on the disc | 0.5 |
| Surface disc swept by the pad on 2 sides of disc, mm² | 38436 |

**Table 3.3** Geometrical dimensions and application parameters of automotive braking.

Convective heat transfer results from fluid moving over a surface that carries heat away. For rotors, convective heat transfer occurs directly between the skin in contact with air or water, as well as between the brake pad that is in contact with the surrounding environment. In this way, air moving over skin provides convective cooling. The rate of convective heat transfer is a function of the fluid and surface temperatures, the surface region, and the speed of the stream across the surface. To progress, convective heat flow, increasing the area of contact either between the rotor or the pad and the flow, as well as the speed of the flow is important. It is calculated from the Nusselt number equation, given below.

$$Nu_L = \frac{h * D_o}{k} \qquad (1)$$

Where, $Nu_L$= Nusselt number, $h$ = convective heat transfer coefficient, (W/m² °C),

$D_{\mathrm{O}}$ = Rotor external diameter, m, $k$ = Thermal conductivity of Fluid, (air), N/m °C

By modifying this equation, we can obtain the convective heat transfer coefficient which is required for our study. Nusselt number can be calculated from the equation given below.

$$Nu_L = 0.027 * {R_e}^{0.8} * Pr^{0.33} \quad \text{\_\_\_\_\_\_\_\_\_\_(2)}$$

Where, $R_{\mathrm{e}}$ is the Reynolds number, $Pr$ is Prandtl number which is a constant number, in this study $Pr$ is taken for air which is 0.71.

The thermal loading is characterized by the heat flux entering the disc through the real contact area (two sides of the disc). The initial and boundary conditions are introduced into module ANSYS Workbench. The thermal calculation will be carried out by choosing the steady state and by introducing physical properties of the materials. The chosen data for the numerical application are summarized as follows:

$$q = h * \Delta T \quad \text{\_\_\_\_\_\_\_\_\_\_(3)}$$

Boundary conditions that are to be applied for brake disc incorporates clamping force on both sides of the brake disc where pads would clamp the disc, rotational velocity in the direction of rotation of disc. Fixed supports are given at the hub where the disc will mount to the axle of the wheel. After applying these boundary conditions, model is solved for static structural analysis, the pressure applied on the brake disc and pad contact region is assumed to be as 1MPa which can be considered as booster pressure used for clamping through brake pads, and the rotational velocity is applied to make sure that the disc is in dynamic condition which is having certain velocity of 441.1 rad/s (or) 7.7 m/s.

# CHAPTER 4
# RESULTS AND DISCUSSION

The analysis of the disc brake was carried out by taking various parameters in account such as the type of braking, the cooling mode of the disc and the choice of disc material. The brake disc is made of grey cast iron, Aluminum alloy, titanium alloy, and carbon fiber reinforced silicon carbide composite material.

The initial temperature of the disc is 22°C, the surface convection condition is applied at all surfaces of the disc where the dissipation of heat transfer takes place, the value given for the convective heat transfer coefficient (h) is applied to the surfaces of the disc on the outer disc hub, inner disc hub, and slotted grooves areas. The contact surface of the disc receives an entering heat flux calculated by the equation mentioned above.

## 4.1 STRUCTURAL ANALYSIS:

### 4.1.1 Von Mises Stress Analysis:

In material science, Stress is the force applied to a material per unit area of its cross-section, was observed when a pressure of 1MPa is applied on the ventilated disc and a Rotational Velocity of 441.1rad/s is applied on X-axis of the disc at a time duration of 45s.

Fig. 4.1 shows the stress observed in gray cast iron and a maximum stress of 20.768MPa and a minimum stress of 0.0035354 MPa. Fig. 4.2, represents the Stress developed by Aluminum Alloy (AL6061-T6) which is a maximum stress of 20.7Mpa and a minimum stress of 0.0035354 MPa. Fig. 4.3 presents the stress obtained by Titanium Alloy (TI_6AL_4V) is a maximum stress of 20.75Mpa and minimum stress of 0.0035354 MPa. Fig. 4.4 gives the stress in C/SiC and a maximum stress of 20.733 MPa and minimum stress of 0.0035708 MPa was observed.

Overall, there is no major difference is found in stress, developed on all four different materials, because of the application of pressure on disc is unchanged for all four of the ventilated brake discs.

From the below Fig: 4.1, 4.2, 4.3 and 4.4 of all four materials (Aluminum Alloy, Gray cast iron, C/SiC and Titanium Alloy) we can say that Aluminum Alloy (Al 6061-T6) and C/SiC have less equivalent stress compared to other two metals.

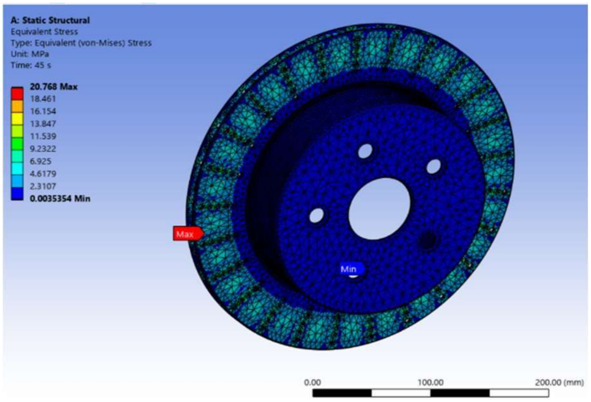


**Fig.4.1: Stress on Grey cast iron**

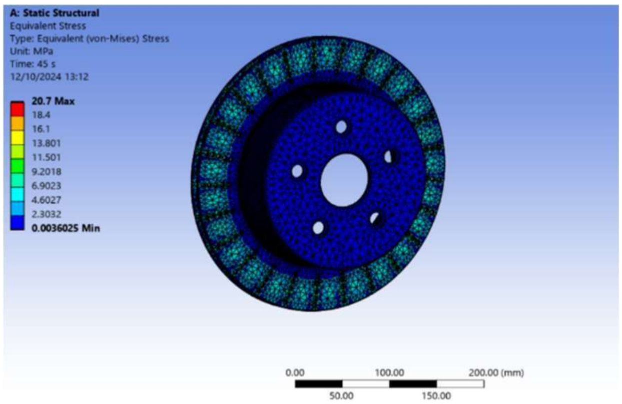


**Fig.4.2: Stress on Al6061-T6**

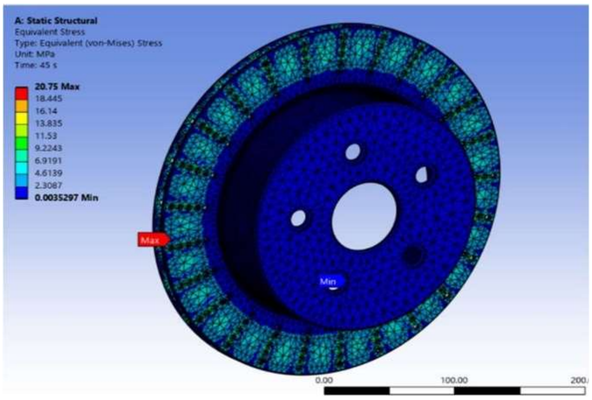


**Fig.4.3: Stress on Ti-6Al-4V**

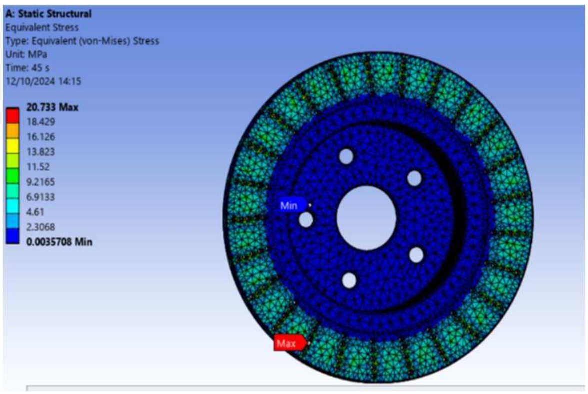


**Fig.4.4: Stress on C/SiC**

### 4.1.2 Elastic Strain analysis:

Elastic strain was observed when a pressure of 1MPa and Rotational Velocity of 441.1rad/s is applied on the ventilated disc on X-axis of rotation of the disc for a simulation time duration of 45s.

The Fig: 4.5 shows the equivalent elastic strain observed in Gray cast iron and a maximum strain of 0.00019197 mm/mm and a minimum strain of 4.9013e-8 mm/mm. Fig: 4.6 provides the strain in Aluminum Alloy (AL6061_T6) and maximum strain of 0.00030534 mm/mm and minimum strain of 7.2985e-8 mm/mm. Fig: 4.7 gives the equivalent elastic strain observed in Titanium Alloy (TI_6AL_4V) a maximum strain of 0.00019751 mm/mm and minimum strain of 4.8539e-8 mm/mm. Fig: 4.8 represents the equivalent elastic strain in C/SiC and a maximum strain of 0.00014081 mm/mm and a minimum strain of 3.6593e-8 mm/mm.

From below Fig: 4.5, 4.6, 4.7 and 4.8 of all four materials (Aluminum Alloy, Gray cast iron, C/SiC and Titanium Alloy) we can say that Grey Cast Iron and C/SiC have less equivalent elastic strain compared to other two materials.

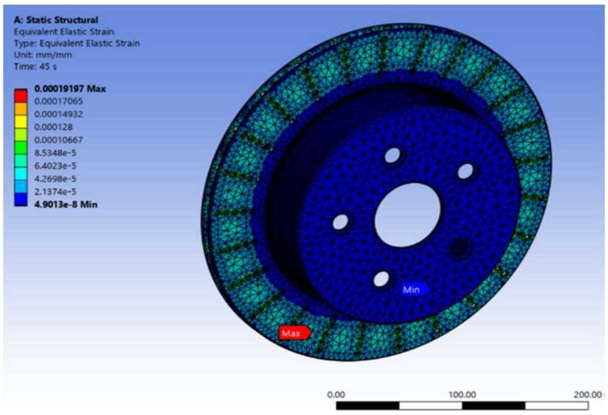


Fig.4.5: Strain on Gray cast iron

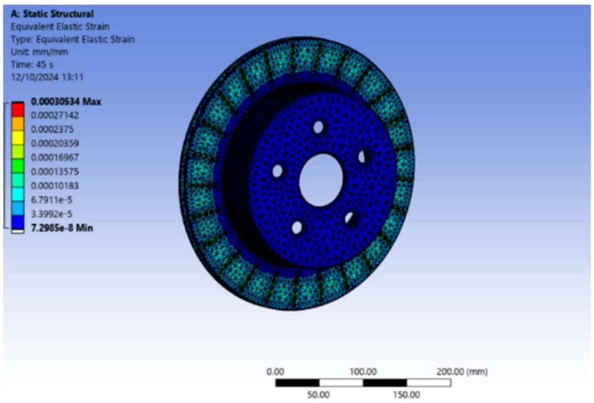


Fig.4.6: Strain on Al6061-T6

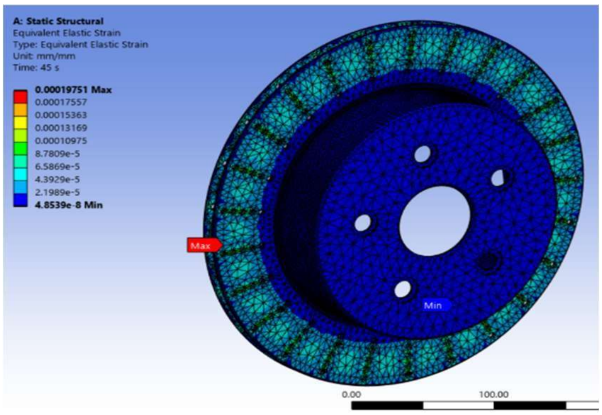


Fig.4.7: Strain on Ti-6Al-4V

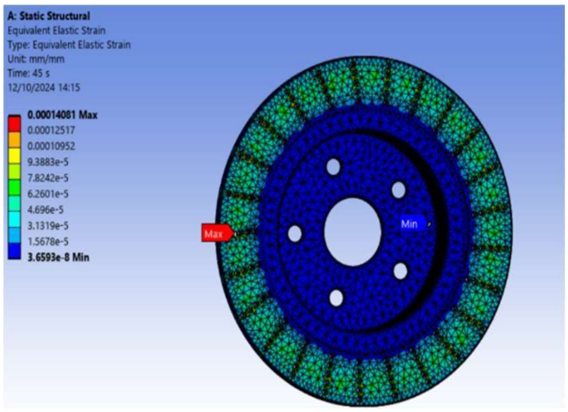


Fig.4.8: Strain on C/SiC

### 4.1.3 Total Deformation:

Total deformation is a structural parameter affected when the pressure is applied on the body of the disc under different material conditions. This happens due to rubbing action between brake pad and brake disc, also integrated with the internal micro-thermal stresses developed due to friction.

The below Fig 20 shows the total deformation in gray cast iron with a deformation of 0.0053857 mm. Fig 21 shows the deformation of Aluminum alloy (AL6061_T6) with a total deformation of 0.0084701 mm. Fig 22 shows the deformation of titanium alloy (TI_6AL_4V) with a total deformation of 0.0054714 mm. Fig 23 shows the total deformation of C/SiC with a total deformation of 0.0039556 mm.

From below, Figs. 20-23, we observed that C/SiC (carbon ceramics) has the least deformation compared with other materials, due to its high hardness and ability of high heat resistance, it also has good strength to weight ratio.

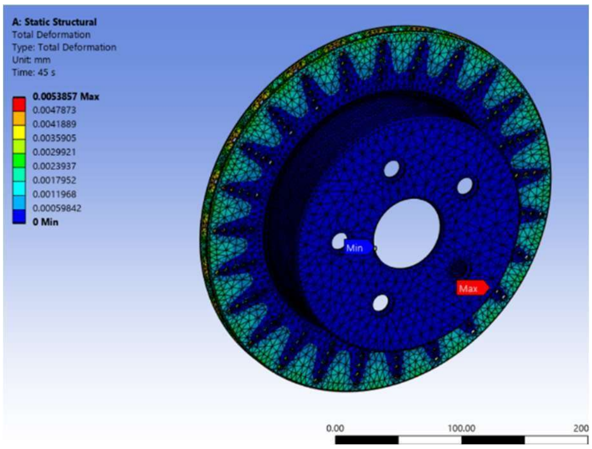


**Fig.4.9: Total Deformation on grey cast iron**

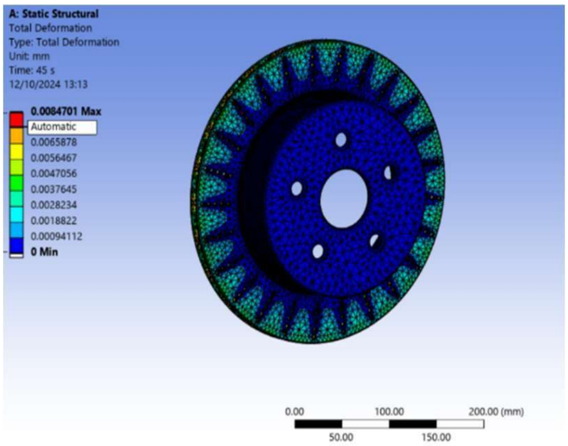


**Fig.4.10 Total Deformation on AL6061-T6**

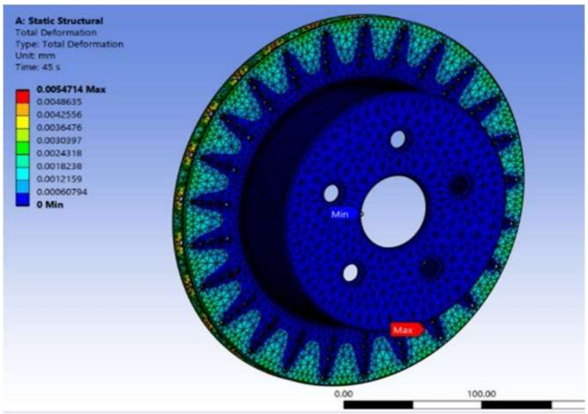


**Fig.4.11 Total Deformation on Ti-6Al-4V**

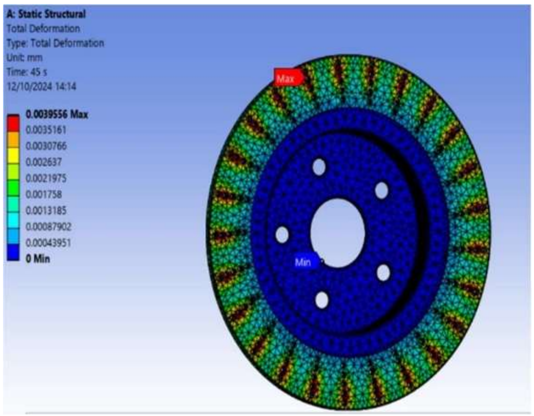


**Fig.4.12 Total Deformation on C/SiC**

| | Temperature(°C) | | Total Heat Flux(W/m²) | |
|---|---|---|---|---|
| | **Maximum** | **Minimum** | **Maximum** | **Minimum** |
| Grey cast Iron | 506.69 | 54.488 | 1196100 | 0.026478 |
| Al 6061-T6 | 326.77 | 94.92 | 1647200 | 0.067343 |
| Ti-6Al-4V | 1057.3 | 23.371 | 832380 | 0.087621 |
| C/SiC | 181.11 | 24.808 | 1094900 | 0.0031042 |

**Table 5.2:** Steady State Thermal Performance of Drilled hole brake disc with various materials

## 4.2 Thermal Analysis:

Thermal analysis is conducted to study the effects and change occurrence on the brake disc caused by the induced heat energy, will represent thermal stresses and thermal deformation and cracking that happens in a microlevel.

### 4.2.1 Temperature results:

From the static thermal analysis, we observed the temperature difference around the surface of the ventilated disc for the given boundary conditions, stating that lower the maximum temperature, better the heat dissipation property of material. This gives the idea of the thermal load acting on the contacting surfaces. The following was observed on different material properties. The convective heat transfer coefficient (h) applied at the ventilated surfaces is around 445.12W/m² °C, calculated from equation1.

The above Fig 24 provides temperature difference obtained in gray cast iron with a maximum of 506.69°C and a minimum of 54.488°C. Fig 25 gives the temperature obtained scale for Aluminum alloy (AL6061-T6) ranged from a maximum of 326.77°C to minimum of 94.92°C. Fig.26. says the temperature it reaches in Titanium alloy (Ti-6AL-4V) for the given conditions are a maximum of 1057.3°C and minimum of 23.371°C. Fig 27 shows the temperature gradient in C/SiC (carbon ceramics) with maximum of 181.11°C and minimum of 24.808°C.

From the above results we observed that the material which gives the lowest maximum temperature obtained on body of disc is C/SiC, followed by grey cast iron, followed by aluminum alloy, and lastly titanium alloy for the given conditions.

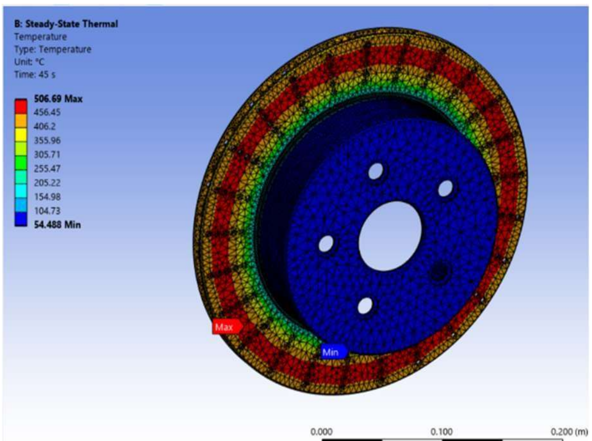


**Fig.4.13: Temperature on Grey cast iron**

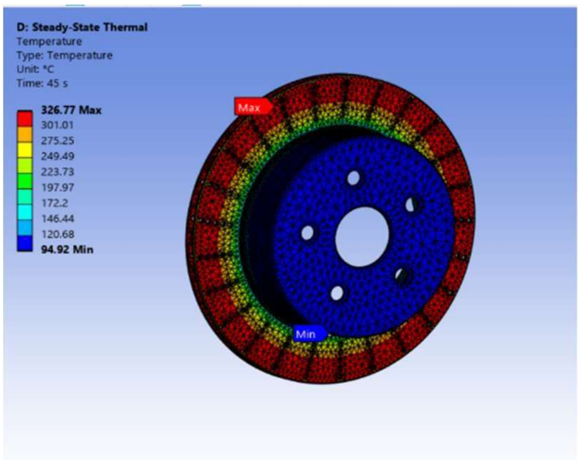


**Fig.4.14: Temperature on Al6061-T6**

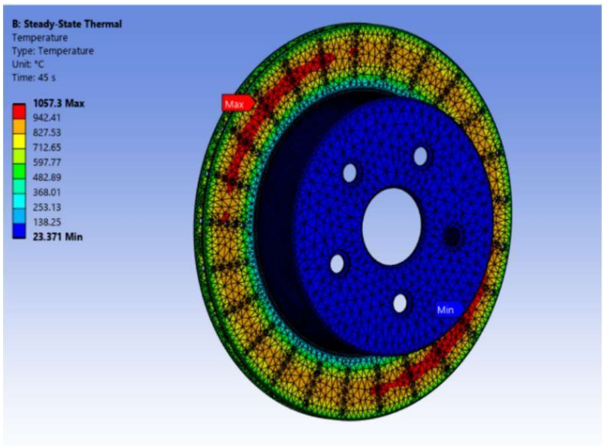


**Fig.4.15: Temperature on Ti-6Al-4V**

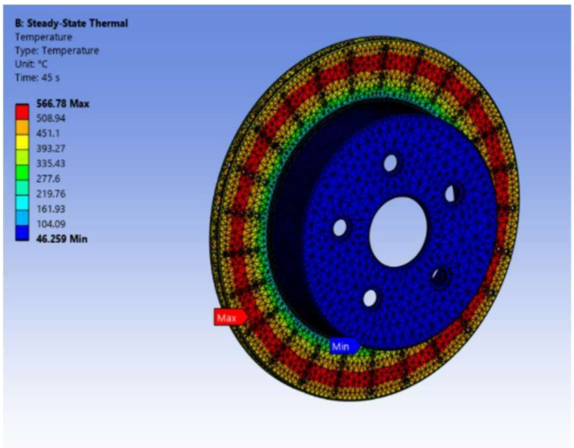


**Fig.4.16: Temperature on C/SiC**

### 4.2.2 Total Heat Flux:

Heat flux, also known as thermal flux, is a term used to express an amount of energy transferred from one place to the other in the form of heat. Heat, the energy associated with the temperature of an object, travels from high temperature to low temperature. When heat flux of 133402.46 W/m² was given to the following materials, the following reading were obtained in the time duration of 45s.

The below, Fig: 4.17 shows the heat flux obtained on gray cast iron with maximum of 1.1961e6 W/m². Fig: 4.18 represents the heat transfer ability in Aluminum alloy with maximum being 1.6472e6 W/m². Fig: 4.19 shows the heat dissipation rate on Titanium alloy with a maximum of 8.3238e5 W/m². Fig: 4.20 gives the heat flux acting on C/SiC, with a maximum of 1.0949e6 W/m².

From the above results we state that the Al6061-T6 has the good heat dissipation ability compared with others this means the development of internal thermal stresses will be less this will lower the crack formation in the ventilated disc. But even though due to its soft nature the material undergoes to wear and deformation.

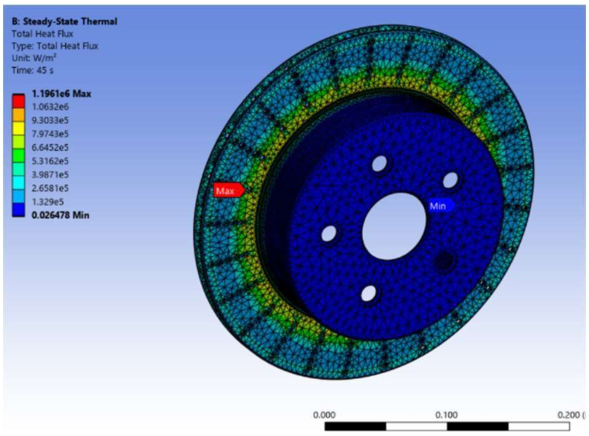


**Fig.4.17 Heat flux on grey cast iron.**

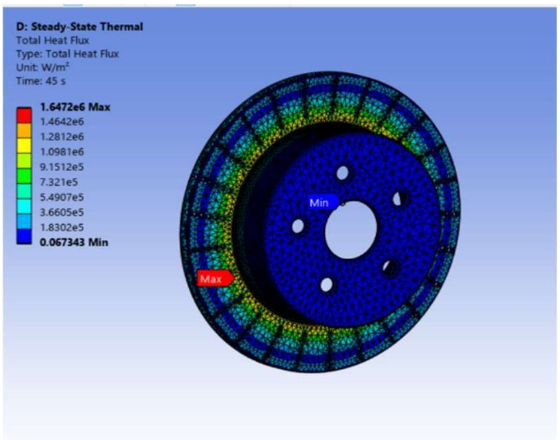


**Fig. 4.18 Heat flux on Al6061-T6**

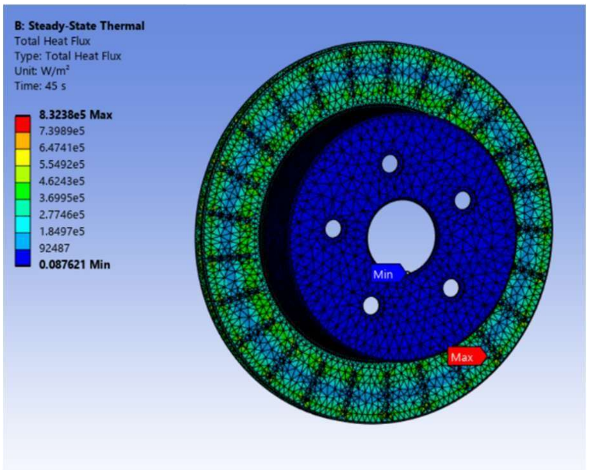


**Fig.4.19: Heat flux on Ti-6Al-4V.**

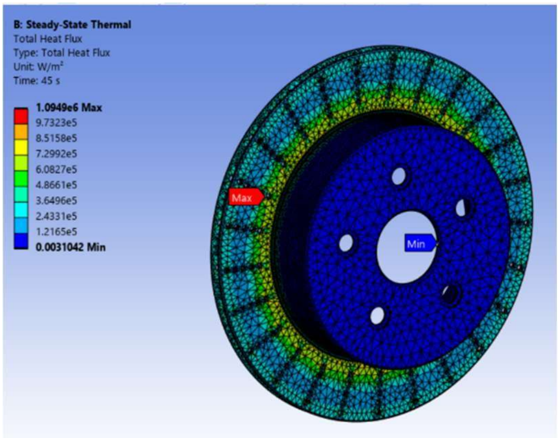


**Fig.4.20: Heat flux on C/SiC**

| | **Total Deformation(mm)** | | **(Von-Mises) Stress (MPa)** | | **Elastic Strain(mm/mm)** | |
|---|---|---|---|---|---|---|
| | **Maximum** | **Minimum** | **Maximum** | **Minimum** | **Maximum** | **Minimum** |
| Grey cast Iron | 0.0053857 | 0 | 20.768 | 0.0035354 | 0.00019197 | 4.90E-08 |
| Al 6061-T6 | 0.0084701 | 0 | 20.7 | 0.0036025 | 0.00030534 | 7.30E-08 |
| Ti-6Al-4V | 0.0054714 | 0 | 20.75 | 0.0035297 | 0.00019751 | 4.85E-08 |
| C/SiC | 0.0039556 | 0 | 20.733 | 0.0035708 | 0.00014081 | 3.66E-08 |

**Table 5.1:** Static Structural performance of Drilled hole brake disc with various materials

# CHAPTER 5
# CONCLUSION

In this study, we presented the thermo-mechanical behavior of a ventilated disc in a steady state. By means of Ansys simulation, we were able to study the structural and thermal behavior of the ventilated disc with four different material properties (Grey cast iron, Al6061-T6, Ti-6Al-4V, C/SiC) for a determined braking efficiency. The results obtained are very useful for the study of thermos-mechanical behavior of the disc brake.

Through this numerical simulation, we noted that Al6061-T6 has 138% high heat dissipation capacity compared with existing cast iron, followed by carbon ceramics with 92% and titanium alloy with 70%, compared with existing cast iron material.

- When comes to the lowest maximum temperature and the minimum deformation of ventilated disc is observed with C/SiC material, are 181.11°C and 0.0039556 mm which are top compared with others.
- Since the performance of the disc depends on the life time functionality, the lower the wear and deformation then the higher will be the life time and efficiency. Table 5 & 6.

The various interactions between the thermos-mechanical phenomena generally correspond to damage: deformations generate cracking by tiredness, rupture or wear.

# CHAPTER 6
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