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Design and Analysis of Automobile Disc Brake using ANSYS

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ABSTRACT

The application of disc brake in the growing automotive world is considered a major automotive performance factor to be considered while designing any automobile class and variants. A disc brake is one of the essential components in any automobile as it is used to turn down the speed of the automobile. During braking operation, the braking pads and discs are undergoing severe conditions of wear and high temperature. To prevent harm to the disc brake or other components, the heat generated by this disc brake must then be released into the environment. Therefore, it is crucial to provide effective heat dissipation to the environment. Increasing the surface area where heat is dissipated into the environment is one potential solution. Comparison can be done for deformation, stresses, temperature etc. form the three materials to check which material is best. Catia is a 3d modeling software widely used in the design process. ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements. The project aims to model a disc brake. Structural and Thermal analysis is done on the disc brake A proper rotor design and superior heat-dissipating material provide better performance during the braking mechanism. In this project, the optimal arrangement of holes, slots, and cut sections curved are studied by using Ansys software.

KEYWORDS: Braking system, Disc Brake Rotor, Thermal, Structural Analysis, CATIA, ANSYS WORKBENCH 2019 R3.

1. INTRODUCTION

A brake is defined as a mechanical device, which is used to absorb the energy possessed by a moving system or mechanism utilizing friction. The primary purpose of the brake is to slow down or completely stop the motion of a moving system, such as a rotating drum, machine, or vehicle. It is also used to hold the parts of the system in position at rest. An automobile brake is used either to reduce the speed of the car or to bring it to rest. It is also used to keep the car stationary on the downhill road. The energy absorbed by the brake can be either kinetic or potential or both. In automobile applications, the brake absorbs the kinetic energy of the moving vehicle. In hoists and elevators, the brake absorbs the potential energy released by the objects during the braking period. The energy absorbed by the brake is converted into heat energy and dissipated to the surroundings. Heat dissipation is a serious problem in brake applications.

1.1 Mechanical Brake System

This mechanical braking system is the hand brake or the emergency brake; it generates friction between two surfaces as they rub against each other. In this braking system, a particular force is applied to the pedal and it's carried to the final drum by mechanical components such as a fulcrum, springs, and that are used as linkages to transmit force from one point to another, for 2 slowing down the vehicle. The slowing down of the speed or capacity of a brake depends on the surface friction as well as the actuation force applied to it.

1.2 Hydraulic Brake System

The brakes which are actuated by the hydraulic pressure (pressure of fluid) are called hydraulic brakes. Hydraulic brakes are commonly used in automobiles. Principle Hydraulic brakes work on the principle of Pascal's law which states that "pressure at a point in a fluid is equal in all directions in space". According to this law when pressure is applied to the fluid it travels equally in all directions so that uniform braking action is applied on all four wheels.

1.3 Pneumatic Brake System

The pneumatic-assisted drum-brake system, which is operated by air pressure and works 3 on the same principle as the mechanical drum brake system, is the third type. It is shown in fig1.3 It is shown in fig1.3. It is also known as the "S-Cam" braking system since it is actuated by a larger size cam or an "S-shaped cam". However, high-pressure compressed air spins the cam by actuating a pneumatic piston. Drum brakes are used on most medium-to-heavy commercial trucks.

1.4 Electromagnetic Brake System

Electromagnetic braking means applying brakes using electronic and magnetic power. Here we use the principle of electromagnetism to achieve frictionless braking. It is shown in fig1.4. This tends to increase the life span and reliability of brakes since no friction leads to less wearing out of brakes. Also, it requires less maintenance and oiling. This is an upcoming technological replacement for traditional braking systems. The main purpose behind the proposed use of these brakes in vehicles is that it is frictionless. This leads to a sizably less maintenance cost due to no friction and no oiling. Also, traditional braking systems are prone to slipping while this one is guaranteed to apply brakes to the vehicle. So without friction or need for lubrication this technology is a preferred replacement for traditional braking. Also, it is quite smaller in size compared to traditional braking systems.

1.5 Electrical brake system

The Electric Braking System or (Electrical Braking System) is one of the types of a braking system, which is also called an Electric Friction Brake or Electric TrailerBrake or Electrical Braking System. Electric Braking System is based on the brake pedal depression strategy and is similar to the Drum Braking System but the only difference is that the Electrical Braking System is related to Electro Magnetic Force while Drum Brakes use Hydraulic Pressure to apply the brakes. Whenever, the driver pushes the brake pedal, if the braking process takes place using Electric Power then it is called an Electric Braking System.The Electrical Braking System is applied in a Hydraulic Braking System and a Pneumatic Braking System where the mechanical work is done by Hydraulic or Pneumatic and the process is 5 run with Electricity, we use DC motor to control the Electric brake application and there will Electronic Control Unit (ECU), which observes the signals from sensors and act according to the situation of the vehicle.

1.6 Disc Brake System

Disc brakes are generally used in passenger cars, but due to their stable performance at higher speeds and resistance to break fade, they are gradually spreading into the commercial vehicle segment, where drum brakes were traditionally chosen for their longer service life. There is increasing demand from customers for longer service life and higher quality, and Akebono is committed to meeting them through further development of the disc brake's reliability. There are two types of disc brakes. The "opposed piston type disc brake" has pistons on both sides of the disc rotor, while the "floating type disc brake" has a piston on only one side. Floating caliper type disc brakes are also called sliding pin-type disc brakes. Brake rotors of disc brakes rotate with the wheels, and brake pads, which are fitted to the brake calipers, clamp on these rotors to stop or decelerate the wheels. The brake pads pushing against the rotors generate friction, which transforms kinetic energy into thermal energy.

1.7 Drum Brake System

Brake shoes fitted with brake linings that press against the drums from the inside to generate braking force are set inside of the drums. With this system, friction is generated by pressing the brake linings against the inside surfaces of the drums. This friction converts kinetic energy into thermal energy. Drum rotation helps to press the shoes and the lining against the drum with more force, offering superior braking force in comparison with disc brakes. On the other hand, it is very important to design the components so that the heat from the thermal energy is dissipated efficiently into the atmosphere. Drum brakes are brake systems with brake drums that rotate with the wheels. Inside each drum are brake shoes fitted with brake linings. Pistons press against the drums from the inside to generate braking force, thus making it possible to decelerate and stop the vehicle.

1.8 Brake disc

The brake disc is the rotating part of a wheel's disc brake assembly, against which the brake pads are applied. The material is typically Gray iron a form of cast iron. The design of the discs varies somewhat. Some are simply solid, but others are hollowed out with fins or vanes joining the disc's two contact surfaces. The weight and power of the vehicle determine the need for ventilated discs. The "ventilated" disc design helps to dissipate the generated heat and is commonly used on the more heavily loaded front discs. Discs for motorcycles, bicycles and many cars often have holes or slots cut through the disc. This is done for better heat dissipation, to aid surface-water dispersal, to reduce noise, to reduce mass, or for marketing cosmetics.

Slotted discs have shallow channels machined into the disc to aid in removing dust and gas. Slotting is the preferred method in most racing environments to remove gas and water and to deglaze brake pads. Some discs are both drilled and slotted. Slotted discs are generally not used on standard vehicles because they quickly wear down brake pads; however, this removal of material is beneficial to race vehicles since it keeps the pads soft and avoids verification of their surfaces. On the road, drilled or slotted discs still have a positive effect in wet conditions because the holes or slots prevent a film of water from building up between the disc and the pads.

Two-piece discs are a disc where the center mounting part of the disc is manufactured separately from the outer friction ring. The central section used for fitment is often referred to as the bell or hat and is commonly manufactured from an alloy such as a 7075 alloy and hard anodized for a lasting finish. The outer disc ring usually is manufactured from grey iron but in special applications can be from steel or carbon ceramic. Originating from Motorsport but now common in high-performance applications and aftermarket upgrades. Two-piece discs can be supplied as a fixed assembly with regular nuts, bolts, and washers or a more complicated floating system where drive bobbins allow the two parts of the brake disc to expand and contract at different rates, therefore, reducing the chance a disc will warp from overheating. Key advantages of a two-piece disc are a saving in critical un-sprung weight and the dissipation of heat from the disc surface through the alloy bell. Both fixed and floating options have their drawbacks and advantages, floating discs are prone to rattle and collection of debris and are best suited to Motorsport whereas fixed is best for road use.

1.9 Requirement of brakes

The function of brakes is to stop the vehicle within the required time. The brake of the vehicle absorbs all the energy given by the engine plus that due to the momentum of the vehicle. This energy must then be dissipated. In most vehicles, the energy is absorbed by the brakes in the form of heat and dissipated into the stream of air passing around the vehicle. Apart from stopping the vehicle, the brakes should perform the others function too as the vehicle should stop without any jerk and the retardation should be smooth. Also, the rate of retardation should be equal to the pedal effort and the effort applied by the driver to stop the vehicle should not be excessive. The rate of wear should also be low. The brake system should not be affected by water, heat, dust, etc. It should require very low maintenance and be durable.

Advantages:

1. Disc brakes provide increased stopping power: Most importantly, disc brakes give you better braking control versus rim brakes. They allow you to stop more quickly, accurately, with control, and at the speed, you want in a variety of conditions.
2. Disc brakes stay cleaner: With rim brakes, the braking surface is on the outside of the wheel and close to the road. This makes them vulnerable to collecting dirt. Disc brakes, on the other hand, are at the hub of the wheel and further from the road. This means they do get hit by as much grime being

tossed up from the road. Cleaner brakes provide more consistent stopping power regardless of the elements you find yourself cycling through.

3. Disc brakes allow for wider tire options: A rim brake must go around the tire to reach the rims. This limits the maximum tire width. Disc brakes simply donate have this problem because the braking is happening at the wheel hub. As a result, it is the frame that limits the maximum tire width.
4. Disc brakes require less effort to stop the vehicle.
5. It generates less heat. The disk brake is simple to install and service. The disk brake is easy to control.
6. Disk brake can never become self-locking. Disk brake has high torque transmitting capacity in a small volume.
7. In the disk brake, the braking torque is linearly proportional to the actuating force.

Disadvantages:

1. A disc brake is much more prone to noise so timely service is required.
2. The rotors wrap easier than the drum brake system.
3. Disc brakes are not self-energizing and thus need a higher clamping force, which requires a power booster.
4. Expensive compared to a drum brake.
5. Too many components are used in this brake so increase weight.

2. LITERATURE REVIEW

M.H. Pranta et.al [1] performed a computational study on the structural and thermal behavior of modified disk brake rotors In their experiment they, modified the ventilated disk brake rotor with curved holes, vents, and slots, and the stress and temperature distribution were analyzed using Ansys. The brake was modeled in SolidWorks and simulation was done using ANSYS. Structural and thermal characteristics were compared with a reference disk brake rotor.

Camelia Pinca-Bretotean and Rakesh Bhandari [2] two cases have been analyzed. An investigation of thermal behavior of brake disk pad assembly with Ansys. Provide insight into the heat flow behavior. Experimental evaluations of a hydraulic brake system can verify the simulation models. Together with the ten successive brakes, numerical as well as experimental tests are made.

S. Mithlesh et.al [3] the modified designs with larger hole diameters were found to be better in stress. With an increase in whole diameter, the heat dissipation will be better as more heat can flow easily through the larger holes. The whole diameter of the disc and contact area between the brake pad and disc are varied by keeping in view the total weight of the braking system.

Vishvajeet et.al [4] the wind turbine is a device that converts kinetic energy from the wind into electrical power. The main theme of this paper is to replace them with natural fiber. Natural fibrereinforced polymer composites in wind turbines, requirements to the composites, their properties, constituents, and manufacturing technologies.

Pragya Mahajan et.al [5] It is necessary to optimize and design a lightweight brake disc assembly that has high braking power, strength, and rigidity, to achieve desirable results, parameters of assembly like effective diameter of the brake disc, the thickness of brake disc, heat flux, maximum temperature, fluid parameters, caliper specifications, design and arrangement of floaters, etc. are 11 determined and calculated to have an optimized geometry. These values are determined based on vehicle parameters such as overall weight, the velocity of the vehicle, braking time, the kinetic energy of the vehicle, static and dynamic weight distribution, the height of the center of gravity of the vehicle, wheelbase, wheel diameter and coefficient of friction of tires.

Daanvir Karan Dhir [6] the finite element method to examine the increase in temperature of an automotive disc brake. The heat flux produced and the heat transfer coefficient taken into account were used to determine the stiffness of the rotor and the maximum temperature rise on the disc rotor. Effect of variations in disc rotor geometry, such as holes and airfoil vents, in comparison to a simple flange-type disc.

HabtamuDubale et.al [7] Thermal stress, and thermal deformation, have been used to compare the three profiles. The outcome revealed that the type with the grooved surface displayed 34 Mpa of comparable stress, and the solid type and the drilled type displayed 80 Mpa and 57 Mpa, respectively. The more effective the grooved type brake than the other two profiles. The thermal stress developed and thermal deformation on the would-be significantly reduced.

Ashish Kumar Shrivastava et.al [8] Using a detailed 3-dimensional, limited component model of an actual automobile brake rotor, this article examines temperature and warmth motion at plate contacts. Based on the (FEM) study, rotor discs are generated using CATIAV5R20 and replicated using ANSYS R20The different properties of various materials are used to simulate and perform thermal analysis on the brake rotor of a car.

Leta Tesfaye Jule et.al [9] the objective is to study the materials thermal behaviour with a solid disc and the cross-drilled rotor to optimum design. The geometry was modelled in PRO-E software, and the analysis was done in ANSYS software. Three materials with different properties have been designed with solid and cross-drilled rotors. By the analysis, cross-drilled disc performance has produced the best optimum results.

Balaji Ra et.al [10] Aluminum matrix composites with Al2O3 reinforcements give predominant mechanical and physical properties. Kevlar is a thermo- safe and solid manufactured fiber, identified with different Aramids, Kevlar-119 has higher elongation capacity, adaptable and weariness resistant, yarn types found in mechanical elastic products such as tires, hoses, and other wide and larger productivity of applications are utilized, it achieves excellence of thermal and other properties.

Deekshith Ch et.al [11] Heat generation and dissipation of disc brake rotor is analyzed. Further analysis is carried out to check heat flux and temperature distribution by changing thickness and material. Two thicknesses 5mm and 6mm and two materials namely Stainless Steel and Gray Cast Iron are considered for analysis in the present work The objective of this work is to compare the temperature distribution and heat flux of disc brake rotor of two different materials.

Daanvir Karan Dhir [12] Stainless steel and grey cast iron using the same brake rotor. The analysis that is found that the performance and life of disc brake depend upon heat dissipation. The results can be concluded that grey cast iron has performed better as compared to stainless steel.

PraharshaGurram et.al [13] the study of structural, thermal analysis for vented with cross-drilled holes disc brake rotor of Audi A6 is done. Disc brake rotor which can dissipate heat generated during braking at a faster rate and also being structurally safe, like Grey cast iron, Stainless steel, Aluminum silicon carbide MMC, carbon ceramic matrix, E-Glass fiber, Titanium alloy, Aluminum alloy, Aluminum metal matrix composite.

SreeramPolimera et.al [14] Used a design tool used is CATIA V5 and the analysis tool ANSYS 2021 R1. Two designs are considered, the conventional design and the new design called 'Parametric Design'. The type of analysis used in this project is Transient Thermal and Static Structural. The analysis inputs are temperature, braking time, force on brake pads, rotational velocity, and coupled analysis of Transient thermal, structural analysis is done to check the temperature distribution, stress distribution, and the deformation of the disc.

M.A. Maleque et.al [15] Material performance requirements were analyzed and alternative solutions were evaluated among cast iron, aluminum alloy, titanium alloy, ceramics, and composites. Mechanical properties including compressive strength, friction coefficient, wear resistance, thermal conductivity, and specific gravity as well as cost, were used as the key analysis led to aluminum metal matrix composite.

Ali Belhocine and MostefaBouchetara [16] the numerical simulation for the coupled transient thermal field and stress field is carried out by sequentially thermal-structural coupled method based on ANSYS to evaluate the stress fields and deformations which are established in the disc with the pressure on the pads. The results obtained by the simulation are satisfactory when compared with 13 those of the specialized literature.

Ji-Hoon Choi and In Lee [17]. The computational results are presented for the distributions of pressure and temperature on each friction surface between the contacting bodies. Also, the thermoplastic instability (TEI) phenomenon (the unstable growth of contact pressure and temperature) is investigated in the present study, and the influence of the material properties on the thermoplastic-based on these numerical results, the thermoplastic behaviors of the carbon–carbon composites with excellent mechanical and thermal properties are also discussed.

Sunil Gupta et.al [18] the software simulation is performed with the aim of thermal analysis. It is found that discs with optimized geometry can perform better in terms of thermal action performance, heat generation can be controlled and greater heat dissipation can be achieved, it also helps to improve the life and durability of disc brake.

R RAJAPPAN et.al [19] It is crucial in the quick dissipation of heat from the rotor disc. Keeping this in mind, a comparison between the different materials is modeled in Creo parametric and it is analyzed in ANSYS 2019 R3, transient analysis of Cast Iron, Tungsten carbide, and Hafnium carbide is modeled and analyzed using Creo and ANSYS 2019 R3 respectively. The best among them is selected as a material for the disc rotor.

PraharshaGurram et.al [20] A detailed study of structural and thermal analysis for the modified disc rotors such as solid, vented and vented with cross-drilled disc rotors The design was carried out using CATIA V5, and the analysis is done by using ANSYS WORKBENCH 16.2 Software. Finally, the required profile and material which has less thermal stresses and structural deformation is observed by comparing the obtained results in the analysis.

From the literature, it is found that gray cast iron has been used for discs and we are using gray cast iron material for the entire work of the disc is playing a major role gray cast iron so we are going to modify the geometry of the disc by including slots, holes, edge cuts.

3. METHODOLOGY

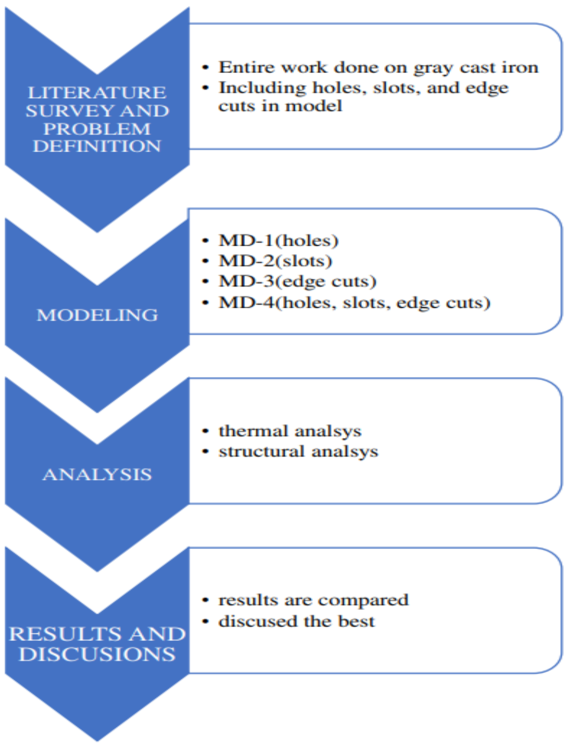

Fig 1: Methodology

From literature survey it is recommended the gray cast iron as disc material. so we are using gray cast iron in this entire analysis. In our study we are going to include holes, slots, and edge cutes to the disc [11].The disc mentioned in reference [11] is used for our entire work and we observed the same numerical results are mentioned. In reference [11]. For modeling of the disc Catia v5 has been used and four models are developed as follows: Modified disc-1(MD-1, holes) Modified disc-1(MD-1, slots) Modified disc-1(MD-1, edge cuts) Modified disc-1(MD-1, holes, slots, and edge cuts) briefly explained in the coming chapters. Mathematically, the structure to be analyzed is subdivided into a mesh of finite sized elements of simple shape. Within cache element, the variation of displacement is assumed to be determined by simple polynomial shape functions and nodal displacements. In recent years, FEA has been used almost universally to solve structural engineering problems. Finite element Analysis is a powerful numerical technique for analysis. FEA is used for stress analysis in that area of solid mechanics. The basic concept of finite element method is that a body / structure may be divided in to smaller elements called finite elements. The properties of the element are formulated and combined to obtain the solution for the entire body or structure. For a given practical design problem the engineer has to idealize the physical system into a FE model with proper boundary conditions and loads that are acting on the system. Then the discretization of a given body or structure into cells of finite elements is performed and the mathematical model is analyzed for every element and then for complete structure. The various unknown parameters are computed by using known parameters. Equations for the strains and stresses are developed in terms of the unknown nodal displacements. From this, the equations of equilibrium are assembled in a matrix from which can be easily be programmed and solved on a computer. After applying the appropriate boundary conditions, the nodal displacements are found by solving the matrix stiffness equation. Once the nodal displacements are known, element stresses and strains can be calculated these models are imported to Ansys workbench (Ansys 19 R3). The thermal and structural analysis. In thermal heat flux, and temperature are studied, in structural deformation and Voice strain are studied. The results are compared and discussed with each other.

4. MODELLING AND ANALYSIS

1. INTRODUCTION TO CATIA V5 SOFTWARE:

Computer-Aided Design (CAD) is the use of computer software to design a product or an object. Computer Aided Manufacturing (CAM) is the use of computer software and hardware to plan, manage and control the operations of a manufacturing plant. Computer Aided Engineering is the use of computer software to solve engineering problems and analyze products created using CAD. CATIA is an acronym for Computer Aided Three-dimensional Interactive Application. It is one of the leading 3D software used by organizations in multiple industries ranging from aerospace, and automobile to consumer products. CATIA provides the capability to visualize designs in 3D. When it was introduced, this concept was innovative. Since Dassault Systems did not have expertise in marketing, they had revenue sharing tie-up with IBM which proved extremely fruitful to both companies to market CATIA. In the early stages, CATIA was extensively used in the design of the Mirage aircraft; however, the potential of the software soon made it a popular choice in the automotive sector as well. The company also expanded the scope of the software. CATIA can be used at different stages of the design - ideate, draw, test, and iterate. The software comes with different workbenches that allow CATIA to be used across varied industries from parts design, surface design, and assembly to sheet metal design. CATIA can also be used for CNC.CATIA offers many workbenches that can be loosely termed modules. A few of the important workbenches and their brief functionality description is given below: Part Design: The most essential workbench needed for solid modeling. This CATIA module makes it possible to design precise 3D mechanical parts with an intuitive and flexible user interface, from sketching in an assembly context to iterative detailed design.

2. COMMANDS USED IN CATIA:

2.1 Sketcher Module:

The Sketcher workbench is a set of tools that helps you create and constrain 2D geometries. Features (pads, pockets, shafts, etc...) may then be created solids or modifications to solids using these 2D profiles. You can access the Sketcher workbench in many ways. Two simple ways are by 19 using the top pull-down menu (Start – Mechanical Design – Sketcher), or by selecting the Sketcher icon. When you enter the sketcher, CATIA requires that you choose a plane to sketch on. You can choose this plane either before or after you select the Sketcher icon. The Sketcher workbench contains the following standard workbench-specific toolbars. The below fig 2.1 shows the settings of the Sketcher Module.

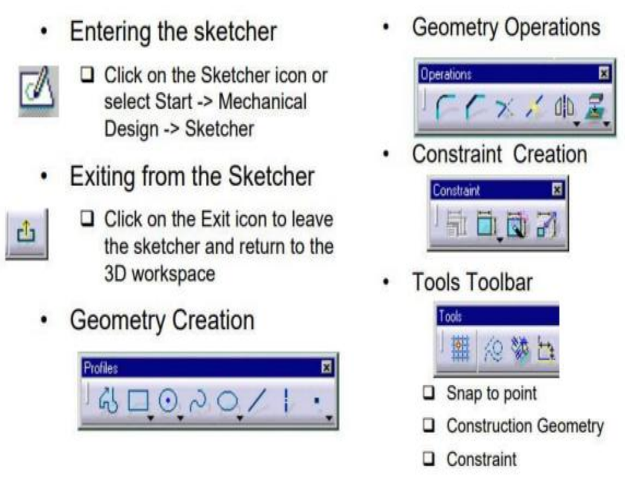

Fig 2.1: Sketcher Module

Profile toolbar: The commands located in this toolbar allow you to create simple geometries (rectangle, circle, line, etc...) and more complex geometries (profile, spline, etc...).

Operation toolbar: Once a profile has been created, it can be modified using commands such as trim, mirror, chamfer, and other commands located in the Operation toolbar.

Constraint toolbar: Profiles may be constrained with dimensional (distances, angles, etc...) or geometrical (tangent, parallel, etc...) constraints using the commands located in the Constraint toolbar.

Sketch tools toolbar: The commands in this toolbar allow you to work in different modes which makes sketching easier.

2.2 Edge Fillet:

A fillet is a curved face of a constant or variable radius that is tangent to, and that joins two 20 surfaces. Together, these three surfaces form either an inside corner or an outside corner. In drafting terminology, the curved surface of an outside corner is generally called a round and that of an inside corner is normally referred to as a fillet. Edge fillets are smooth transitional surfaces between two adjacent faces. It is shown in fig 2.2.

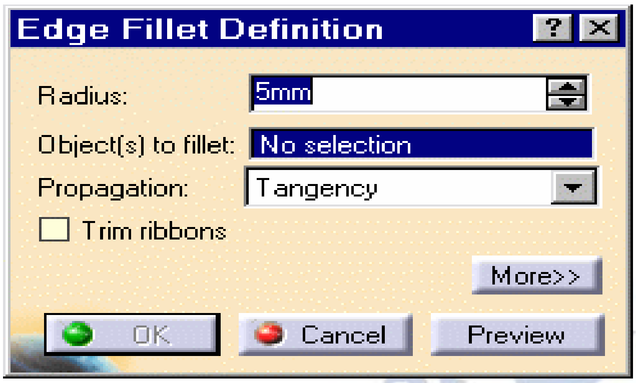

Fig 2.2 Edge fillet

2.3 Circle:

This task shows how to create an arc using three reference points to define the required size and radius. In this task, we will use the Sketch tools toolbar but, of course, you can create this arc manually. For this, move the cursor to activate Smart Pick and click as soon as you get what you wish.By default, arc centers appear on the sketch and are associative. In case you create arcs by clicking, if you do not need them, you can specify this in the Tools > Options dialog box. For this, go to Tools > Options, Mechanical Design > Sketcher option at the left of the dialog box (Sketcher tab). It is shown in figure2.3

Fig 2.3 Circle

5. MODELING OF MODIFIED DISC BRAKE USING CATIA V5 SOFTWARE.

5.1 Modelling reference disc

The main goal of this investigation is to investigate the total deformation, von-misses stress, heat flux and temperature of a modified disc brake at a force of 500N for gray cast iron are: It is shown in figure 5.1. Several assumptions have been made as follows [11].

Disc radius = 120mm

Thickness= 5mm

Disc bolts radius = 6mm

No. of bolt holes=6

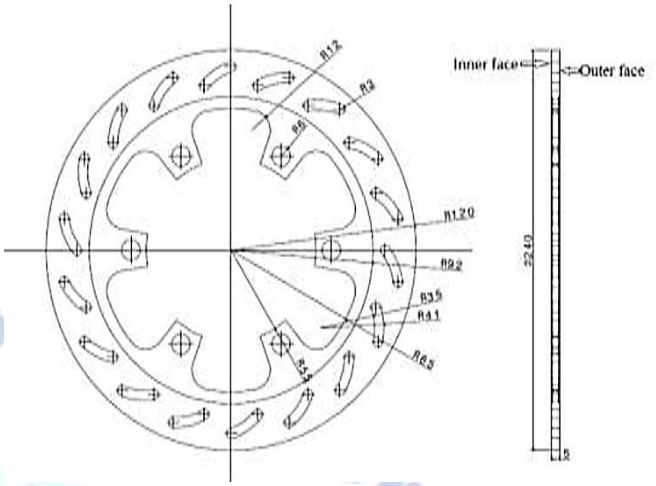

Fig 5.1 Reference disc dimensions [11]

CATIA V5 is Computer-aided design (CAD) software that is used to build the geometry model. The geometry model of the modified disc is drawn according to the actual reference disc dimensions. The modeling is done using CATIA V5. The procedure utilized to model the modified disc by CATIA software is presented below:

1. To sketch the part, click on start, select mechanical design, and select part design. It is shown in figure.

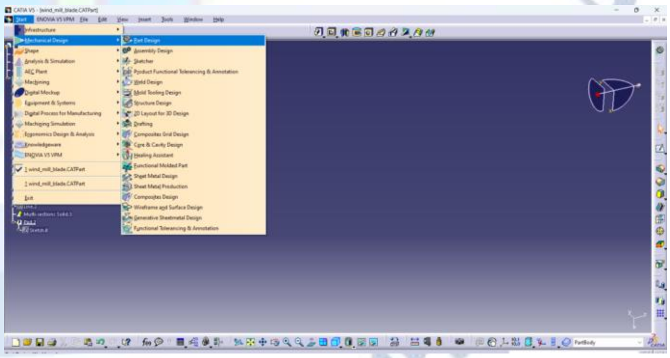

Fig 5.2 Options to open part design

2. Firstly, we need to select the plane on which the sketch is needed to draw. It is shown in figure 5.2.

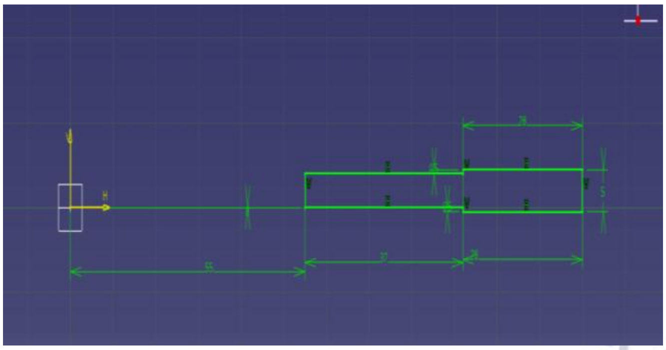

Fig 3.3 Modelling

3. Exit the workbench. select the shaft tool and revolve the plane.
4. Open the sketchers, draw the bolts of the disc again exit the workbench.
5. Use a pocket tool to remove the material.

4. Modified disc- 1 (MD-1)

This modified disc is as same as the reference disc further holes are added along the slots. It is shown in figure 4.1 and figure 4.2.

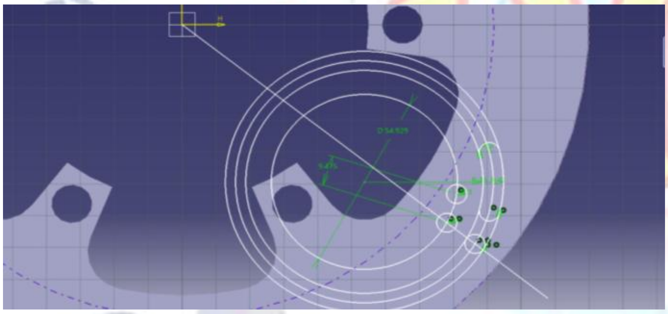

Fig 4.1: Modelling modified disc- 1 (MD-1)

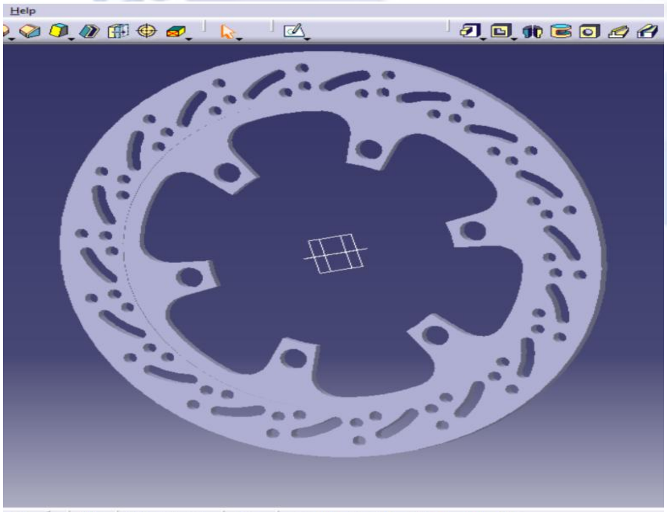

Fig 4.2: Completed Modelling of the modified disc- 1 (MD-1)

5. Modified disc- 2 (MD-2)

This modified disc is as same as the reference disc further slots are doubled in a count of slot 36. It is shown in figure 5.1.

Fig 5.1: Completed Modelling of modified disc- 2 (MD-2)

6. Modified disc- 3 (MD-3)

In this model, all the edge cuts are included shown in figure 6.1 and figure 6.2.

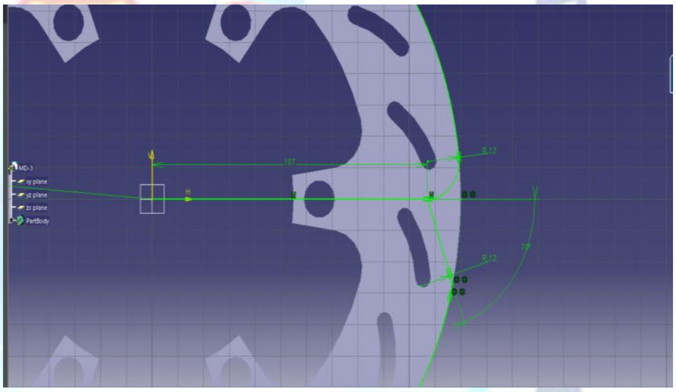

Fig 6.1: Modelling of modified disc- 3 (MD-3)

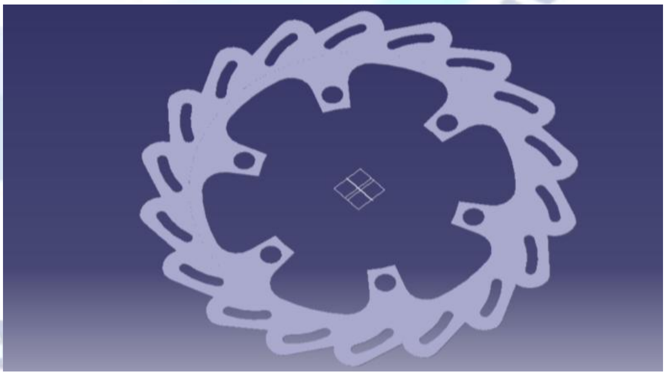

Fig 6.2: Completed Modelling of modified disc- 3 (MD-3)

7. Modified disc- 4 (MD-4)

In this model, all the holes, slots, and edge cuts are included shown in figure7.1.

Fig 7.1: Completed Modeling of modified disc (MD-4)

2. ANALYSIS

The analysis is done to disc brake by using gray cast iron materials to compare the total deformations, von-misses stress, heat flux, and temperature of a disc brake at the given boundary conditions.

2.1. Software used for analysis:

ANSYS version 2019 R3 was used to analyze the deformations, maximum shear stress, elastic strain, and von-misses stress of a disc brake to find out the optimal arrangement of holes, edge cuts, and slots of discs by performing structural and thermal analysis on the brake disc model. ANSYS can import model designs from the CAD program and can develop geometry in the pre-processing step.

ANSYS Static Structural steady-state thermal was applied to this simulation process. It determines the displacements, stresses, heat flux, and temperature in components caused by loads.

Steps Used in Static Structural Analysis:

A steady-state thermal analysis calculates the consequences of steady thermal loads on the element. Thermal analysis is to observe temperatures, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by loads that don't vary over time. Heat flux and heat generated in various cases considered are tabulated in table 1 for easy reference.

Table-1 heat flux and heat generation values

	Heat generation (Q in Joules)	Heat flux (q in KW/m^2)
Modified disc -1	5168.52	68.9136
Modified disc -2	4482.9	68.967
Modified disc -3	4140.9	69.001
Modified disc - 4	3788.49	68.881

Thermal analysis procedural steps are given below

1. Open the ANSYS workbench and select the study state thermal from the analysis system.
2. Import geometry and mesh the modal.
3. Applied boundary conditions, applied on the brake pad rubbing surface area as heat flux and convention to the whole body. As shown in figure 2.1, figure 2.2, figure 2.3, figure 2.4.

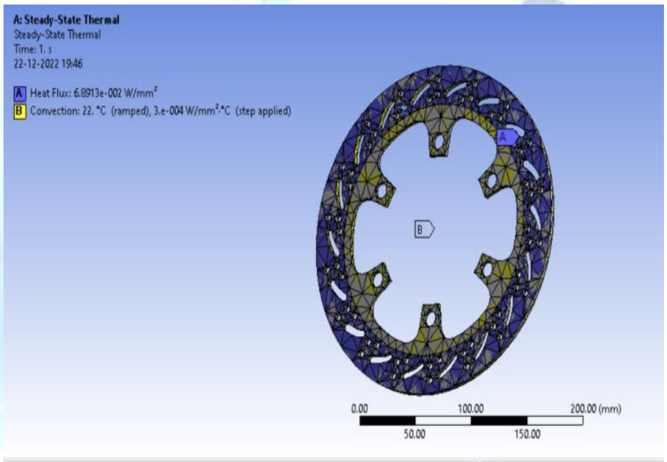

Fig 2.1: Applied boundary conditions (MD-1)

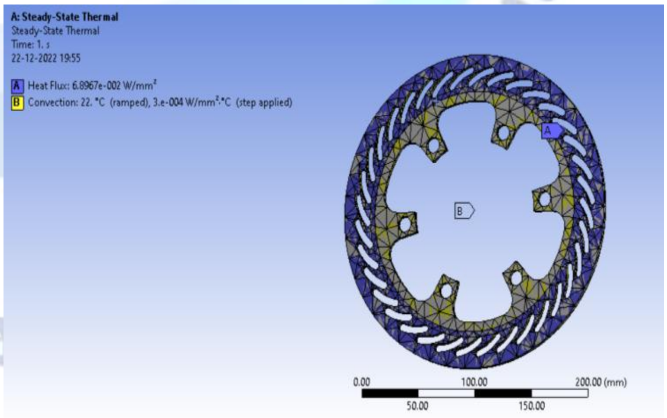

Fig 2.2 Applied boundary conditions (MD-2)

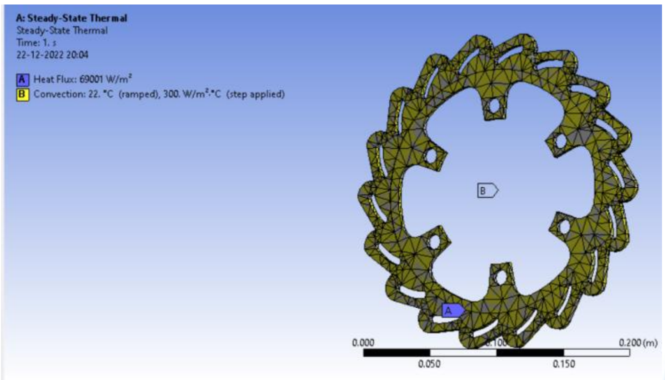

Fig 2.3 Applied boundary conditions (MD-3)

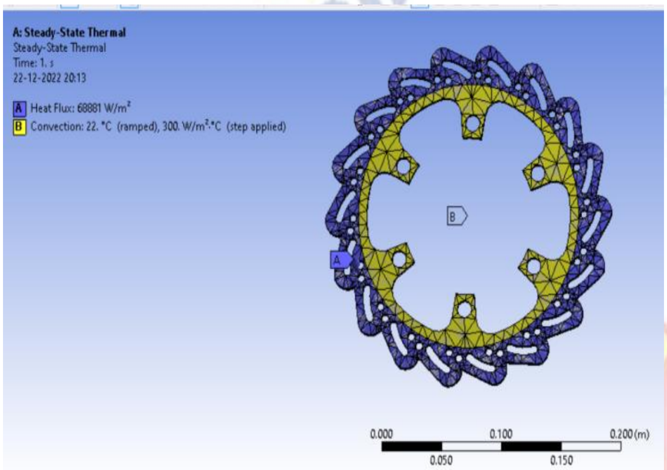

Fig 2.4 Applied boundary conditions (MD-4)

4. Now heat flux and temperature are solved.
5. The total heat flux and temperature compared with each other material to select the Efficient material for the construction of the brake disc.

6. RESULT

In this section modified disc are compared with deformation, stresses, heat flux and temperature are taking into consideration. Boundary conditions are applied for modified disc brake rotor to optimize results. Thermal analysis is performed for heat flux and temperature. Heat flux i.e., heat generated per seconds per unit area and convective heat transfer coefficient are applied to modified disc brake rotor as boundary conditions. After applying boundary conditions, as a result temperature and heat loss per unit area are calculated for best material suitable for disc brake rotor. Following tabular column shows the structural and thermal analysis results.

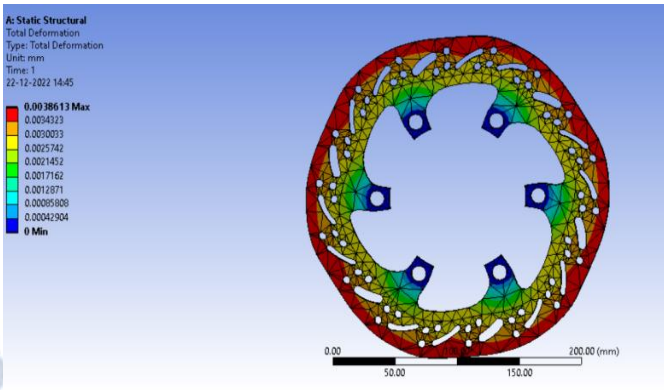

Fig 5.1 Total deformation (MD-1)

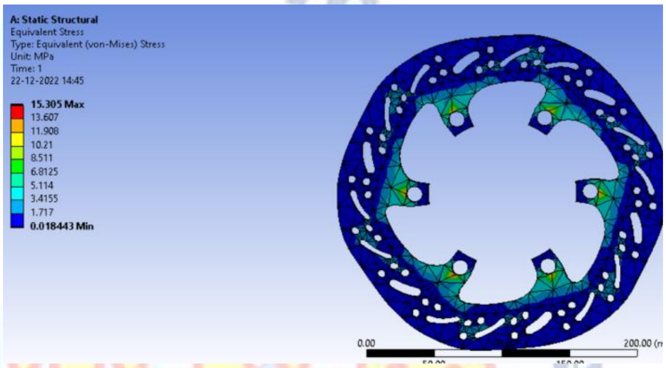

Fig 5.2 Von-misses stress (MD-1)

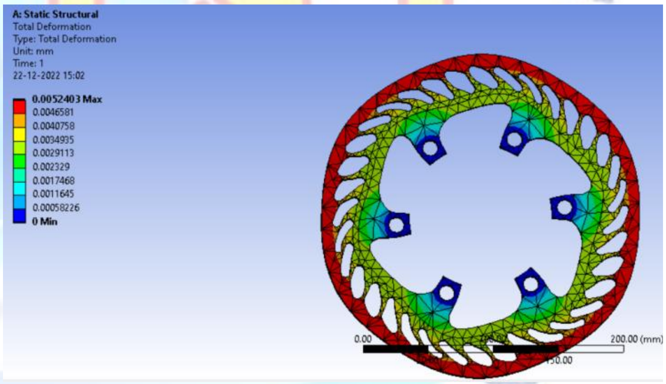

Fig 5.3 Total deformation (MD-2)

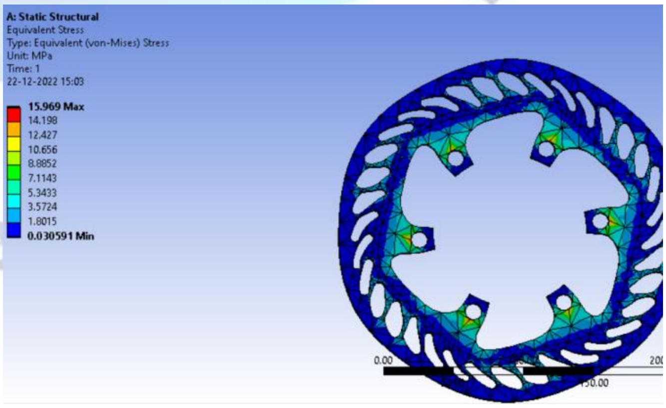

Fig 5.4 Von-misses stress (MD-2)

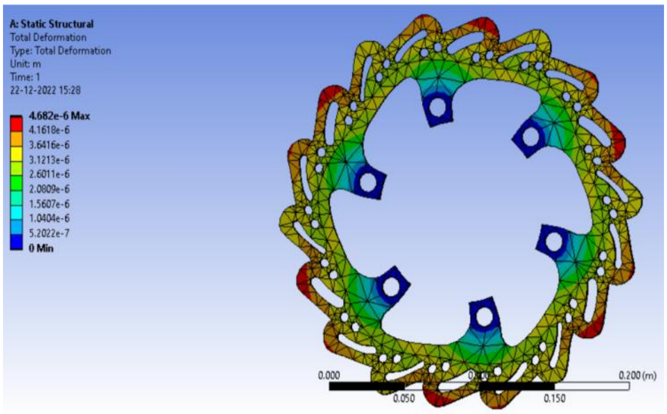

Fig 5.5 Total Deformation (MD-4)

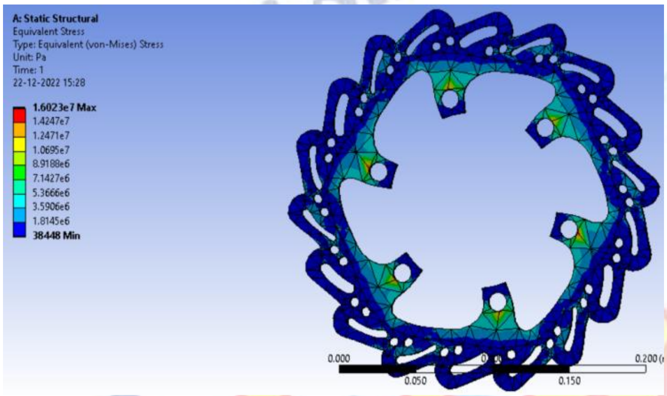

Fig 5.6 Von-misses stress (MD-4)

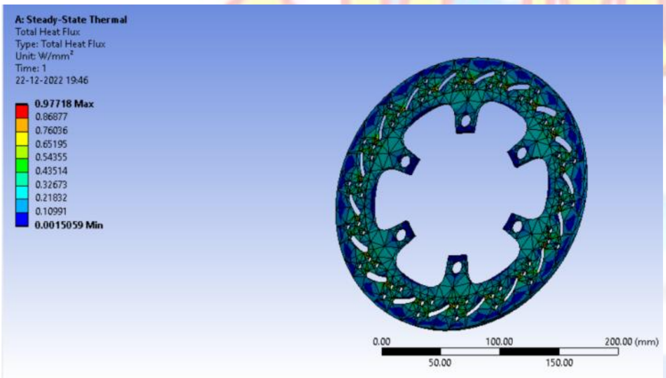

Fig 5.7 Heat flux (MD-1)

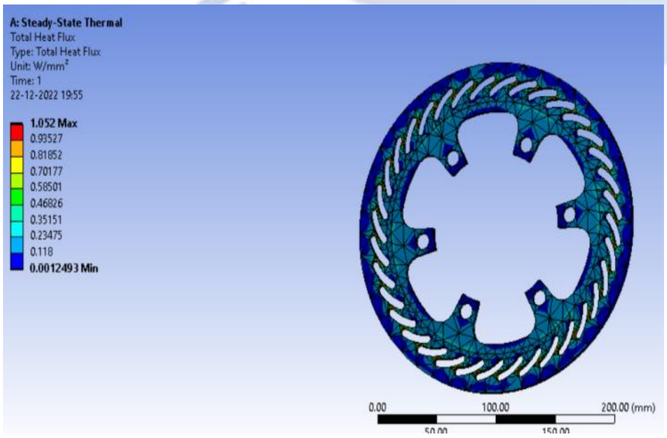

Fig 5.9 Heat flux (MD-2)

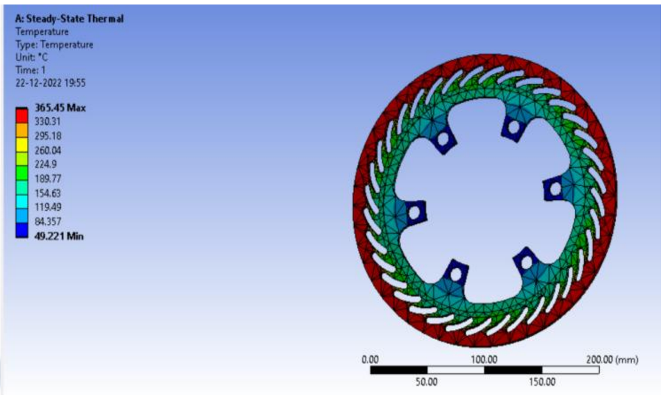

Fig 5.10 Temperature (MD-2)

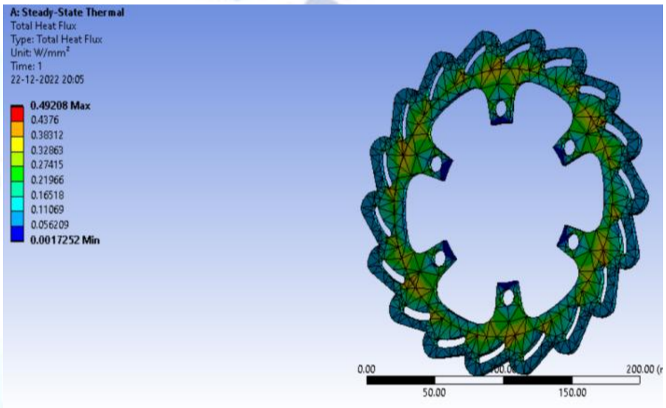

Fig 5.11 Heat flux (MD-3)

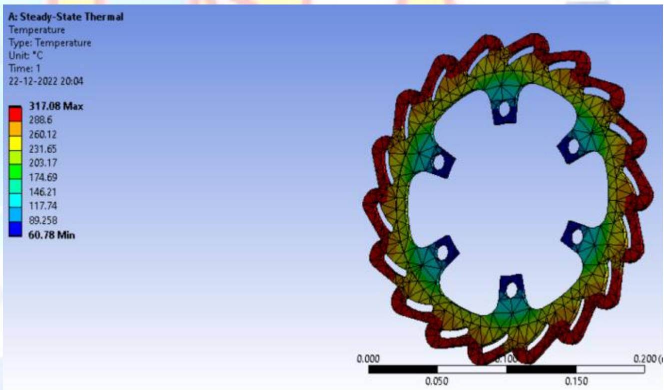

Fig 5.12 Temperature (MD-3)

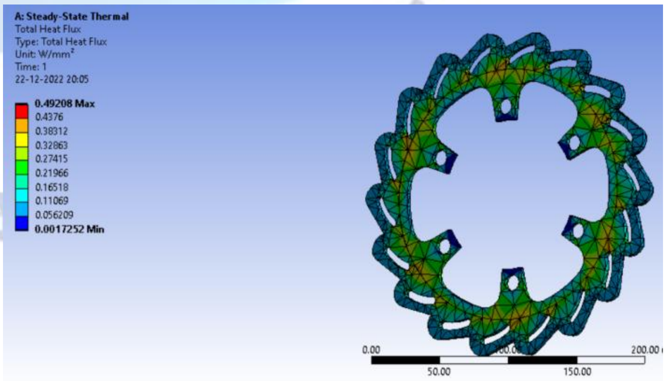

Fig 5.13 Heat flux (MD-4)

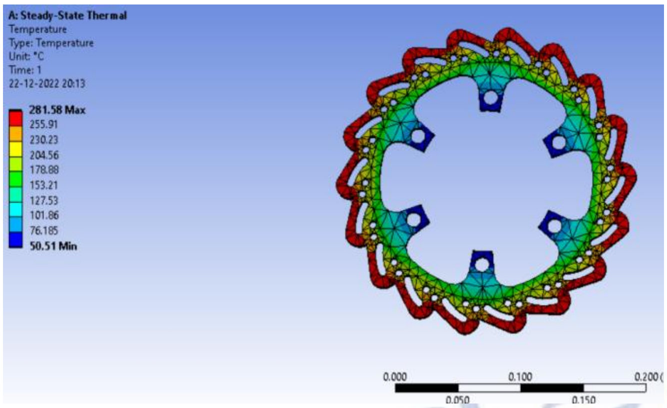

Fig 5.14 Temperature (MD-4)

Deformation of the MD-1 is shown in figure 5.1, it is observed that maximum deformation is 0.0038613 mm at the outer surface of a disc. Von-misses stress of the MD-1 is shown in figure 5.2, it is observed that the maximum von-misses is 15.305 MPa. Deformation of the MD-2 is shown in figure 5.3, it is observed that maximum deformation is 0.0052403 mm at the outer surface of a disc. Von-misses stress distribution of the MD-2 is shown in figure 5.4, it is observed that the maximum von-misses is 15.969 MPa. Deformation of the MD-4 is shown in figure 5.5, it is observed that maximum deformation is 0.004682 mm at the outer surface of the disc. Von-misses stress distribution of the MD-4 is shown in figure 5.6, it is observed that the maximum von-misses is 16.023 MPa.

The heat flux distribution of the MD-1 is shown in figure 5.7, it is observed that the maximum value is 0.97718 W/mm² and the minimum value is 0.0015059 W/mm². The temperature distribution of the MD-1 is shown in figure 5.8, it is maximum value is 383.82 °C and its minimum value is 58.31 °C. The heat flux distribution of the MD-2 is shown in figure 5.9, it is observed that the maximum value is 1.052 W/mm² and the minimum value is 0.001249 W/mm². The temperature distribution of the MD-2 is shown in figure 5.10, it is maximum value is 365.45 °C and its minimum value is 49.221 °C. The heat flux distribution of the MD-3 is shown in figure 5.11, it is observed that the maximum value is 0.49208 W/mm² and the minimum value is 0.0017252 W/mm². The temperature distribution of the MD-3 is shown in figure 5.12, it is maximum value is 317 °C and its minimum value is 60.78 °C. The heat flux distribution of the MD-4 is shown in figure 5.13, it is observed that the maximum value is 0.49208 W/mm² and the minimum value is 0.0017252 W/mm². The temperature distribution of the MD-4 is shown in figure 5.14, it is maximum value is 281.58 °C and its minimum value is 50.51 °C.

Table 5.1 Values obtained in analysis

	Deformations (mm)	Von-misses stress (MPa)	Heat flux (W/mm²)	Temperature (⁰C)
Modified disc -1	0.0038613	15.305	0.9771	383.82
Modified disc -2	0.0053403	15.969	1.052	362.45
Modified disc -3	0.0045109	15.788	0.4920	317.08
Modified disc -4	0.004682	16.023	0.68869	281.58

It is observed that all the equivalent stress values obtained from structural analysis are less than the allowable stress value, so that the design is secure based on the strength and rigidity criteria. the heat flux value is observed to be less than the disc with reference design made of grey cast iron. the heat generated is high and heat flux value is also observed to be high which results in high heat dissipation. Hence it is the finest probable combination of thickness and material for the current experimentation.

7. CONCLUSION

The following conclusions are drawn from the present work:

1. From the set of variables taken for the experiment, the best result among all is found at modified disc-4 (MD-4) of Gray Cast Iron material based on its high heat flux.
2. Maximum heat flux of 0.68869 W/mm² is produced in Gray Cast Iron with 5 mm thickness hence the modified disc-4 (MD-4) is suitable for disc brake rotor.
3. By structural analysis all stresses are under allowable stress, but heat flux is more on the Grey Cast Iron with 5 mm thickness hence the combination is better for the disc brake rotor.
4. From the set of variables, the best results are found at deformation are at modified disc-1 (MD-1) 0.0038613mm, stress at 15.305MPa.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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