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DESIGN AND ANALYSIS OF CARBON-CERAMIC DISC PLATES FOR MOTORCYCLES

Dr. Arun Manohar Gurram[1], Mukesh Raaj Kandamani[2], Raghuveer Dontikurti[3]

[1]Associate Professor, PG Scholar, [2]Assistant Professor[3]
[1] Department Mechanical Engineering, Centurion University of Technology and Management, Andhra Pradesh , India
[2] Department Mechanical Engineering, Centurion University of Technology and Management, Odisha, India
[3] Department Mechanical Engineering, Aditya Institute of Technology and Management, Andhra Pradesh, India

Abstract: The braking system is the most essential part of any automobile. The commonest means of braking is disk brakes. Every brake system currently used is effective, however the performance during braking differs with different manufacturers and different materials. Due to customer's need for more performance in everyday riding, researchers are looking for various alternative materials to increase the efficiency and durability in day to day life. Various materials like structural steel and carbon ceramic alloy have been analyzed in terms of heat, stress and durability using ANSYS 16.1. The design of the disc brake we have used has been inspired from TVS Apache RTR 160's rear disc brake which has been created in the 3D modelling software, Catia V5. With the results we can compare and conclude the better material which can be used with the improved design and has high wear resistance, good thermal conductivity, better brake-fade resistance and lighter in weight.

***Index Terms* - Petal disc brake rotor, FEA, Carbon-Ceramic Composite, Structural-Steel, Metal-Matrix composite**

I. INTRODUCTION

Today's technology is in need for speed, safety is equally important, for that deceleration of engines of max efficiency for maintaining the safe speed and brakes, and for this, latest technology is being used. Brake systems are required to stop the vehicle within the smallest possible distance. By converting kinetic energy into heat energy which is in turn dissipated to the atmosphere. For coping up with today's speed, new materials are introduced in the manufacturing of brakes. All automotive brakes are designed to push a friction-creating brake pad against a braking surface on the revolving wheel by way of a hand-operated lever. As pressure is increased at the brake lever the friction force is increased. A disc brake focuses forces on a smaller rotor, situated towards the center of the wheel.

Disc brake systems are widely used on front wheels in mid-range two-wheelers such as – commuter & sports bikes. The Disc brake system is used on the front wheels of most hatchback cars, entry-level sedans & MUVs; whereas, it is also widely used on both front & rear wheels of high-end cars and SUVs in combination with hydraulic / vacuum brake actuating systems. Disc brake got its name from the circular-shaped plate or disc or rotor; onto which the disc brake parts are mounted. A conventional Disc Brake system consists of a brake disc, two friction pads, and brake caliper. In the Disc brake system; the friction pads apply grip on the external surface of the disc to perform braking. The braking system must decelerate a vehicle in a controlled and repeatable fashion and when appropriate force applied causes the vehicle to stop. The braking should permit the vehicle at a constant speed when traveling downhill. The brake system holds the vehicle stationary when flat or on the gradient.

Major disadvantages of brake discs are large rotor surfaces will produce a noisy sound. The surface of the brake shoes and the disc became hard causes of this noise. Another deficiency is the ineffective disc brakes when used as a parking brake. This happens because the brake pads have difficulty in retaining a smooth rotor surface. The disc brake system is only effective to reduce the vehicle's speed, but it is not as effective as drum brakes capable of self-energizing to remain stationary while parked. In this paper, we will be introducing an effective alternative to the existing practice of using cast iron brakes. Stainless steel is extensively used as the material for manufacturing disc brakes. This is much on the heavier side and thus reduces initial acceleration and causes more fuel consumption. For reducing these effects, we can use discs made out of composite materials. Carbon-ceramic braking systems offer significant advantages over other materials. The brake discs last longer and better handle a wider range of temperatures.

II. LITERATURE SURVEY

2.1 Non- axis symmetric three- dimensional model transient temperature field analysis

An analytical model is presented in this paper for the determination of the contact temperature distribution on the working surface of a brake. To consider the effects of the moving heat source (the pad) with relative sliding speed variation, a transient finite element technique is used to characterize the temperature fields of the solid rotor with appropriate thermal boundary conditions. Numerical results show that the operating characteristics of the brake exert an essentially influence on the surface temperature distribution and the maximal contact temperature. [1]

2.2 Characteristics of cooling is Automobile disc brakes

Characteristics of cooling in automobile disc brakes was the main objective in this investigation experimentally using a modified spin rig using analysis in finite element (FE) and CFD (computational fluid dynamics) methods. Conduction, Convection and Radiation have been calculated along with the design of the brake rotor assembly and their interfaces. Long drag brake application is the parameters for analysis. Thermal power dissipated when analyzed shows the contribution of each heat transfer factor. [2]

2.3 Transient thermoelastic behaviors in disk brakes using FEA

Transient analysis of the thermoelastic contact problem of disk brakes with generations of input temperatures is performed using the element method. Analysis of thermoelastic material occurring on disk brakes, combined thermal conductivity and elite equilibrium is solved with contact problems. A numerical simulation of thermoelastic behavior of disc brakes is found in the repeated booking mode. The results are in order to distribute the pressure and heat in each area of the conflict between the contacting bodies. [3]

2.4 Investigation of disc/pad interface temperatures in friction braking

It was found that the number of braking applications had the strongest effect on the friction interface temperature. The real contact area between the disc and pad, i.e. pad regions where the bulk of the kinetic energy is dissipated via friction, had a significant effect on the braking interface temperature. For understanding the effect of real contact area on local interface temperatures and friction coefficient, finite element analysis (FEA) was conducted, and it was found that the maximum temperature at the friction interface does not increase linearly with decreasing contact area ratio. This finding is potentially significant in optimizing the design and formulation of friction materials for stable friction and wear performance. [4]

2.5 Thermoelastic Instability Phenomenon

The computational results are presented for the distribution of the temperature on the friction surface between the contacting bodies. Also, the influence of the material properties on the thermoelastic behavior, represented by the maximum temperature on the contact surface is compared among different types of brake disk materials found in the literature, such as grey cast iron (grey iron grade 250, high-carbon grade iron, titanium alloyed grey iron, and compact graphite iron (CGI)), Aluminum metal matrix composites (AlMMC's), namely Al2O3 Al-MMC \and SiC Al-MMC (Ceramic brakes). [5]

2.6 Investigation of disc brake rotor by Finite element analysis

In this study, a finite element analysis approach has been conducted in order to identify the temperature distributions and behaviors of disc brake rotors in transient response. CAE has been used as finite elements software to perform thermal analysis on transient response. Thus, this study provides better understanding on the thermal characteristic of disc brake rotor and assist the automotive industry in developing optimum and effective disc brake rotor. [6]

2.7 Structural and Thermal Analysis of Rotor Disc of Disc Brake

The thermal-structural analysis of disc brake is used to determine the deformation and the Von Mises stress in the disc for solid and ventilated disc with two different materials to investigate the performance of the rotor disc. A comparison between theoretical and analytical results are obtained from

The finite element model is done. The obtained values from the analysis which are less than their allowable values. Hence the suitable design and material of rotor disc is suggested and based on the performance, strength and rigidity. [7]

2.8 Disc Rotor Optimization and Design

Whenever possible, software results should be compared with appropriate theoretical results. In most cases, a theory will be used to compare head-to-head rather than obtaining order-magnitude estimates because FEA is probably being used because a theoretical solution is not available. [8]

2.9 A review on Thermal and Contact Stress Analytics of Disc Braking System

Numerical methods and analysis procedures used in the study of automotive disc brake. It covers Finite Element Method approaches in the automotive industry. This review can help analysts to choose right methods and make decisions on new areas of method development. The complex Eigenvalue method is chosen for contact analysis of car disc brake. The essence of such a method lies in the asymmetric stiffness matrix derived from the contact stiffness and the friction coefficient at the disc interfaces. This paper presents the analysis of the contact pressure distributions at the disc interfaces using a detailed 3- dimensional finite element model of a real car disc brake. It is also investigating different levels in modelling a disc brake system and simulating contact pressure distributions at varying load. [9]

2.10 Temperature and Thermal Stresses of Vehicles Gray Cast Brake

The main objective of this study was to evaluate the thermos-mechanical effectiveness of dry contact between the brake disc and the pads between the braking phase. The simulation is computer-based ANSYS. The temperature simulations are actually used to identify the geometric design feature of the disc to include the air intake system in vehicles. Thermo structure analysis is then used to combine the detection of clear and Von Mises stresses in disc, the contact pressure on the brake-pads. [10]

2.11 Disc brake design and analysis

A carbon ceramic matrix disc brake material was used to calculate the standard strength, shear Force and piston Force and calculates the recording distance of the disc brake. A typical two-wheeled disc brake model for the wheels using Ansys, performed by Thermal and Modal Analysis to calculate the malfunction, total temperature, frequency and temperature of the disc brake model. This is important to understand the action force and fiction force on disc brake new material, which uses the disc brake to work effectively, which can help reduce the risk that can occur each day. [11]

2.12 Comsol method for thermal analysis in Disc Brakes

We can conclude that cast iron may be used on brake discs which will provide limited cooling at low temperatures compared to other related alternatives. Ceramic has good cooling features but is more expensive than other materials and cannot be easily used. It can therefore be used in runaway vehicles where high temperatures will be produced. [12]

2.13 Cross Drilled Motorcycle Petal Disc Brake Rotor using different Composite Materials

In real life the existing metal i.e. cast iron shows good performance compared to other materials but with long and heavy performance, they sometimes fail. So, some different building materials get their place instead of standard Cast Iron disc brake rotor especially for supercars. Detailed study can be done on the disc brake rotor with various things through a dynamic learning environment about its failure. [13]

2.14 Motorcycle Sprocket material by Virtual Optimization

Excessive weight reduction can be done by rearranging the sprocket. Investigators are also looking for additional resources to use the standard soft metal. Material costs are also limited to the use of alternatives to existing sprocket motorcycle accessories. Therefore, these can be used for further development of the chain sprocket and more efficiency can be achieved during the power transfer.[14]

2.15 Disc Brake for Minimizing Temperature Analysis

Based on the various results collected from the analysis, it is determined that gray cast iron is the ideal material for cracking discs. The new disc is a suitable disc brake compared to the previous Bajaj pulsar disc for two-wheeler and other new disc dissertation bookings. The new disc 5 carries high brake force during the run without getting cracks, barking. [15]

2.16 Disc brake with brake pad and its analysis

Thermal analysis is performed on solid and airy discs made of materials made of Aluminum and Gray Cast Iron. From the above analysis we found that the Ventilated disc made of Aluminum exhibits an excellent Heat Dissipation Effect. Finally, we concluded that the Ventilated Disc made of Aluminum Alloy is the best rotor to use. [16]

2.17 Carbon-Carbon composites

The environment in which the asset is required to operate will set the value of the secondary operations / structures before any component is fully operational. In order to pass on qualities such as oxidation strength, fatigue resistance and 'flight strength', it will be necessary to combine a 'basic' combination with a host of other factors such as a combination of a protective shield and a matrix system that can meet all the requirements.[17]

2.18 Ceramic matrix composites with siloxane matrix and its properties

A composite Carbon fiber composite composed of liquid coated carbon fibers and a polysiloxane based silicon oxycarbide matrix was produced. The influence of fiber coating, the number of cycles of intensity and the calculation temperature have been investigated. Good results were obtained with carbon-based coatings and silicon carbonitride which led to a significant increase in composite strength. The integration leads to the destruction of the fiber and matrix during the repair and upgrading of fiber-matrix display structures. Highly used 'high technology', where costs are allowed for improved performance (such as parts of an aircraft engine), oxidation protection is a major problem [18]

2.19 Petal disc for ATV and it's design and analysis

In order to build a disc brake, we must first consider all the dimensions of heavy objects and geometry with wheels, and from the point of view of knowing the shape of the junction wheel. the construction of the harp in such a way that there will be a provision for the disc. The design of the disc brake should be lightweight as we use ATV. the most important thing to consider in designing the design process and its reliability, considering the production process is a key factor affecting its performance and performance. Consideration of heat dissipation during disc brake binding i.e. The formation of the disc brake provides a high degree of heat in the form of radiation and convection through the disc. [19]

2.20 Properties of SiCf/SiBCN ceramic matrix composites

The carbo-thermal reaction during the degradation process causes a cracking effect and reduces the composite properties of the SiCf / SiBCN compounds at room temperature. Excess carbon in powder and fibers can react with SiO_2 in the surface of the fibers and the reaction layer mainly contains SiC during the process of degradation. The reaction will also create a strong bond between the matrix and the fibers and create a composite split in an irregular manner. [20]

III. Components and Construction

The main components of a disk brake are the Brake Pads, Rotor, Caliper and Caliper Support

3.1 Disc Brake Pads

Brake pads are found inside the calipers. They're designed to clamp down on the rotor at high speeds, which means their main job (besides stopping your bike) is to hold up under heat and friction. There are two main types of brake pads. Resin brake pads (also called organic) are composed of organic materials like glass, rubber, and fibrous binders bonded together with resin. Sintered brake pads (also known as metallic) are made of metallic grains that are bonded together at high pressure.

3.2 Disc Brake Rotor

Generally, road and cyclocross use 140 to 160mm, XC mountain biking uses 160mm, trail riding uses 160 to 180mm (sometimes a mix, with the larger rotor up front), enduro uses 180mm, and DH uses 200 to 205mm. Rotors come as small as 140 millimeters in diameter for road and cyclocross applications, all the way up to 205mm for downhill mountain biking. Generally, road and cyclocross use 140 to 160mm, XC mountain biking uses 160mm, trail riding uses 160 to 180mm (sometimes a mix, with the larger rotor up front), enduro uses 180mm, and DH uses 200 to 205mm. Larger rotors are able to dissipate heat over a larger surface area, but are heavier, so you'll want the smallest rotor you can get away with for the type of riding you generally do.

3.3 Calipers

Calipers contain opposed pistons that sit on either side of the rotor; pressure from the brake line engages these pistons, which push the brake pads inward to contact the disc. The resulting friction slows the bike. When the driver steps on the brake pedal, the power is amplified by the brake booster and changed into a hydraulic pressure by the master cylinder. The pressure reaches the brakes on the wheels via tubing filled with brake oil (brake fluid). The delivered pressure pushes the pistons on the brakes of the four wheels. The pistons in turn press the brake pads, which are friction material, against the brake rotors which rotate with the wheels. The pads clamp on the rotors from both sides and decelerate the wheels, thereby slowing down and stopping the vehicle.

3.4 Carbon-Ceramic Disc

A special feature of the carbon ceramic brake discs is represented by the ceramic composite material. This material is obtained through a particular process, which gives the possibility to add or deposit a layer of material to improve the friction coefficient on both the braking surfaces.

The core and the additional friction layer are made by a composite material, which is composed of carbon fibers (reinforcement), silicon carbide and metallic silicon (matrix). Silicon carbide, the main matrix component, assures great hardness for the composite material while carbon fibers guarantee high mechanical strength resistance, providing the fracture toughness required in this kind of application.

The entire characteristic profile makes fiber-reinforced silicon carbide to a first-choice material for high-performance brake systems: in particular the low weight, the hardness, the stable characteristics also at high pressure and temperature, the resistance to thermal shock and the quasi ductility provide long life time of the brake disc and avoid all issues, which are typical for cast iron brake discs.

Under high loads, iron and steel discs can overheat, which in severe cases can cause them to warp and deform. Definitely not something you want to experience. To battle this issue, high-performance applications use brake discs made from carbon ceramics. They're formed when silicon resin is shot through with small grains of carbon fibre and moulded into the shape of a brake disc. This is what gives them their unique appearance: the chopped-up grains of carbon fibre suspended in the resin.

Just like the ceramic pads, they have excellent thermal properties which allow them to withstand very high temperatures while still delivering excellent braking performance. And once again, the downside is in the form of warm-up times.

IV. CAD MODEL

V. The design of the petal disc brake rotor was highly influenced from the rear disc brake assembly of TVS Apache RTR 160 motorcycle. Steel alloy is used in the conventional model of the disc brake rotor. The 3D model was then developed in CATIA V5 R21. The 3D model and the dimensions are given below.

Table 4.1 Mechanical Properties of the Rotor

Brake Rotor Diameter	200mm
Bolt Hole Diameter	10mm
No. of Bolt holes	3
Rotor Thickness	4mm

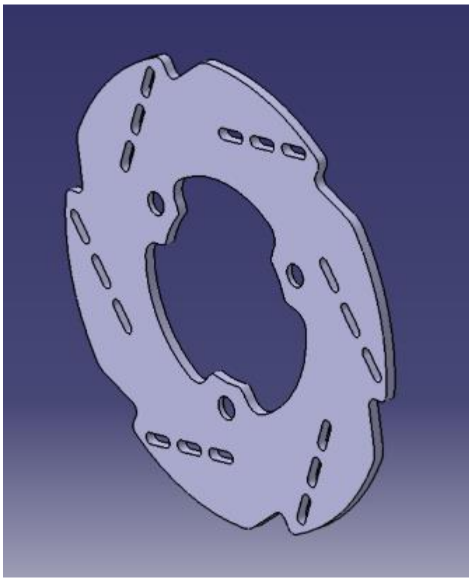

Fig. 4.1.1 CAD Model of Rotor

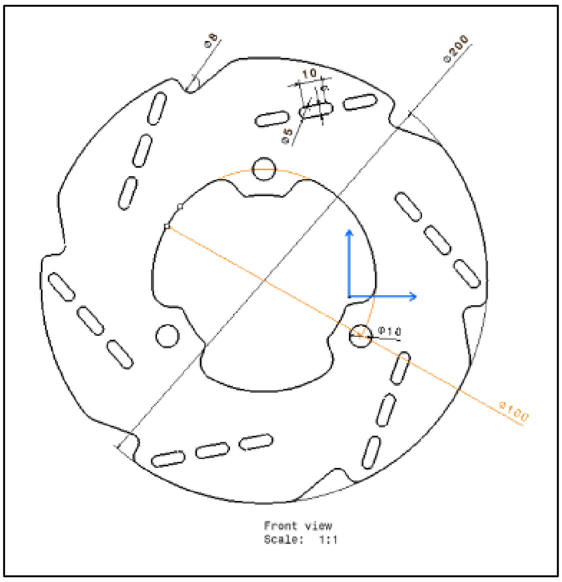

Fig. 4.1.2 CAD drawing of Rotor

V. Finite Element Analysis

The finite element method is the most widely used method for solving problems of engineering and mathematical models. Typical problem areas of interest include the traditional fields of structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential.

Here static structural and steady state thermal analysis has done by ANSYS 16.1

5.1 Meshing

Meshing is an integral part of the engineering simulation process where complex geometries are divided into simple elements that can be used as discrete local approximations of the larger domain. The mesh influences the accuracy, convergence and speed of the simulation. Mesh was created by mesh engine in ANSYS. Here the CATPART file from CATIA V5 R21 was imported with the diagrammatical values and start to mesh with the selected faces or else whole points are meshed.

5.2 Conditions

These conditions are the reference points which act as boundary conditions for calculating the results of the analysis. Forces acting on the rotor:

- Hydraulic pressure which is pushing the friction pad on the disc from the opposite sides
- The Hydraulic pressure = 1 MPa
- The disc brake rotor has been constrained at the bolt holes and the slotted part of the rotor is applied with rotational velocity of 205 rad/s (when the vehicle is moving at a speed of 100 km/h)

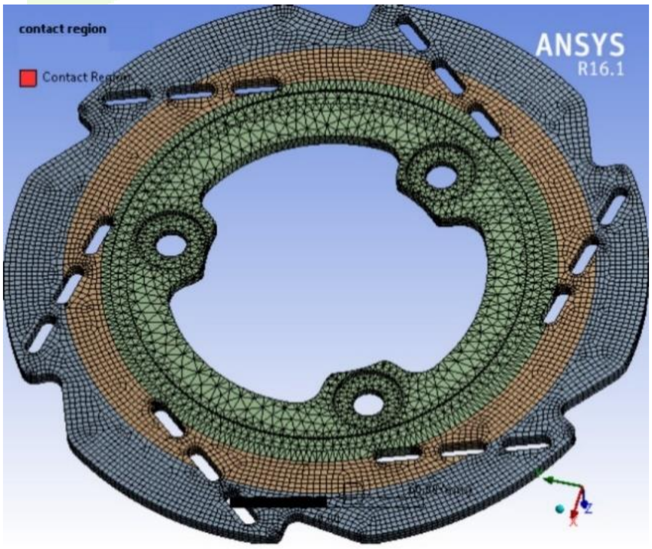

Fig 5.1.1. Disc Rotor Meshed in ANSYS

5.3 Material Data

Table 5.3.1

carbon ceramic > Constants

Density	2.45e-006 kg mm^-3
Thermal Conductivity	4.e-002 W mm^-1 C^-1
Specific Heat	8.e+005 mJ kg^-1 C^-1

Table 5.3.2

carbon ceramic > Tensile Yield Strength

Tensile Yield Strength MPa
40

Table 5.3.3

carbon ceramic > Isotropic Elasticity

Temperature C	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
	30000	0.28	22727	11719

5.4 Solutions

After the above process, the ANSYS software commutated results such as Total Deformation, Equivalent stress, Temperature and Total Heat flux of the optimized material like Carbon-Ceramic, which can be compared with other materials. This result would lead us to the conclusion of whether the optimized material will be compatible to increase the performance.

5.4.1 Stress and Total deformation

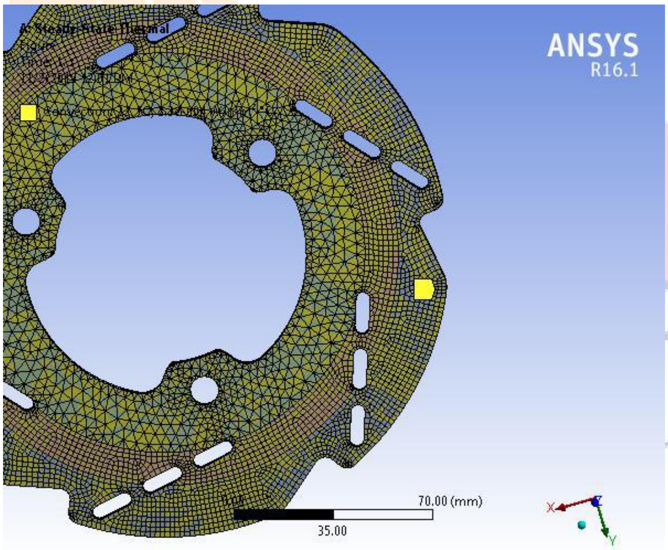

Fig 5.4.1.1. Rotor During Steady State

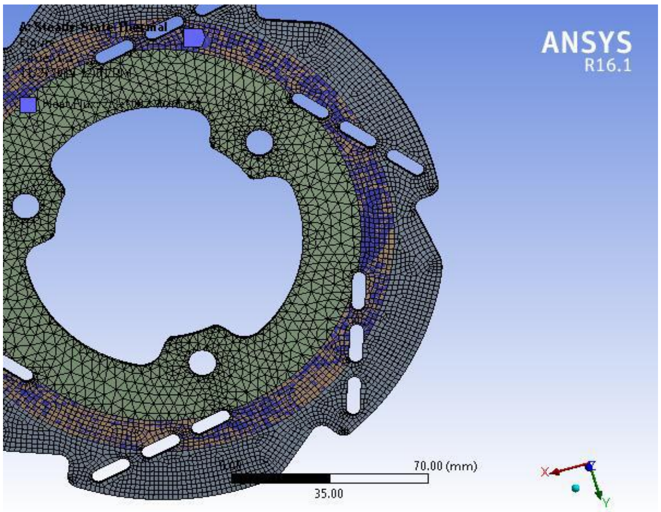

Fig 5.4.1.2. Total Deformation and Stress indication

Table 5.4.1.1. Result for Total Deformation

Time [s]	Minimum [mm]	Maximum [mm]
3.	0.	0.1211

Table 5.4.1.2. Result for Equivalent Stress

Time [s]	Minimum [MPa]	Maximum [MPa]
3.	0.58439	1464.3

.4.2 Temperature and Heat Flux

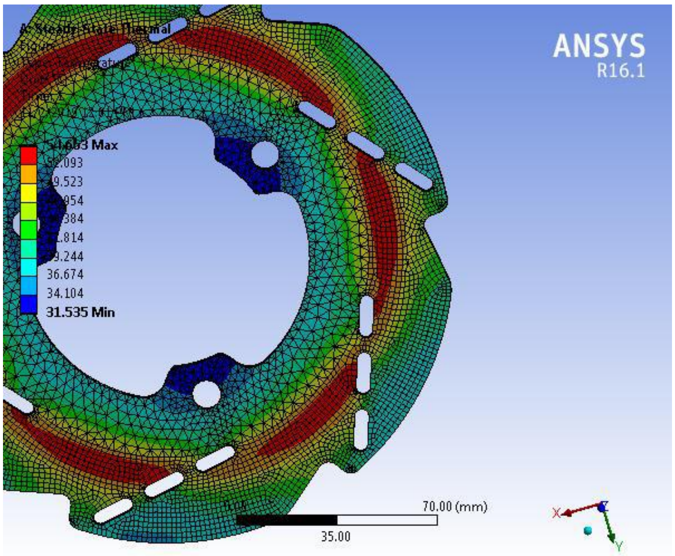

Fig 5.4.2.1. Temperature difference during application of brake

Table 5.4.2.1. Result for Temperature variation

Time [s]	Minimum [°C]	Maximum [°C]
1.	31.53	54.66

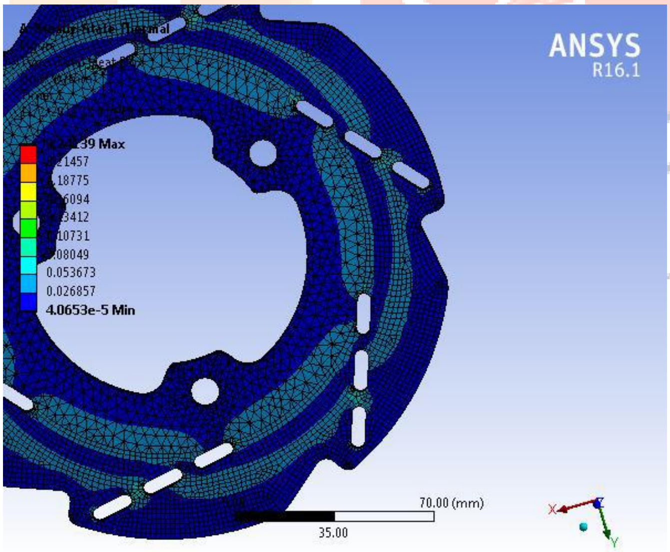

Fig 5.4.2.2. Heat Flux result

Table 5.4.2.2. Result for Total Heat Flux

Time [s]	Minimum [W/mm²]	Maximum [W/mm²]
1.	4.0653	0.24139

VI. CONCLUSION

The research possibilities for disc brake is very vast which is focused on performance improvement, reduction of cost and the development in design aspects and material. In real life an already existing material i.e. cast iron shows good performance which is tried and tested as compared to other materials but at times they tend to fail. Hence conventional materials are being replaced with better optimized material to improve the efficiency and performance especially in supercars.

An alternative solution is added to automobile braking system. The suitable material (Carbon-Ceramic) for the braking operation is selected and all the values obtained from the analysis are more effective in improving the performance of the brakes, also the petal design for the disc brake has resulted in better strength and rigidity.

Hence it is concluded that Carbon-Ceramic material can be used effectively as an alternative for Motorcycle Disc Brake System.

VII. Future Scope

With the above result and utilizing other references and journals, this research can be taken forward to fabrication and testing it in real time. It can also be improved by optimizing the design in such a way the rotor is reduced in weight yet staying rigid, and combination of different materials as alloys to test the strength and efficiency at the same time.

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