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# Design and Analysis of a Disc Brake Rotor Made of Aluminum Alloy

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**Abstract:** Automobiles have grown indispensable in our rapidly evolving environment. The dependability of a vehicle is just as important as its safety features. Disc brakes made of 6061 aluminium are the focus of this project's design and study. Solidworks is used for modelling, and for thermal and structural reasons, Finite Element Analysis is run as a coupled field. Disc brakes that generate frictional heat undergo a transient finite element analysis (FEA) study of the thermoelastic contact problem (ANSYS). Prior to the distribution of temperatures, there was the thermal analysis, and in structural analysis, the distribution of stresses is done using the Ansys analysis programme. It is possible to model the disc brake's thermoelastic behaviour under repeated braking conditions, which is a phenomenon that happens in disc brakes. In order to aid in the conceptual design of the disc brake system, the computational results for the distribution of heat flux and temperature on each friction surface between the contacting bodies are presented. The impact of material properties on the thermo elastic behaviours, specifically the maximum temperature on these surfaces, is also investigated. The investigation is carried out by contrasting the materials of grey cast iron and aluminium alloy 6061. Other properties, such wear resistance, are measured in accordance with ASTM guidelines. The acquired properties are contrasted with those of the preexisting material, grey cast iron. Compared to aluminium alloy 6061, grey cast iron performs better under thermoelastic circumstances.

**Keywords:** Aluminum alloy 6061, Grey cast Iron, Temperature distribution, stress distribution. Thermoelastic conditions,

## Introduction

The term "brake" refers to a mechanical device that is used to constrain motion by absorbing energy from a system that is moving. A moving vehicle, wheel, or axle can be slowed down or stopped, or it can be prevented from moving at all. This is performed by the use of friction, which is the most common method. In order to convert the kinetic energy of the moving object into heat, the majority of brakes make use of friction between two surfaces that are forced together [6-11]. However, alternative techniques of energy conversion may also be utilised. The callipers of a disc brake are used to apply pressure to pairs of pads that are pressed against a disc, also known as a "rotor," in order to facilitate friction. This action slows the rotation of a shaft, such as an axle attached to a vehicle, with the purpose of either reducing the speed at which the shaft rotates or holding it motionless. It is necessary to disperse the waste heat that is produced as a result of the conversion of motion energy [12-17]. In the same way that disc brakes have become an essential component of automobiles, they have also become an intrinsic feature of the automobile. The disc brake has rendered the usage of a variety of traditional techniques of braking ineffective in comparison to the disc brake [18-22].

When compared to the stopping power of the drum brake, the disc brake stops significantly more quickly. When compared to the drum brake, the disc brake takes up just a smaller amount of area and weighs significantly less. Heat is dissipated more efficiently by the disc brake than by any else. When inspecting disc brake systems, it is not necessary to remove the wheels from the vehicle [23-27]. Disc brakes are advantageous because, as they go through the process of warming up, the disc expands and moves closer to the pads. This means that you do not need to apply as much force to the pedal in order to get satisfactory braking. When we compared disc brakes to drum brakes, we found that disc brakes have superior anti-fade qualities. The design of these is pretty straightforward. Furthermore, when compared to the process of replacing friction lining in the drum brakes, replacing friction pads is a significantly simpler task. When it comes to drum brakes, flat friction pads are compared to curved friction lining. This results in uniform wear and a wider selection of friction materials to choose from [28-34]. In the event that it rains or if you drive over puddles, the drum brake has the potential to have water collected inside of it. In rainy situations, this can cause the drum brakes to function less effectively than they normally would [35-39].

Calculus differential equations and partial differential equations are examples of situations in which the employment of infinitesimally "differential elements" is defined by the phrase "finite element." It is a method for dealing with structural analysis, which is a complicated process by which it is quite challenging to obtain proper value in analysing. The utilisation of a greater number of smaller elements in MESH, as opposed to a few bigger elements, results in the production of accurate values [40-45]. In the process of doing complex shape analysis of stress, displacements, and support reactions, it provides a method that is quite sophisticated on its own. Instead of dealing with finite differential equations, finite element analysis (FEA) deals with complex boundaries, and its scope has been expanded by forty years [46-51].

Software design is the process by which an agent generates a specification of a software artefact that is meant to accomplish goals by utilising a set of primitive components that are subject to restrictions with the intention of achieving those goals. Either "all the activity involved in conceptualising, framing, implementing, commissioning, and ultimately modifying complex systems" or "the activity following requirements specification and before programming, as in a stylized software engineering process" are both examples of what can be referred to as "software design [52-57]." Problem-solving and the planning of a software solution are typically involved in the process of designing software. Low-level components, algorithm design, and high-level architecture design are all things that fall under this category.

**Literature Review**

Kumar et al. [1] investigate the static and thermal analysis of the disc brake by employing a variety of materials, including carbon fibre, S2 glass fibre, aluminium, and grey cast iron. The results of their investigation were examined using the Ansys software. Under order to carry out the study, a simulation of the pressure that is developing on the disc as a result of the application of the brake in real-time conditions is implemented. Comparisons and analyses are being performed on the heat flux capabilities of the materials as well as their heat dissipation capabilities. Additionally, the features such as wear resistance have been investigated. In this analysis, both vented and solid discs are taken into consideration. During the static analysis, it was discovered that grey cast iron contains the highest level of deformation, despite the fact that it is a material that is utilised in the industry for basic purposes.

In ANSYS, Ahirwar and Choubey [2] discuss the design and analysis of the disc brake rotor, which involves the use of a variety of materials. The materials that were utilised in the construction of this project are carbon fibre, titanium alloy, aluminium alloy, and grey cast iron. The primary goal is to lessen the amount of thermal distortion that occurs in the modular brake rotor components. In addition, it demonstrates that the effectiveness of the brake system is dependent on the behaviour of the brake when it is subjected to high temperatures. The stress comparison and the deformation comparison are currently being made, and graphs are being graphed, which will lead to the conclusion that carbon fibre will be the material of choice for the disc brake rotor in the future. The process of analysing a braking automobile in real time is the focus of this investigation. In addition to this, the maximum deformation of the materials is being measured and compared to the material that is already there.

The design and thermal analysis of a disc brake rotor made of aluminium alloy 2014 is investigated for its temperature distribution features. This study was conducted by Maneiah et al. [3]. A piece of software called NX9 is being used to perform the analysis on the models. During the finite element analysis, the thermal properties of the aluminium alloy are compared with those of mild steel for a variety of different numbers of elements. The temperature distribution at various radii is also analysed in this comparison.

The research conducted by Ramanajanyulu et al. [4] focuses on the design and analysis of the disc brake rotor in ANSYS, utilising a variety of materials based on their composition. The materials that were utilised in the construction of this project include structural steel, stainless steel, grey cast iron, and aluminium alloy 5083-H116. For the modular brake rotor, the primary goal is to limit the amount of heat and stress that it experiences. In addition, it demonstrates that the effectiveness of the brake system is dependent on the behaviour of the brake when it is subjected to high temperatures. The stress comparison and the deformation comparison are currently being made, and graphs are being graphed, which will lead to the conclusion that carbon fibre will be the material of choice for the disc brake rotor in the future. The process of analysing a braking automobile in real time is the focus of this investigation. In addition to this, the maximum deformation of the materials is being measured and compared to the material that is already there.

An investigation of the mechanical performance and analysis of comparison of various materials, including alloy steel, cast iron steel, and aluminium alloy 1060, was carried out by Nathil and Charyulu [5]. The primary purpose of the investigation is to recreate the disc brake under a variety of mechanical circumstances using a variety of material qualities. It has been determined that the stress experienced by cast iron and aluminium alloy is comparable to one another.

## Research Gap

The discipline of engineering is currently seeing a significant amount of study and the development of new inventions in the material. Additionally, the analysis brings about the most significant revolution in the world of engineering. Therefore, as part of a research project, we will be conducting the analysis of the material. The numerous materials are evaluated using a variety of techniques, and they are discovered for use in a wide range of engineering applications. During the process of determining the possibilities for the disc rotor material, the static conditions are considered, while the dynamic conditions are forgotten about. It is not possible to make use of linked thermoelastic properties or to conduct an analysis where friction characteristics between the rotor and the brake pad are taken into consideration. As a result, we conducted extensive study and analysis on that material, and now we are going to use the finite element analysis method to investigate this material in order to determine its mechanical and thermal behaviour under dynamic situations.

## Material Selection And Fabrication

The discipline of engineering is currently seeing a significant amount of study and the development of new inventions in the material. Additionally, the analysis brings about the most significant revolution in the world of engineering. Therefore, as part of a research project, we will be conducting the analysis of the material. Numerous materials are discovered for use in disc brake applications, and these materials are investigated using a variety of techniques. A trend that has been developing in the design business over the past few years is the utilisation of materials that are lighter in weight. Aluminum has been the subject of investigation by a great number of researchers as a potential replacement material due to the fact that it has a low density and excellent structural and thermal qualities. The use of various grades of aluminium has been investigated, however it has been discovered that the use of aluminium 6061 is lacking in comparison to other grades [58-66]. The production of composites made of aluminium has been the subject of research, and the findings indicate that aluminium composite can be suggested in situations when cost is not a consideration. However, the industry requires that the material be readily available and inexpensive in order to meet its requirements. On the other hand, aluminium 6061 might be a suitable substitute. As a result, we conducted extensive study and analysis on that material, and now we are going to use the finite element analysis method to investigate this material in order to determine its mechanical and thermal behaviour [67-73].

## Design Procedure

If we want to solve the analysis, we use ANSYS 15. We begin by designing the three-dimensional geometry in

SOLIDWORKS 13 using the precise dimensions of the model that is already in existence. After that, we make an effort to introduce material data for grey cast iron and aluminium alloy 6061 in a separate manner. Through the utilisation of SOLIDWORKS, the precise dimensions of the brake pad and brake rotor are modelled by utilising the material that is already there [74-81]. After being assembled in the Solidworks assembly platform, the modelled brake rotor and brake pad are then imported into the Ansys workbench for the purpose of conducting an analysis for thermal and static stresses (Figure 1).

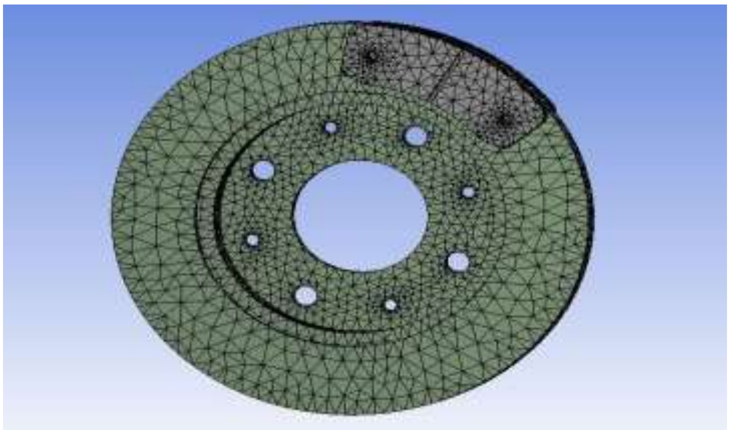

**Figure 1:** Mesh (Internet Source )

#### Experimental Method

An device known as a tribometer is used to measure tribological quantities between two surfaces that are in contact with one another. These quantities include the coefficient of friction, the friction force, and the wear volume. A bouncing ball, also known as a ball on a disc tribometer, is nothing more than a ball that is struck against a surface at an angle [82-89]. In the course of a typical test, a ball is moved along a track at an angle until it collides with a surface and then bounces off of the surface. The ball and the surface come into contact with one another, which causes friction to be formed. This friction causes a horizontal force to be exerted on the surface, while the ball experiences a rotational force [90-96]. Find the rotational speed of the ball by utilising high-speed photography or measure the force on the horizontal surface to get the frictional force. Both of these methods are used to determine the frictional force. Due to the significant instantaneous force that is created by the collision on the ball, the pressure that is present in the contact is extremely high [97-105].

A simulation of any given physical phenomenon is what is known as a finite element analysis (FEA), and it is accomplished through the use of a numerical approach known as the finite element method (FEM). Fracture element analysis (FEA) is a numerical method that is used to forecast how a part or assembly will react under specific conditions. For the purpose of assisting engineers in locating weak spots, places of tension, and other parts of their designs, it serves as the foundation for contemporary simulation software [106-112]. In most cases, the outcomes of a simulation that incorporates the finite element analysis (FEA) technique are shown by means of a colour scale that illustrates, for instance, the pressure distribution over the item.

#### Comparative Analysis

The ANSYS simulation is obtained by repeated brake applications in order to explore the behaviour of disc brakes in terms of transient thermoelastic analysis. In point of fact, the variation in the spinning speed that occurs while braking is something that must be determined by the mechanics of the vehicle. The rotational speed of the disc, on the other hand, was believed to be a known value throughout the course of this investigation. This figure illustrates the temporal history of the hydraulic pressure P and the angular speed ω that are assumed to be present during the brake cycle. Braking (for 4.5 seconds), acceleration (for 10.5), and driving at a constant speed are the components that make up one cycle (5 sec) [113-121]. It was assumed that the hydraulic pressure P would build linearly to 1 Mpa by 1.5 seconds in each operation, and then it would remain constant till 4.5 seconds came around. It was also assumed that the angular velocity ù would decrease in a linear fashion, and it would eventually reach zero at 4.5 seconds. When doing the computations, the time step $\Delta t = 1$ second was utilised. When calculating the heat convection coefficient, the formula h = 100 w / m2K is widely used. The investigation is carried out for two distinct rotating rates of the rotor, namely 145 and 241.55 revolutions per second [122-127].

Temperature

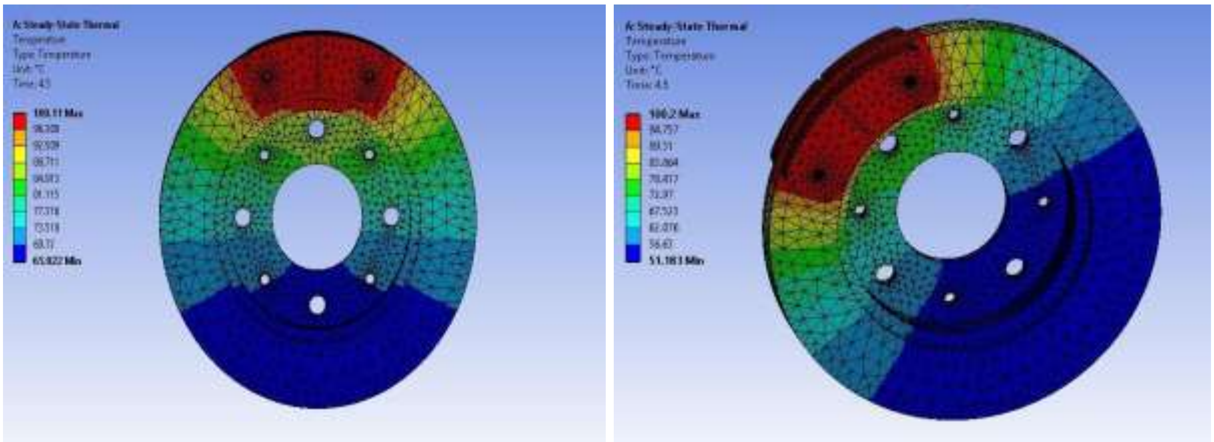

**Figure 2**: Temp of AL6061 and GCI (Internet Source )

In order to imitate the formation of heat, the temperature that was applied to the inner walls of the crack had to be high enough. It was discovered that the maximum temperature that was achieved was nearly same for both Al6061 and GCI at approximately 1000 degrees Celsius (Figure 2) [128-132]. However, the highest temperature that can be reached in aluminium is lower than the maximum temperature that can be reached in grey cast iron. When compared to grey cast iron, the overall heat flow of AL6061 is somewhat lower. The highest value that can be achieved by Al6061 is 3672.9 W/mm2, while the greatest value that can be achieved by grey cast iron is 3635.7 W/mm2 (Figure 3).

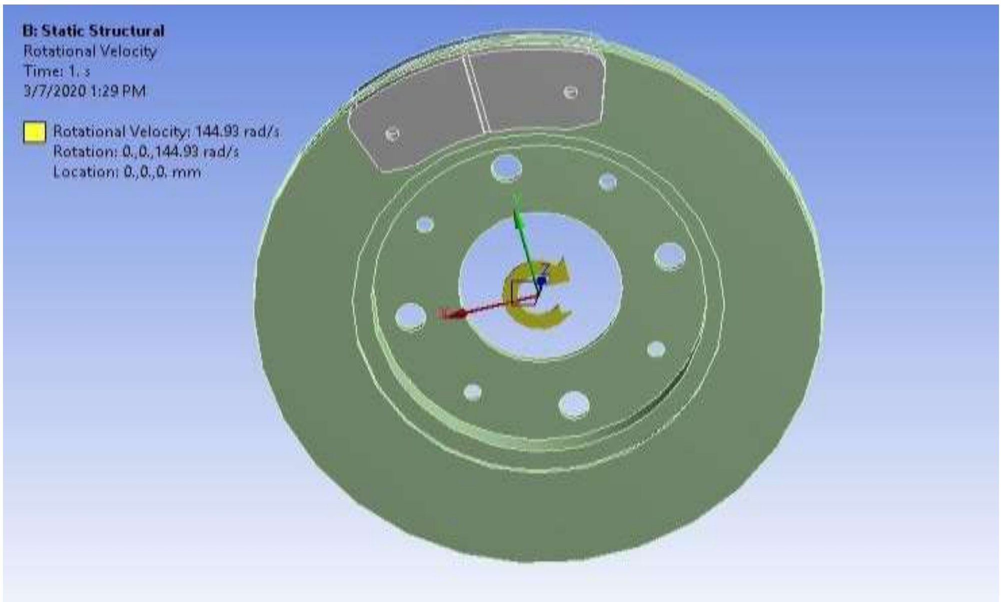


**Figure 3:** Boundary Condition at 60 kmph (Internet Source )

**Sample 1** Load: 5N Speed: 300 rpm Time: 900 sec

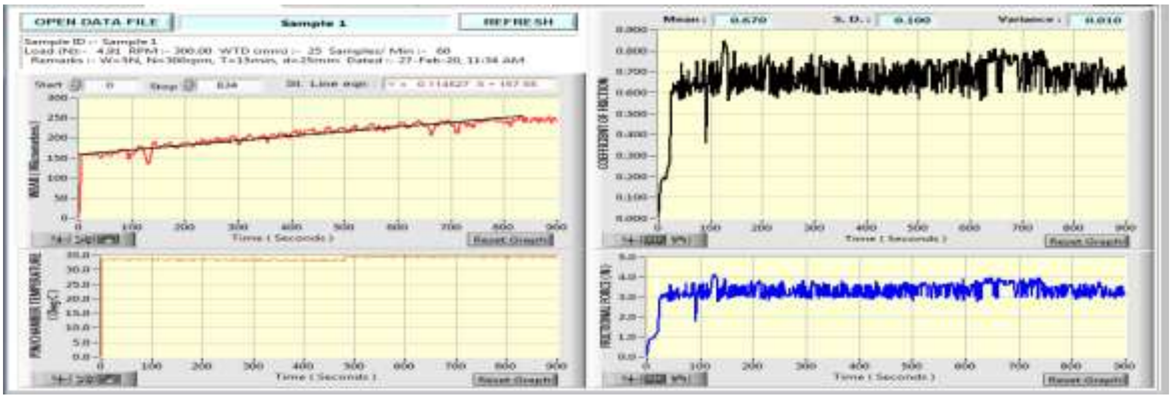


**Figure 4:** Tribological properties at 300 rpm Mean coefficient of friction: 0.670

Mean frictional force: 3.5 N

Wear property gradually increases from 150 micrometres at 1 sec to 250 micrometres at 850 sec.

**Sample 2** Load: 10 N Speed: 500 rpm Time: 900 sec

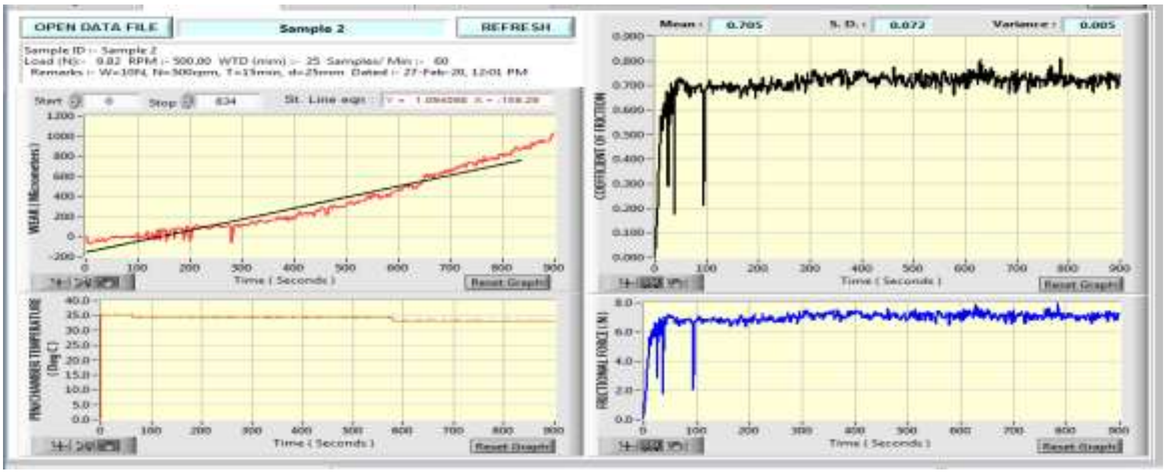


**Figure 5:** Tribological properties at 500 rpm Mean coefficient of friction: 0.705

Mean frictional force: 7 N

Wear property gradually increases from 0 micrometres at 1 sec to 1000 micrometres at 900 sec.

**Sample 3** Load: 15N Speed: 850 rpm Time: 900 sec

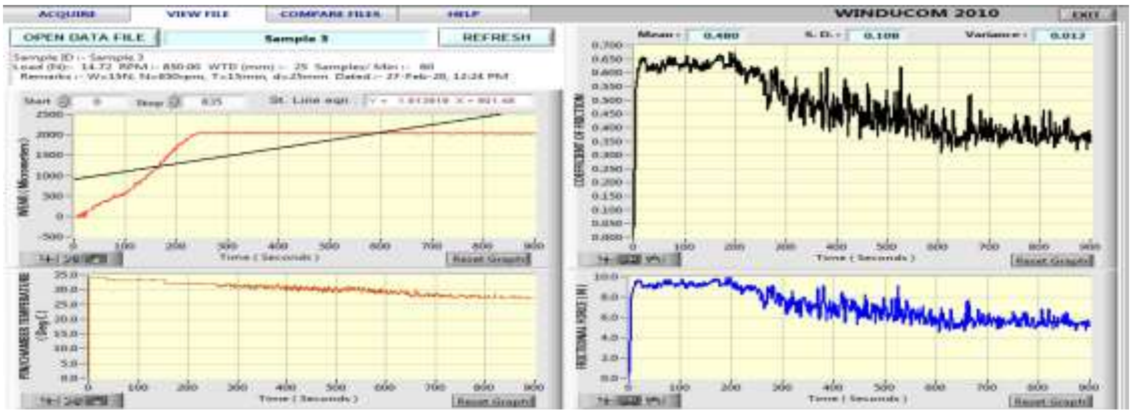

**Figure 6:** Tribological properties at 850 rpm Mean coefficient of friction: 0.480

Mean frictional force: 6.5 N

Wear property gradually increases and becomes near constant 200 micrometres from 200 sec to 900 sec.

**Table 1: Mass loss characteristics**

| Sample | Load (N) | Speed (rpm) | Time (sec) | Ball mass loss (grams) | Disc mass loss (grams) |
|---|---|---|---|---|---|
| 1 | 5 | 300 | 900 | 0.0013 | 0.0281 |
| 2 | 10 | 500 | 900 | 0.0004 | 0.0556 |
| 3 | 15 | 850 | 900 | 0.0010 | 0.1616 |

**Table 2: Wear test readings**

| Sample | Load (N) | Velocity (m/s) | Speed (rpm) | Ball mass (grams) | | Disc mass (grams) | |
|---|---|---|---|---|---|---|---|
| | | | | Before | After | Before | After |
| 1 | 5 | 0.39 | 300 | 4.0734 | 4.0721 | 22.6309 | 22.6028 |
| 2 | 10 | 0.654 | 500 | 4.0720 | 4.0713 | 24.6956 | 24.64 |
| 3 | 15 | 1.112 | 850 | 4.0739 | 4.0729 | 25.6850 | 25.5234 |

Upon examination of the aforementioned data (Figures 4 to 6 as well as Tables 1 and 2), it has been determined that the wear rate of the specimen becomes nearly constant as the speed of the specimen increases. The disc mass loss that occurs as a result of wear rises in a manner that is both nonlinear and proportionate to the corresponding speed and load, as shown in the tables [133-139].

## Result & Discussion

Under thermoelastic circumstances, the grey cast iron material possesses superior qualities to those of the aluminium alloy. These superior properties may be seen in the areas of equivalent stress, deformation, and frictional characteristics including frictional stress and sliding distance [140-141]. When it comes to steady state thermal values, grey cast iron and aluminium alloy are practically same in terms of their thermal properties. However, aluminium alloy is slightly lower than grey cast iron in terms of its thermal characteristics. At last, we conduct an analysis of the graph by contrasting the deformation, stress, and heat flow of every sample prior to the application of each individual load. When both the load and the speed are increased, the wear in aluminium alloy becomes closer and closer to being constant. Both the rotational speed and the load that is being applied to the ball cause an increase in the frictional force. Additionally, the frictional force increases as the rotational speed increases. With ball loads of 10 N and 15 N, it obtains a mean value of 6.5 N. This is the maximum value. In a similar manner, the ball mass loss looks to be gradually growing as the load that is currently being applied to the disc grows. The results of the ball-on-disc experiment indicate that the wear rate appears to remain constant in aluminium as the speed of the disc increases, whereas it increases in grey cast iron over the same time period. Because of the increased stress on the ball and the increased speed of the disc, the temperature of the pin and chamber likewise drops.

## Conclusion

Based on the comparison between the simulation and the graph that was acquired through analysis, we have come to the conclusion that aluminium is suitable for use in thermal analysis due to the fact that it possesses favourable thermal properties. In the process of comparing the static analysis in the journals that were included in the literature review, it was discovered that the deformation in aluminium was significantly lower. As a result, it is ideal to make use of aluminium. Nevertheless, when compared with the thermoelastic qualities, the deformation and the sliding distance are more in aluminium than they are in grey cast iron. In order to get around this issue, it is important to adjust the braking pressure and friction of the brake brake. It would appear that grey cast iron possesses superior thermoelastic qualities; hence, it is suitable for use in the construction of heavy vehicles due to its low-stress properties. Despite this, aluminium can be utilised in low-weight vehicles, particularly two-wheelers, due to the fact that it has a high coefficient of friction. Grey cast iron is recommended for use in general-purpose applications, taking into consideration the generic material.

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