

INVESTIGATION ON TRIBOLOGICAL BEHAVIOR OF SILICON IN AUTOMOTIVE BRAKE PAD

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Engineering degree in Automobile Engineering

By

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SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with Grade "A" by NAAC

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the Bonafide work of **MUTHUPANDI K (39860013)**, **ANTONY MARSHALL R (39860006)** who carried out the project entitled **“INVESTIGATION ON TRIBOLOGICAL BEHAVIOUR OF SILICON IN AUTOMOTIVE BRAKE PAD”** under my supervision from June 2022 to April 2023.

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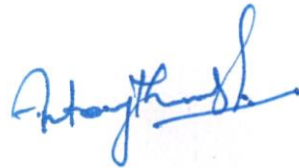
DECLARATION

We, **MUTHUPANDI K (Reg. No.39860013)** and **ANTONY MARSHALL R (Reg. No.39860006)** hereby declare that the Project Report entitled **“INVESTIGATION ON TRIBOLOGICAL BEHAVIOR OF SILICON IN AUTOMOTIVE BRAKE PAD”** done by us under the guidance of **Mr. E. Manoj, ME.**, is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Automobile.

DATE: 26-04-2023

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1.



2.



SIGNATURE OF THE CANDIDATE

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ABSTRACT

One of the most crucial systems in the automotive industry is the brake pad. A brake pad was made with n incredible ingredients. In this case, silicon is crucial to the performance of brake pads. We get three mechanical and tribological characteristics by varying the silicon content by 5%, 10%, and 15%. Discovering tribological qualities is what we aim to do using pin and disc tribometer. This shows that rather than on basic knowledge, the choice of brake friction materials is more reliant on custom and experimental trial and error. The article aims to dispel any doubt by outlining the advantages and disadvantages of the typical components and construction found in modern dry.

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CHAPTER 1

INTRODUCTION

The brake pad is among the most crucial elements of any car's braking system. Brake pads are constructed from steel backing plates and contain friction material as well. There are several objectives that the brake pads' composition may fulfil. Even little concentration changes of 1% or 2% can have an influence on the performance of the selected brake pad friction compound for the intended application. This study mainly concentrates on analyzing tribological behavior of Silicon in automobile brake pad friction material by modifying the composition of Silicon, generating samples, comparing behavior characterization by testing, and other approaches. (1)

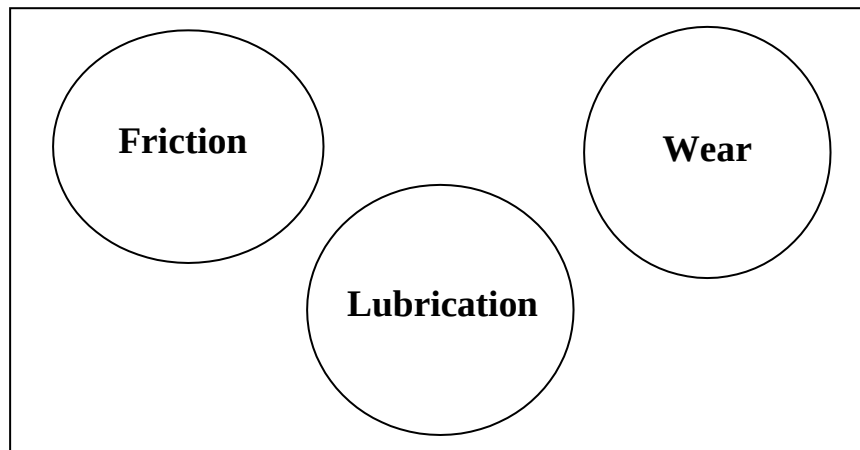


Figure: 1.1 Concept of Tribology

1.1 BRAKE PAD

The brake pad is the brain of any modern disc braking system. A typical disc braking system (Figure 1.2) consists of a wheel-mounted rotor disc and a calliper assembly that squeezes the disc in between a set of brake pads. For structural stability, brake pads' friction material and steel back plates are frequently assembled together. As the rotating rotor disc is squeezed between a pair of brake pads, friction force is created and kinetic energy is converted into heat energy. The automobile therefore slows down and comes to a stop. The rotor disc is commonly made of grey cast iron. SAE requirements With the defined value range of hardness, chemical composition, J431 G3000 is used for light commercial vehicles and residential automobiles because it has the tensile

strength and other qualities that are needed (LCV). The friction material used in brake pads for domestic cars is a combination of several constituent materials, such as Coke, Silicon, Bronze powder, Vermiculite, Phenolic Resin, Steel fibres, Rubber particles, Friction dust, Silica, Aramide fibres, etc., mixed in varying proportions. (2)



Figure: 1.2 A typical Disc Brake system with Brake pads

1.2 BRAKE PAD MATERIAL CLASSIFICATION

A broad categorization of brake pad friction material is provided by the list below (Figure 1.3):

1. Non-metallic components
2. Materials made of semi-metals
3. Totally metallic substances
4. Ceramic components

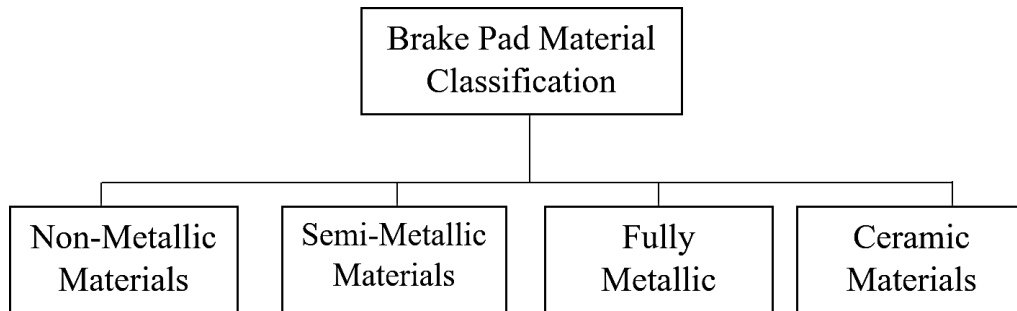


Figure: 1.3 Classification of Brake pad friction materials

1.2.1 Non-metallic materials

In order to provide the appropriate physical, mechanical, and braking properties, non-metallic materials are made up of a range of synthetic materials, such as synthetic resin, Aramid fibers, sintered glass, and other polymers, combined in different ratios.

1.2.2 Semi-metallic materials

Semi-metallic materials are created by combining metal flakes with other synthetic materials. They are more durable than non-metallic materials. They are more resistant to fading and more resilient. They need greater actuation force than non-metallic materials, and eventually the rotor disc may wear out more quickly as a result.

1.2.3 Fully metallic materials

Fully metallic materials are regularly used in sports racing automobiles. They are made of sintered steel, with no synthetic materials at all. During braking, the rotor disc creates more noise due to its extremely high wear rate. They require more braking force.

1.2.4 Ceramic material

Ceramic brake pad materials are made from clay, porcelain, and copper flakes. Ceramic brake pads are more prone to warpage due to their poor heat dissipation properties. Yet, their brake fade is modest and their friction is steady. (3)

1.3 MATERIAL CHARACTERISTIC REQUIREMENTS OF BRAKE PAD

The following are some crucial qualities that a good brake pad friction material must have

- a. The material's resistance to brake fade
- b. compatibility with brief exposure to moisture
- c. capacity to maintain friction coefficient across a variety of environmental circumstances
- d. Improved heat dissipation capabilities
- e. Reduced braking noise (4)

1.4 OBJECTIVE OF THE STUDY

- i. Sample brake pad pins will be made by varying the amount of silicon material in different proportions along with suitable binder, filler, and friction materials using the powder metallurgy manufacturing method, which entails particle size reduction through the ball milling process, compression moulding, and with the necessary temperature.
- ii. To compare the mechanical and tribological characteristics, as well as the mechanical and tribological testing methods used to characterise sample brake padpins. (5)

CHAPTER 2

LITERATURE SURVEY

Bulent Ozturka (2015) In the current work, ceramic and basalt fibres were used to create hybrid friction materials. Basalt fibre percentage varied from 0 to 40% while ceramic fibre content remained constant at 10%. Using a pin-on-disc type apparatus against a cast iron counterface, the mechanical properties, friction, and wear characteristics of friction materials were evaluated. The sliding speeds were 3.2-12.8 m/s, the disc temperature was 100-350°C, and the applied loads were 312.5-625 N. SEM analysis was performed on the specimens' scratched surfaces. The mechanical and tribological characteristics of the composites are significantly influenced by the fibre content, according to experiments. With increasing extra basalt fibre content, the hybrid friction materials' friction coefficient rose. Nevertheless, the specific wear rates of the composites increased again above this value after decreasing up to 30% vol% fibre content.

I. Mutlu (2013) The brakes are often constructed of a variety of materials, including phenolic resin, copper powder, barium sulphate, aluminium oxide, etc. A pin-on-disc type wear tester and 20 specimens with various component compositions were created for this investigation. The specimens' friction and wear properties in relation to a cast iron disc were investigated. Moreover, SEM was used to characterise the microstructure of the braking pads, and it was also used to look at how temperature and pressure affected the pads' behaviour at temperatures between 50 and 400°C and 1050 and 3000 kPa. Lastly, oil, braking liquid, saltwater, and water were used to study how the environment affected the pads.

Peter Filip (2017) The complexity of friction phenomena in polymer matrix composites has been explored, and the processes behind friction are still not fully understood. In this study, we characterise the production of friction layers and relate their characteristics to the performance of a new class of polymer matrix composites. Material's friction performance is determined by the friction layer's characteristics. The friction layer that is produced on the friction surface is notably different from the bulk in terms of structure and chemical composition. The mechanical-chemical interaction that occurs during the friction process is contrasted with a "non-friction" scenario in which the identical material was subjected to "similar" apparent temperature and compressive pressure.

Min Hyung Cho (2014) To test the impact of components on various elements of friction qualities, a brake lining with 16 compounds was examined. The composite contains conventional components for commercial brake friction materials and was designed as a non-asbestos organic based friction compound for an automobile braking system. 32 distinct friction material specimens were created using an experimental design and a basic recipe. Using a scaled friction tester, the effects of the constituents were investigated on wear rate, fade (loss of friction), friction-induced vibration, and noise propensity. Our analysis demonstrated that the specimen had low noise propensity and high porosity and compressibility. The results also shown that while cashew resin decreased the incidence of noise, friction materials with larger amounts of phenolic resin, rockwool, zirconium silicate (zircon), MgO, and Ca(OH)₂ had a significant noise tendency. The relative proportions of magnesia, rockwool, calcium hydroxide, and zirconium silicate had a significant impact on the wear resistance of the friction material.

Yafei Lu (2019) The capacity of the raw materials to enhance the wear characteristics of the mixture via two-phase friction composites was researched, and the raw materials used in automotive friction formulations were categorised using a combinatorial technique into two categories. The softer additions (graphite, MoS₂, and Twaron), harder additives (Al₂O₃, steel wool), and organic binder are all part of group one, which increased wear resistance (benzoxazine).

W. Osterle (2011) examined that The surface of a typical brake pad material was subjected to braking simulation tests, and the chemical and microstructural changes that occurred there were primarily studied using scanning and transmission electron microscopy and surface analytical methods. It has been demonstrated that patches of a third body material, made up of a mixture of all the components of the pad and iron oxides from the disc, form. The primary phase of the pad material, barite, still maintains a crystal structure in the milled debris particles, but the grain size has been dramatically reduced to the nanometer range. The primary wear process is the separation of the filler particles from the organic binder, which is aided by regional phenolic resin degradation during asperity heating.

Mikael Eriksson (2012) The tribological contact in car brakes, according to research, entails dry sliding contact at high speeds and large contact forces. The often utilised organic binder-type brake pad friction compounds have relatively low bulk strengths and are highly inhomogeneous. Despite their modest strength, the pads' unique contact surfaces that develop during usage provide them excellent wear and friction properties.

Mikael Eriksson (1999) explained how, despite numerous studies conducted over the years to shed light on the causes of vehicle brake squeal, the phenomena is still not completely understood. This study focuses on the relationship between brake pad surface topography and the occurrence of squeals, a topic that was almost untouched up until now. In a unique test apparatus, two sets of brake pads underwent brake testing. Both pads are of the metal-fiber reinforced organic variety; the first has a production-standard composition, while the second has been significantly modified for improved high-speed performance. After stopping the testing under both quiet and screaming situations, the brake pad surfaces were characterized.

T. P. Newcomb (2018) the primary categories of friction brakes are described. A section on friction and wear behavior is presented after discussions of friction materials, their composition, fabrication, testing, and selection. Lastly a glance at potential future advancements.

Jayashree Bijwe (2010) Asbestos usage prohibitions have prompted calls for the replacement of traditional asbestos-ased friction products. More effective friction materials for vehicles without asbestos have been developed as a result of research in this area during the past ten years. Fiber reinforced polymers have a lot of potential for use in modern cars. The latest advancements in the usage of composites as friction materials are the main subject of this review study. Brief descriptions of brakes, their function, braking materials, desirable properties, etc. are provided in the article's first section. The second section discusses the most recent advancements in friction materials with non-asbestos fibre reinforcement.

Collegium Ramazzini (2002) The Collegium Ramazzini argues for an immediate ban on all asbestos mining and usage in order to reduce the burden of sickness and death brought on by asbestos exposure across the world. The prohibition must be implemented

globally and have an international reach in order to be effective. A severe occupational and environmental danger is asbestos. Almost 200,000 fatalities in the United States have been attributed to asbestos, and millions more will follow globally.

Bhabani K (2002) In this study, abrasive wear research on different phenolic resin-filled composites containing alumina powder are discussed. These composites are then abrasively worn against silicon carbide paper in dry, single-pass conditions. The orthogonal experimental design approach was used for the data analysis. Studying how factors like filler concentration, load, sliding speed, and abrasive particle size affect the abrasive wear performance of composites made of phenol-formaldehyde was the goal. The data was subjected to regression analysis in order to create equations for the composites that described the wear volumes of the specimens in terms of the simultaneous contribution from the impact of load, abrading particle size, sliding speed, and their interrelationships. It was established that load was the one of these parameters that affected the wear of these composites the greatest. The chosen operating circumstances appeared to have the least impact on the sliding speed's impact on wear performance.

CHAPTER 3

AIM AND OBJECTIVE OF THE PRESENT INVESTIGATION

3.1 Aim

Silicon is used in vehicle brake pads to increase the braking system's overall performance and safety. In comparison to conventional brake pad materials like asbestos and ceramic, silicon offers improved thermal stability, wear resistance, and lower noise levels. Additionally, the use of silicon in brake pads aids in lowering the production of brake dust, which can have a negative impact on the environment and eventually lead to decreased braking performance. Automotive makers may give drivers a safer, more dependable, and environmentally friendly braking system by adding silicon into brake pads.

3.2 Objective

- To fabricate the brake pad pin by friction as a friction material with different compositions of 5%,10%,15% of silicon.
- To compare the mechanical and tribological properties.
- Minimize brake dust: Silicon reduces the amount of brake dust generated during braking, which not only helps to keep the wheels and tires cleaner, but also reduces the risk of respiratory problems and other health issues associated with brake dust.
- Increase environmental friendliness: By reducing brake dust, using silicon in brake pads helps to reduce the environmental impact of driving, as well as improving the overall sustainability of the automotive industry.
- Enhance durability: Silicon in brake pads increases the wear resistance and thermal stability of the pads, reducing the risk of brake fade, glazing, and other issues that can affect brake pad durability.
- Reduce noise and vibration: Silicon has excellent damping properties, which helps to reduce brake noise and vibration, resulting in a quieter and more comfortable driving experience.

3.3 PROBLEM IDENTIFICATION

- Due to its superior frictional properties on a range of surfaces and climates, asbestos material was once used in brake pads.
- Nevertheless, research into other materials and compositions started since asbestos is detrimental for the environment.
- There is a lot of study being done to find out more about the tribological behaviour of brake pad materials. Thus yet, only a small number of material combinations have been found.
- Thus, it is important to experiment with innovative material combinations and learn about their tribological to understand and come up with a better response. (6)

CHAPTER 4

METHODOLOGY

The following flow chart illustrates how this research was intended to be carried out and the mechanical and tribological analyses of the friction materials used in brake pads were studied. (7)

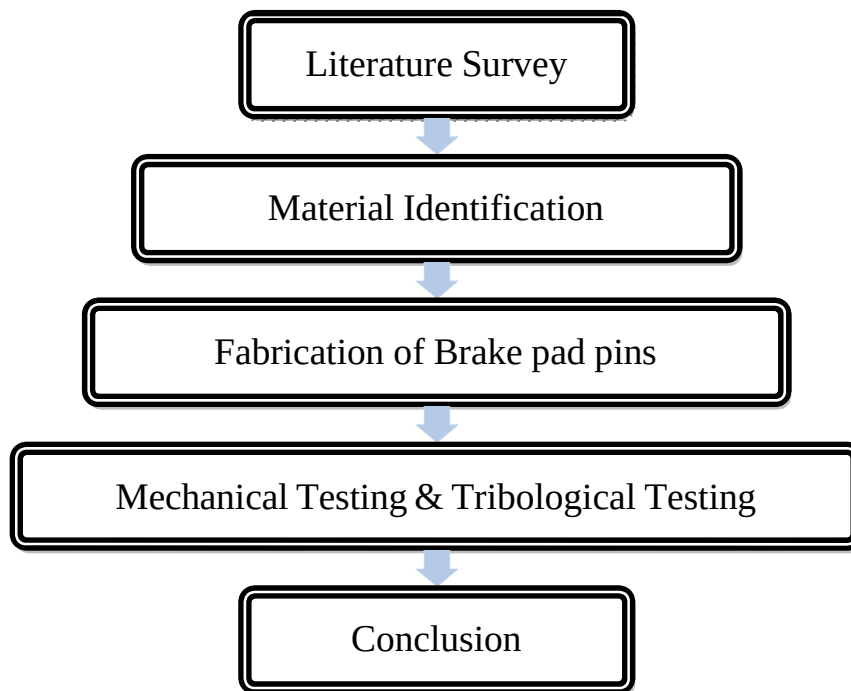


Figure: 4.1 Methodology

A thorough literature examination was done to find out more about the current status of brake pad friction material development activities as well as prior field research and development work. Based on the literature study, a suitable material composition for brake pad friction was identified for the development of sample brake pad pins. Mechanical and tribological testing activities were carried out to investigate the tribological behaviour of brake pad friction material, and the results are provided in the conclusion. (8)

CHAPTER 5

MATERIALS AND METHODS

Based on the review of the literature, it is evident that a composite of several materials in small proportions, where each material plays its individual or combined roles such as friction material, binding material, fillers, lubricants, etc., achieves the desired characteristics and performance of brake pad friction material.

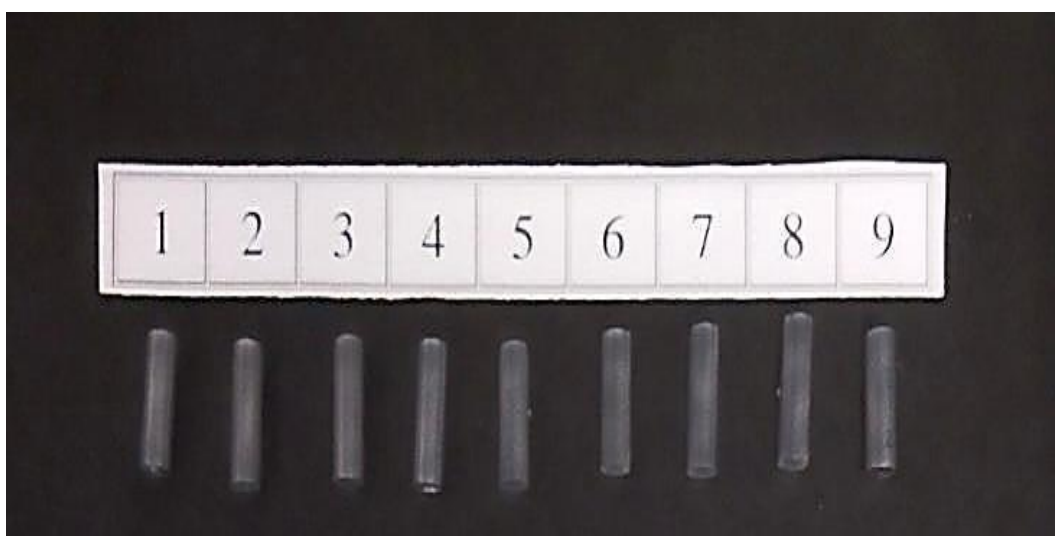
Table (5.1) below lists the materials used for our brake pad along with their purpose, and Table (5.2) lists the materials utilised to make three sets of sample brake pad pins, S1, S2, and S3, together with their weight ratios. (9)

Table: 5.1 Classification of brake pad material

Function	Raw materials
Lubricant	Graphite
Reinforcement Fibre	Steel fibres
	Aramid
	Glass Fibre
	Carbon Fiber
Filler	Cashew Dust, Barium Sulphate, Coke
	Vermiculite
Additives	Silicon
Binder	Phenolic

Table: 5.2 Material selected for fabrication of brake pad material

Constituent materials	Sample 1 [S1] % by Wt.	Sample 2 [S2] % by Wt.	Sample 3 [S3] % by Wt.
Silicon	5	10	15
Steel fibres	5	5	5
Rubber particles	5	5	5
Cashew Dust	5	10	5
Silicon	5	5	5
Barium Sulphate	15	5	5
Coke	20	20	20
Bronze powder	15	15	15
Vermiculite	15	15	15
Phenolic resin	10	10	10



Silicon

Due to its lubricating properties, silicon greatly enhances braking comfort and quietness by regulating the braking impact of the friction material. The high heat conductivity properties of silicon are very advantageous for friction linings. Silicon transforms kinetic energy to thermal energy in brake pad materials. The related brake material consistently blends various components. You may lessen braking noise and wear, increase braking comfort, and strengthen your brakes' resistance to oxidation and cyclic temperature stress by integrating silicon into the friction material of the brake pads.

Coke

Coke powders are used as friction reducers. To reduce weight, Coke utilises a filler with a low specific weight. The requisite total carbon by volume concentration is established (Silicon and coke). It reduces fading. It also reduces friction material degradation and wear.

Bronze

Bronze is an alloy formed of copper with around 12 to 12.5% tin, along with other metals (such as other metals like aluminium, manganese, nickel, or zinc) and occasionally non-metals, such as phosphorus, or metalloids, such as silicon or arsenic. Strength, ductility, and machinability are improved by these additions.

Vermiculite

Mica-like in appearance, vermiculite is a mineral from the phyllosilicate class. Essentially a hydrated phlogopite mica, vermiculite has the peculiar exfoliating property of expanding to many times its initial volume when heated.

Phenolic resin

Brake pads are produced from phenolic resin because of its exceptional heat stability. As a result of the friction and abrasion that brake pads are subject to, their temperature rises significantly. Thus, the temperature resistance of the phenolic resin, which is used to create brake pads, is essential. The entire aromatic structure of phenolic resin gives it excellent thermal stability, exceptional chemical resistance, and very little water absorption.

Steel fibres

Steel fibres are isolated, discrete, small strands of steel that have a length to diameter ratio ranging from 20 to 100 with different cross-sections. Steel fibres are utilised as reinforcement in the friction material for brake pads.

Rubber particles

Rubber granules are utilised to improve friction and lessen brake noise. Moreover, it increases the brake pad friction material's ductility and durability.

Cashew Dust

Cashew dust is frequently used as a friction dust. It functions as a dampener and enhances friction stability. Impact load is greatly decreased. Moreover, it has softening properties. It is made from liquid obtained from cashew nuts.

Silicon powder

When silicon is pulverised into a fine powder, it is called silicon powder. Similar to carbon and tin chemically, silicon is a material. It is brittle and hard. It is perfect for creating brake pad friction materials since it won't react with water, oxygen, or acids, preserving the original properties under a variety of environmental conditions.

Barium Sulphate

- Barium sulphate is the filler used in brake pad material.
- It is a barium sulphate, a soft, crystalline material. In water, it won't dissolve. It is white in colour and smellless. (10)

FABRICATION PROCESS

The sample brake pad pins were made using the following steps in the powder metallurgy manufacturing process. The flow chart for fabrication is shown in Figure 5.1 below.

- Ball milling process
- Compression moulding
- Sintering
- Machining (11)

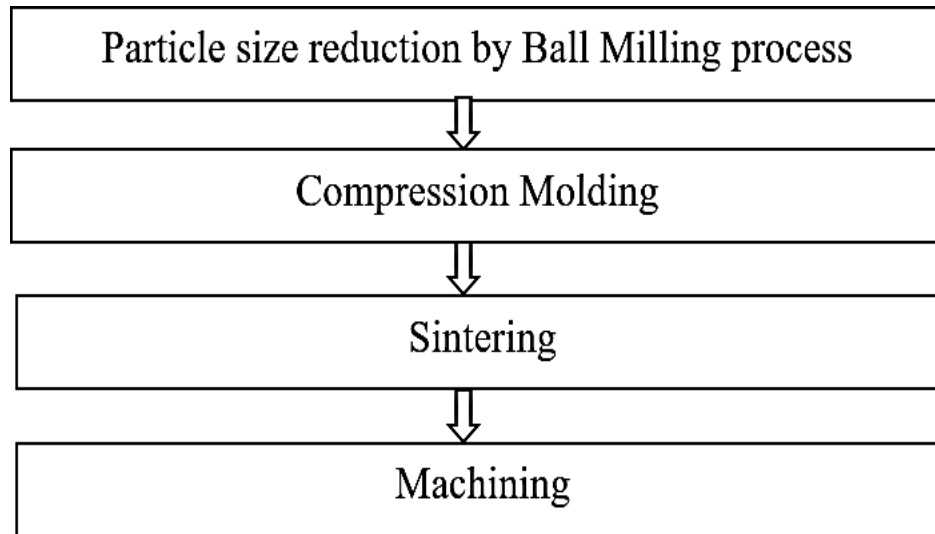


Figure: 5.1 Flow Chart – Fabrication Process

5.1 Ball milling process

The ball mill is one type of grinder used to combine materials for use in powdered metalworking. It operates in accordance with the attrition and effect notion. Particle size is decreased by the impact force of the balls within the rotating ball mill.

The listed raw ingredients must first be mixed to make a homogenous powder under dry circumstances in order to start the ball milling procedure in a planetary ball milling machine. This method involves packing hardened steel balls and powders made of a variety of materials into a hollow cylindrical shell. Hard steel ball with a 10mm diameter are used in ball mill. (12)

Figure shows a conceptual diagram of a ball milling process (5.2). Figure shows how to decrease particle size using a planetary ball mill (5.3) It is made up of cylindrical canisters made of stainless steel. The container is 110 mm in height and 110 mm in diameter. A second steel container has been used for balance even though just one container will be used for the milling process. The balls of hardened steel disintegrate the particles. This was done by using a ball and material with a weight ratio of 10:1. The planetary ball mill is then filled with the selected ingredient combination and rotated for four hours at a speed of 700 rpm. (13)

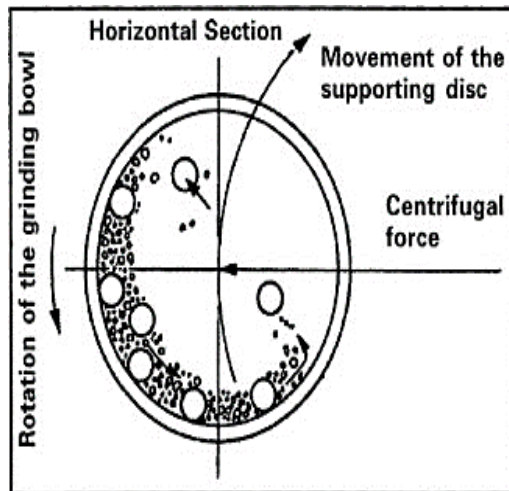


Figure: 5.2 Planetary ball milling process



Figure: 5.3 Ball milling machine

5.2 Compression moulding

Throughout the moulding process, the pre-shaped mould dies are heated to a temperature of around 170 °C. Once the output mixture of different materials from the ball milling process is poured into the die, the upper punch is inserted and precisely sealed.

The compression moulding is made up of two mould parts. The mold's upper portion may be moved, while its lower portion is fixed. The top mould is lowered for about three hours after the imposed load is applied, while maintaining a hydraulic pressure of 15 MPa and a temperature of around 170°C. The hoover compression moulding setup is shown in the following Fig (5.4). (14)

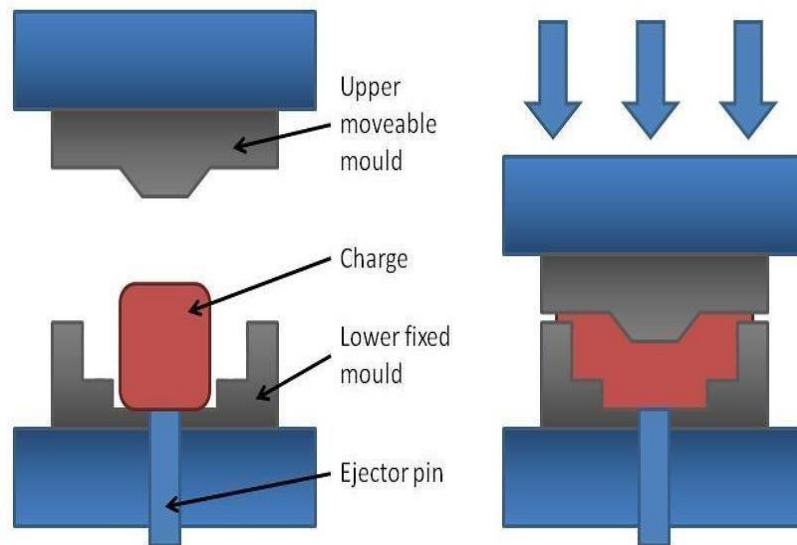


Figure: 5.4 Compression moulding



Figure: 5.5 Die for compression moulding

5.3 Sintering

By heating a material to just below its melting point and holding it there for a predetermined period of time, sintering is a sort of heat treatment used to compress and strengthen a material without actually melting it. The material's strength is also boosted. A schematic representation of the sintering process is shown in Figure (5.6). (15)

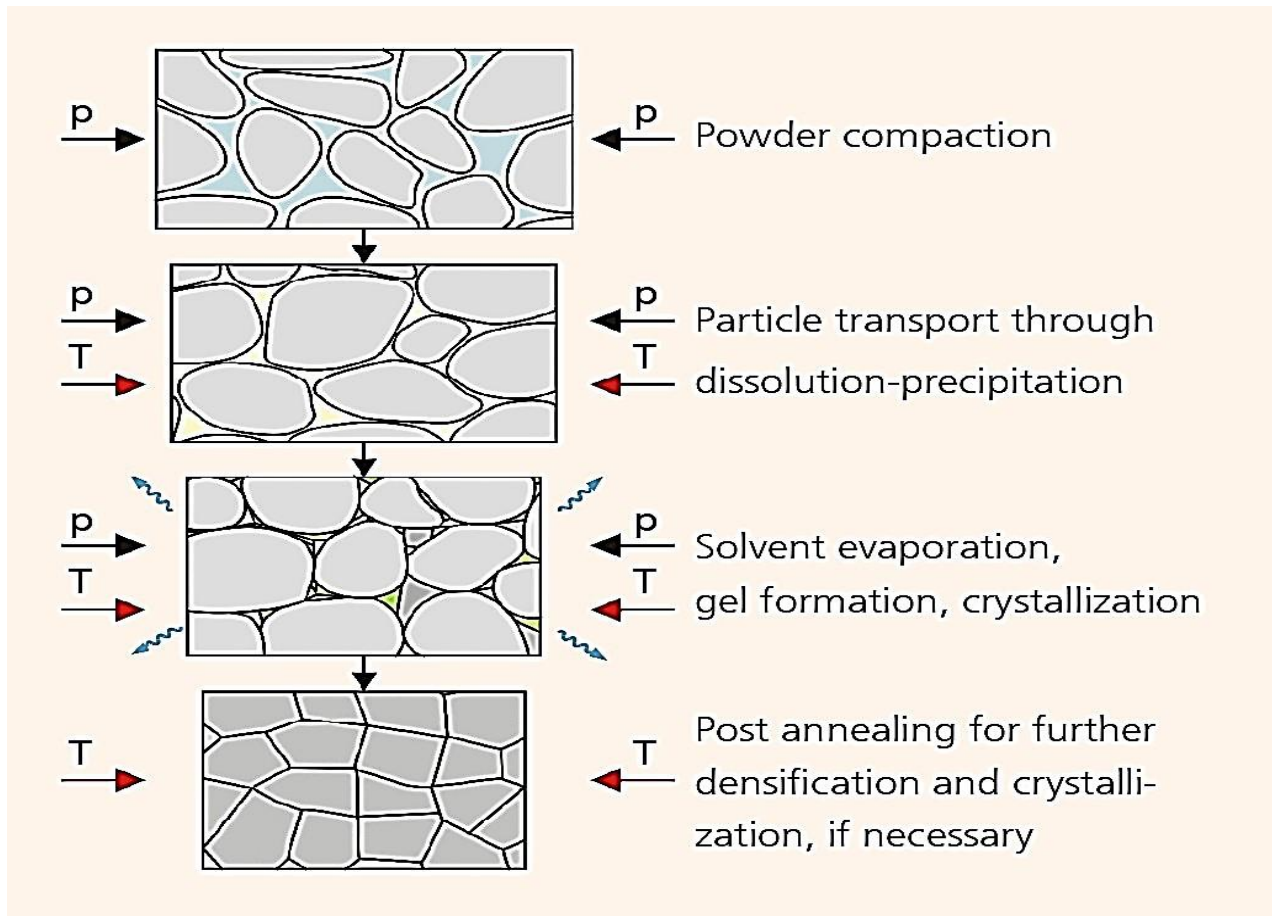


Figure: 5.6 Sintering process

This depicts the sintering boiler that was utilised (5.7). The boiler is used to heat the sample brake pad pins from the compression moulding process for roughly four hours, to a temperature of around 170 degrees Celsius. (16)



Figure: 5.7 Sintering furnace

5.4 Finishing by Machining

The brake pad pins were completed using the gridding approach. The installation of a lathe configuration with the grinding wheel attachment shown in Figure 5.8 was followed by machining to produce the appropriate form and dimensions.



Figure: 5.8 Finishing process

CHAPTER 6

RESULTS & DISCUSSIONS

The findings of mechanical and tribological tests on brake pad pins made as samples are presented in this chapter.

6.1 Hardness Test

Hardness is the capacity of a material to tolerate scratching, plastic deformation, or indentation. Understanding the friction material's hardness value is essential since it guarantees that the brake pad degrades over time rather than the rotor disc. The brake pad pin's hardness should be less than that of the rotor disc. A Vickers' Hardness Tester was used to conduct the hardness testing. A square-base diamond pyramid indenter was used in this study. The ASTM E 92 standard was followed in conducting the test. The manufacturer and model of the hardness tester are HDNS Precision Instruments, MVA-401TS. (17)

The dwell period was 10 seconds, and the indentation load was 0.5 kg. The hardness tester used for testing is shown in Figure 6.

Table: 6.1 Results of Hardness test

Description	Hardness Test Value
Sample 1[S1]	88
Sample 2[S2]	92
Sample 3[S3]	93.5

6.2 Heat Swell Test

The heat swell test's goal is to ascertain how much a brake pad pin will heat up under specific conditions. The brake pad pins' diameter for the heat swell test was 10mm. The specimen's surface has been meticulously polished using 320 grit emery. The diameter was measured at five different locations before the heat swell test, and the measurements were collected. The specimen was maintained at a temperature of around 200 degrees Celsius for 40 to 50 minutes. The same five locations were then utilised to measure the growth in dimensions after being exposed to heat with the specimen being held between two metal bands. The table below includes the average value as well as other statistics (Table 6. 2).

Table: 6.2 Results of Heat swell test

Description	Diameter of brake pad pin before heating [mm]	Diameter of brake pad pin after heating [mm]
Sample 1 [S1]	10.05	10.08
Sample 2 [S2]	10.03	10.05
Sample 3 [S3]	10.02	10.04

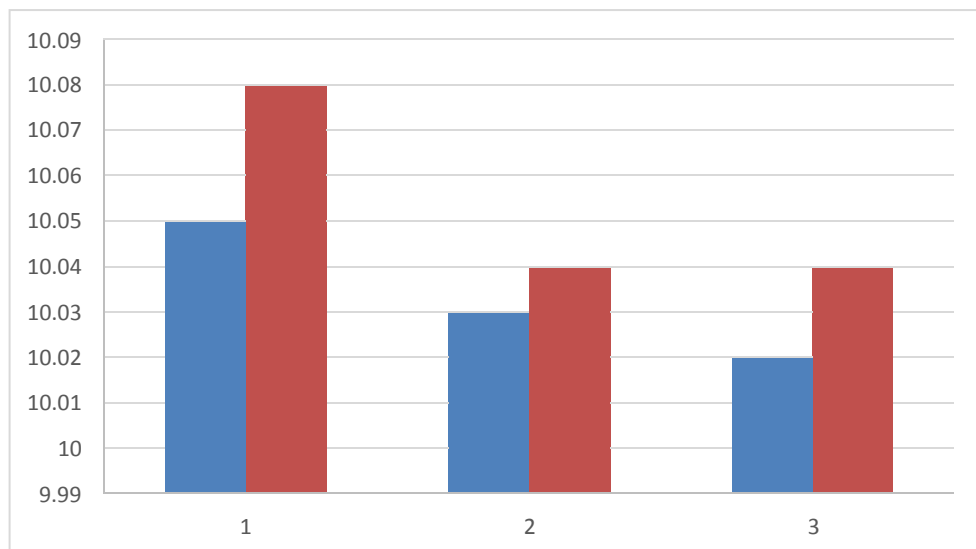


Chart of Heat swell test



Figure: 6.1 Diameter of brake pad pin measured before heating



Figure: 6.2 Diameter of brake pad pin measured after heating

6.3 Water swell Test

A water swell test was performed to examine how brakes respond when subjected to moisture and other water-related environmental variables. The test sample for the water swell test was a 10 mm brake pad pin. The brake pad pins' diameter for the heat swell test was 10mm. The specimen's surface has been meticulously polished using 320 grit emery. The diameter was measured at five different locations before the water swell test, and the measurements were collected. The specimen was then kept in water for 40 to 50 minutes at room temperature. After being exposed to water at the same five spots, the specimen was measured to see whether its dimensions had altered. The table below takes the average value and lists it (Table 6. 3). Normally, any dimension change up to 0.04 mm is allowed. Fig. 6 below shows the equipment used for the water swell test.

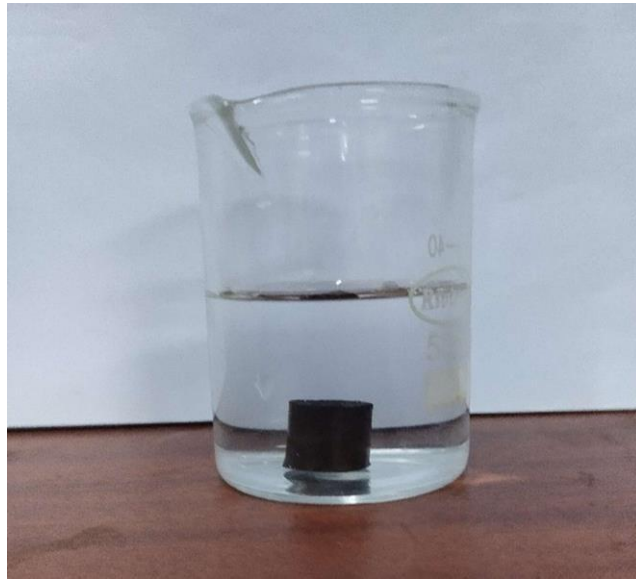


Figure: 6.3 Water swell Test

Table: 6.3 Results of Water swell test

Description	Diameter of brake pad pin before water exposure [mm]	Diameter of brake pad pin after water exposure [mm]
Sample 1 [S1]	10.05	10.08
Sample 2 [S2]	10.03	10.04
Sample 3 [S3]	10.02	10.04

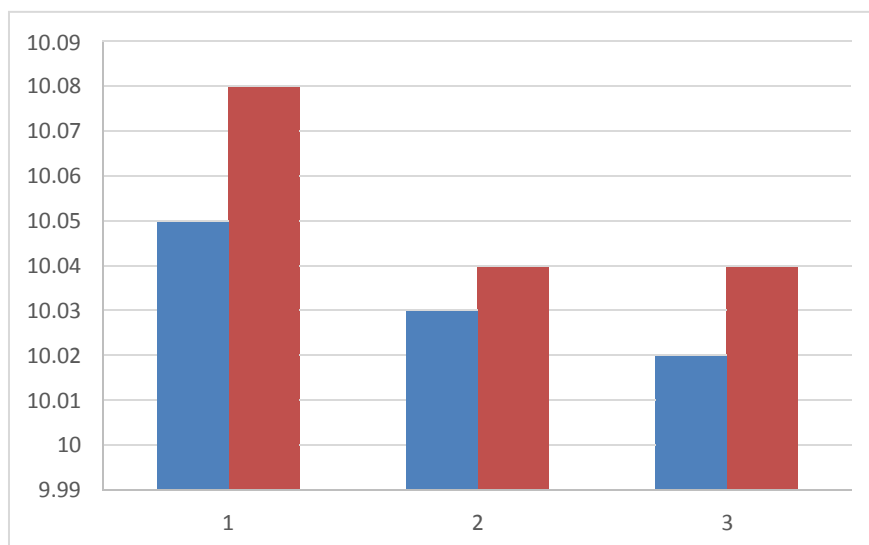


Chart of Water swell test



Figure: 6.4 Diameter of brake pad pin measured before water exposure



Figure: 6.5 Diameter of brake pad pin measured after water exposure

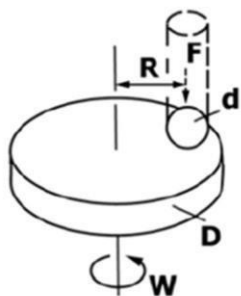
6.4 Wear Test

The tribological test was conducted using the Pin-on Disc wear test apparatus shown in Figure 6.7. The test was conducted in accordance with the guidelines provided in ASTM Standard ASTM G99 - Standard Test Procedure for Wear Testing Using a Pin-On-Disk Apparatus. The sample brake pad pins were tested by sliding them against an EN-31 hardened steel rotor disc. The disc had a 62 HRC hardness rating. Brake pad pins and disc surfaces were cleaned by polishing with 1000 grit SiC abrasive paper to remove surface contaminants for surface preparation. Acetone was then used to clean the apparatus.

The dry sliding wear characteristics of the produced brake pad pins were investigated using a pin-on-disc tribometer. The brake pad pin was fixedly positioned vertically on the rotating hardened steel rotor disc, ready to be struck by a dead weight. The applied normal load, sliding speed, sliding distance, and wear track radius are pre-set before the wear test is conducted.



Figure 6.6 Pin on-disc apparatus for Tribological studies



F – Normal Force
R - Wear Track Radius
d – Diameter of Pin
D - Diameter of Disc
W – Rotation Velocity of Disc

Figure: 6.7 Pin on-disc apparatus specification

Wear Test Specimen	10 mm diameter Sample brake pad pins
Material of construction of rotor Disc	EN-31 hardened steel
Track Radius	36 mm
Applied Normal Load	10-20 N
Sliding Distance	2000m
Sliding speed	1.5 m/s – 2.5 m/s
Temperature	Room temperature, Atmospheric condition

Using test data such as material type, weight, sliding speed, and distance that were fixed constants, the tribometer was utilised to calculate wear loss and coefficient of friction. The wear rate was calculated by using the equation below to calculate the volume loss that arises from the specimen's mass loss.

$$Wear\ rate\ (\frac{mm^3}{m}) = \frac{Mass\ loss(g)}{Q\ (\frac{g}{mm^3}) \times D(m)}$$

The wear results were presented as the volume loss in cubic millimetres for the pin and disc, respectively. When the disc is initially flat and the pin initially has a spherical end shape with radius R, the following equations are used to calculate volume losses, assuming that only one of the two components wears noticeably.

$$\text{Pin (spherical end) volume loss, } mm^3 = \pi \frac{(Wear\ Scar\ diameter, mm)^4}{64 \times Sph\ radius(mm)}$$

Considering that there isn't much disc wear.

For converting mass loss to volume loss, apply the equation below.

$$\text{volume loss, mm}^3 = \frac{\text{mass loss, g}}{\text{density, g/cm}^3} \times 1000.$$

The table below contains the wear test findings (Table. 6.4).

Table: 6.4 Wear Test results

Brake pad pin sample	Load (N)	Sliding speed (m/s)	Wear rate (mm³/m)	Co-efficient of friction
Sample 1	10	1.5	0.000613	0.27
Sample 1	15	2	0.000398	0.33
Sample 1	20	2.5	0.000474	0.31
Sample 2	10	2	0.000328	0.35
Sample 2	15	2.5	0.000198	0.29
Sample 2	20	1.5	0.000387	0.32
Sample 3	10	2.5	0.000213	0.26
Sample 3	15	1.5	0.000314	0.34
Sample 3	20	2	0.000256	0.39

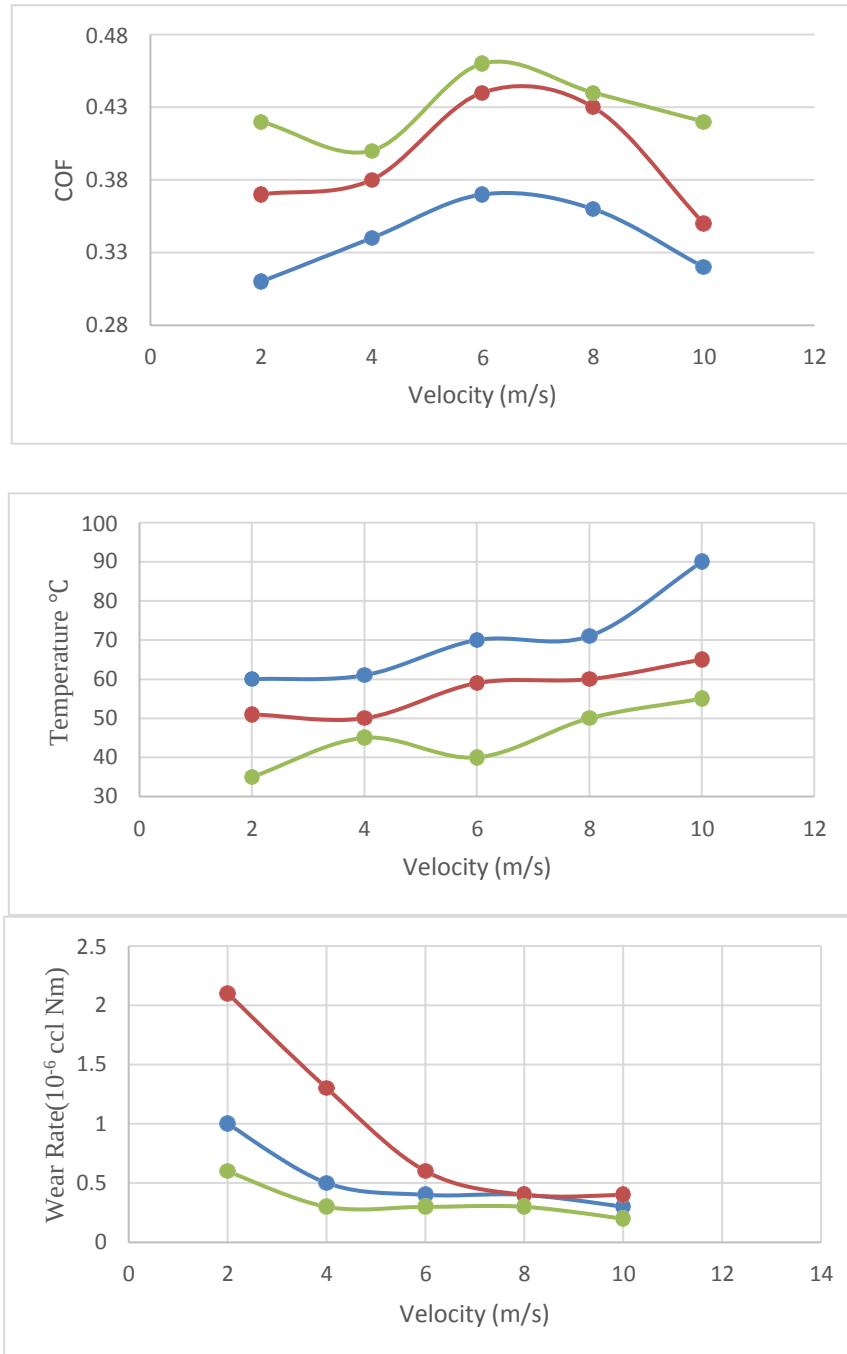


Figure: 6.8 Load Vs Co-efficient of friction Graph

In Figure 6.9, the load (N) is plotted on the X-axis and the coefficient of friction is plotted on the Y-axis to demonstrate the relationship between load and friction. The incident 1 brake pad pin with 5% Silicon and the sample The Coefficient of Friction does not change considerably under different load conditions, as indicated by a flat curve on the two brake pad pins with 10% silicon, even if the sample size is small. 3 brake pad pins with 15% of the total friction coefficient have contributed to a little variance in that value.

CHAPTER 7

CONCLUSION

Three sets of sample brake pad pins, designated Sample 1, Sample 2, and Sample 3, each have silicon concentrations of 5%, 10%, and 15%, respectively. The manufactured sample brake pad pins were put through mechanical and tribological testing. The samples 1, 2, and 3 had corresponding hardness values of 92, 95, and 97 VHN after being put through a hardness test using a Vickers' Hardness tester. Furthermore, compared to Sample 1's 5% Silicon and Sample 3's 15% Silicon, the brake pad sample pin with 10% Silicon [S2] has shown a lower rate of wear. The sample with 10% by weight Silicon showed reduced wear rate, deformed less in the heat and water swell test, and was found to have a superior composition after comparing the above test of three sets of sample brake pad pins. (18)

REFERENCES

- [1] Ilie F, Cristescu AC. Tribological Behavior of Friction Materials of a Disk-Brake Pad Braking System affected by Structural Changes—A Review. *Materials*. 2022 Jul 1;15(14).
- [2] R NP, A HY. EXPERIMENTAL EVALUATION OF TRIBOLOGICAL PROPERTIES OF DISC BRAKE PAD MATERIAL [Internet]. Vol. 5. Available from: www.ijariie.com
- [3] Kumar M, Bijwe J. Optimized selection of metallic fillers for best combination of performance properties of friction materials: A comprehensive study. *Wear*. 2013 Jun 15;303(1–2):569–83.
- [4] Bashir M, Saleem S, Bashir O. FRICTION AND WEAR BEHAVIOR OF DISC BRAKE PAD MATERIAL USING BANANA PEEL POWDER [Internet]. *IJRET: International Journal of Research in Engineering and Technology*. Available from: <http://www.ijret.org>
- [5] Sundarrajan D. Study of Mechanical and Tribological Properties of Automotive Brake Pads. 2021; Available from: www.ijsdr.org
- [6] Talele PH, Kute GB, Bhoje RP, Kumavat GS, Dandge SM, Pawar SY. Tribological Behaviour Of Passenger Vehicle Brake Pad Material. *International Research Journal of Engineering and Technology* [Internet]. 2021; Available from: www.irjet.net
- [7] Kumar Kankanala A, Sai Krishna K. Tribological Analysis of Automotive brakepad. *International Research Journal of Engineering and Technology* [Internet]. 2020; Available from: www.irjet.net
- [8] Anuse VD, Bansode AM, Kate SD, Rangate S V, Patil AA. Study of Tribological Performance of Brake Pad for Increasing the Wear Resistance of Disc Brake [Internet]. Available from: www.iosrjen.org
- [9] Sundarrajan D. Study of Mechanical and Tribological Properties of Automotive Brake Pads. 2021; Available from: www.ijsdr.org
- [10] Sivaras R, Sathishkumar TP, Naveenathakrishnan P. Investigation on Tribological and Mechanical Properties of Filler Reinforced Epoxy Composite [Internet]. Available from: www.ijert.org
- [11] Kolluri D, Ghosh AK, Bijwe J. Analysis of load-speed sensitivity of friction composites based on various synthetic graphites. *Wear*. 2009 Jan 5;266(1–2):266–74.
- [12] Eriksson M, Bergman F, Jacobson S. On the nature of tribological contact in automotive brakes. Vol. 252, *Wear*. 2002.
- [13] Mutlu I, Eldogan O, Findik F. Tribological properties of some phenolic composites suggested for automotive brakes. *Tribol Int*. 2006 Apr;39(4):317–25.
- [14] Elzayady N, Elsoeudy R. Microstructure and wear mechanisms investigation on the brake

- pad. *Journal of Materials Research and Technology*. 2021 Mar;11:2314–35.
- [15] Chandra Verma P, Menapace L, Bonfanti A, Ciudin R, Gialanella S, Straffelini G. Braking pad-disc system: Wear mechanisms and formation of wear fragments. *Wear*. 2015 Jan 5;322–323:251–8.
- [16] Liew KW, El-Tayeb NSM. THE EFFECT OF ROTOR DISC MATERIAL ON TRIBO BEHAVIOR OF AUTOMOTIVE BRAKE PAD MATERIALS. Vol. 29, *Surface Review and Letters*. 2008.
- [17] Jang H, Ko K, Kim SJ, Basch RH, Fash JW. The effect of metal fibers on the friction performance of automotive brake friction materials. *Wear*. 2004;256(3–4):406–14.
- [18] Hee KW, Filip P. Performance of ceramic enhanced phenolic matrix brake lining materials for automotive brake linings. *Wear*. 2005 Aug;259(7–12):1088–96.