

FABRICATION OF ECO-FRIENDLY BRAKE PAD USING SORGHUM HUSK AS FRICTION ADDITIVES

Submitted in partial fulfilment of the requirements for the award of
Bachelor of Engineering Degree in Automobile Engineering

by

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **SIMON M (40860701)** and **KARTHICK KUMARAN R (40860702)** who carried out the project entitled "**FABRICATION OF ECO-FRIENDLY BRAKE PAD USING SORGHUM HUSK AS FRICTION ADDITIVES**" under my supervision from June 2023 to April 2024.

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ABSTRACT

In the investigation for sustainable and eco-friendly alternatives to conventional asbestos-laden brake pads, this study explores the utilization of sorghum husk, an abundant and renewable agricultural waste product. Asbestos, known for its detrimental health and environmental effects, has long been a key component in brake pad formulations. The focus of this research is to assess the potential of sorghum husk as a friction additive in brake pads by varying its concentrations at 5%, 10%, and 15%. The investigation encompasses an in-depth analysis, including mechanical and tribological tests. Preliminary findings reveal that brake pads infused with sorghum husk maintain or enhance performance while exhibiting promising wear resistance. Importantly, this study underscores the environmental advantages by repurposing agricultural waste, signaling a crucial shift toward sustainability in the automotive industry. Ongoing research is crucial to optimize formulations, striving for an optimal balance between performance, sustainability, and cost-effectiveness. The study offers a promising trajectory for the development of sustainable brake pads, paving the way for a greener and safer automotive landscape.

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1. INTRODUCTION

1.1 OVERVIEW OF BRAKE PADS

Brake pads are vital components in a vehicle's braking system, converting kinetic energy into thermal energy through friction against the brake rotor. This process is vital for deceleration or halting the vehicle. Friction generates substantial heat, aiding in the reduction of speed or a complete stop. The efficiency and dependability of brake pads are paramount for vehicular safety, fueling continuous research and innovation. Engineers strive to enhance brake pad materials and designs, optimizing performance, durability, and safety standards. Advancements in brake pad technology are instrumental in ensuring reliable and effective braking systems, significantly contributing to overall road safety and smooth vehicle operation. Brake pads symbolize a critical intersection of science and safety, epitomizing a relentless pursuit to make driving safer and more efficient for everyone on the road.

1.2 IMPORTANCE OF BRAKE PADS

Brake pads are of most important in a vehicle's braking system, serving as a key for safety and control. When the brake pedal is activated, the brake pads make contact with the brake rotors, creating the essential friction needed to slow down or stop the vehicle. This process enables drivers to navigate roads safely by providing the means to respond swiftly to changing traffic conditions, potential obstacles, or emergencies.

1.3 ENVIRONMENTAL AND HEALTH CONCERNS WITH CONVENTIONAL BRAKE PADS

Conventional brake pads have raised significant environmental and health concerns due to their composition and usage of hazardous materials. One of the primary issues is the inclusion of asbestos in older brake pads, which poses severe health risks. Asbestos exposure can lead to lung diseases, including

asbestosis and lung cancer affecting both mechanics during brake pad replacement and the environment during brake pad wear and tear. Furthermore, the production and disposal of conventional brake pads contribute to environmental degradation. The manufacturing process involves the use of various harmful chemicals and the consumption of significant energy, leading to air and water pollution. When these brake pads wear down during use, they release fine particulate matter (PM), heavy metals, and other toxic substances into the air and surrounding environment, further exposing to danger human health and ecosystems. Addressing these concerns necessitates a shift towards eco-friendly brake pads, utilizing alternative materials that do not pose health risks and implementing sustainable manufacturing processes. Such a transition can significantly reduce the environmental and health impact associated with traditional brake pad use.

1.4 EXISTING TYPE OF BRAKE PADS

There are several types of brake pads, each with its own composition and characteristics. Here are the common types.

Ceramic Brake Pads: A mix of ceramic fibers, filler material, and bonding agents. These pads produce less noise, less dust, and have a longer lifespan compared to other types. They offer consistent performance across a wide range of temperatures and are suitable for daily driving and light-duty applications.

Organic Brake Pads: Combination of organic materials such as rubber, glass, Kevlar, and resins. Known for their quieter operation and less aggressive brake dust, organic brake pads provide a softer pedal feel. These may wear down faster compared to other types.

Semi-Metallic Brake Pads: Blend of metals such as copper, iron, steel, and friction modifiers. These pads offer excellent braking performance and are known for their durability and heat depletion capabilities. It is noisy and causes more wear to the brake rotors.

Low-Metallic organic Brake Pads: Combine organic materials with small amounts of metal fibers. These pads offer improved heat transfer and braking performance compared to organic pads. They are quieter and provide better braking at high speeds.

Fully Metallic Brake Pads: It is made from a blend of various metals, providing exceptional durability and heat depletion.

1.5 GENERAL COMPOSITION OF BRAKE PAD MATERIAL

Brake pads, fundamental components within vehicular braking systems, are meticulously engineered to ensure effective and safe deceleration of vehicles. The standard composition of brake pads involves a well-considered integration of fibers, binder, fillers, and friction additives. Each constituent in this composition contributes distinctive attributes, collectively enhancing the durability, performance, and functionality of brake pads.

Fibers: Fibers constitute a crucial component, providing structural reinforcement to the brake pad. Commonly composed of carbon, aramid (Kevlar), glass, and natural fibers, they enhance mechanical strength and thermal stability. Fibers enable the brake pad to endure the extreme friction and heat generated during the braking process.

Binder: The binder, typically phenolic resin, acts as a vital matrix that binds and stabilizes the various components of the brake pad. It ensures a cohesive structure by effectively amalgamating the fibers, fillers, and friction additives. The binder's role is essential in maintaining the brake pad's shape and integrity during prolonged usage and rigorous braking conditions.

Fillers: Fillers, including materials like barium sulfate (BaSO_4), vermiculite, and cashew dust, are supplementary elements that enhance specific properties of the brake pad. These additives contribute to density, thermal

conductivity, and overall performance, fine-tuning the brake pad's characteristics to meet desired standards and specifications.

Friction Additives: Friction additives are fundamental components influencing the frictional properties of the brake pad. Derived from natural or synthetic sources, they enhance the friction coefficient between the brake pad and the rotor. Friction additives, such as those obtained from sources like sorghum husk, play a pivotal role in achieving optimal braking efficiency and stability.

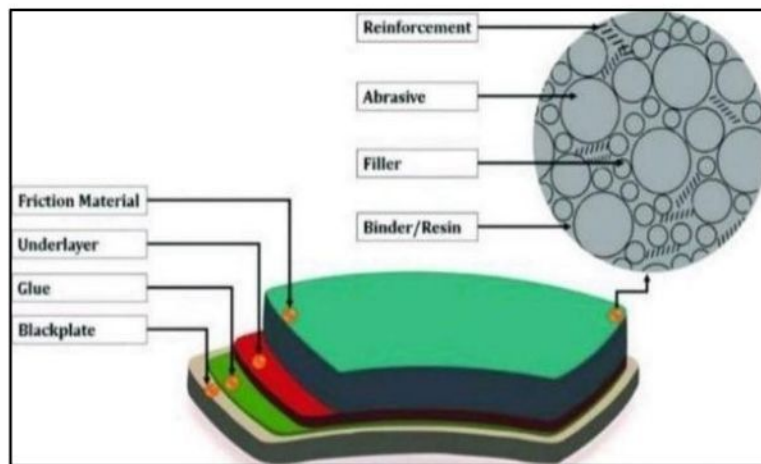


Fig 1.1 Representation of general composition layers of brake pads

1.6 TRANSITION TO ECO FRIENDLY BRAKE PAD:

The transition to eco-friendly brake pads signifies a paradigm shift in the automotive industry towards sustainability and responsible manufacturing. This gets growing environmental awareness and the need to minimize the ecological footprint of vehicles. Natural fibres, recycled materials, and sustainable fillers are being integrated into brake pad formulations. Additionally, low- or zero-emission manufacturing processes, such as water-based adhesives and reduced energy consumption, are becoming standard practices. For more, the shift to eco-friendly brake pads aligns with global efforts to combat air and water pollution. These pads produce fewer harmful particulates and less brake dust, contributing to cleaner air and reduced contamination of water sources. Ultimately, the transition to ecofriendly brake pads embodies a commitment to sustainable practices and a cleaner, greener future for the automotive industry.

1.7 OBJECTIVE OF THE PROJECT

The objective of the project is to explore and innovate in the domain of brake pad technology, specifically focusing on the development and integration of ecofriendly materials, with a special emphasis on utilizing sorghum husk as a frictional additive. The primary aim is to contribute to a sustainable and environmentally conscious automotive industry. This study involves a systematic investigation of incorporating sorghum husk as a friction enhancer in organic brake pads. The concentrations of sorghum husk were varied at 5%, 10%, and 15% to observe how these different proportions influence the brake pad's properties and performance. The research through into several important aspects, encompassing mechanical and tribological tests. These tests include hardness assessment, compressive strength analysis, wear rate measurement, water absorption testing, all critical in understanding the possibility and sustainability of sorghum husk-containing brake pads. Additionally, wear rate measurement is crucial to measure the brake pad material disintegrate over time, which directly impacts the pad's longevity and, subsequently, its replacement frequency. Moreover, wear rate analysis offers insights into the environmental implications, indicating the potential release of particulate matter into the surroundings, a concern that further emphasizes the importance of sustainable brake pad formulations. The preliminary results of the study demonstrate that the brake pads incorporating sorghum husk as a friction additive exhibit comparable performance to conventional brake pads. The influence of varying concentrations of sorghum husk on the brake pads was examined. It was observed that the addition of sorghum husk did not compromise the critical mechanical properties of the brake pads. In fact, in some cases, an improvement in these properties was noted, suggesting the potential to fine-tune the formulations for optimized performance.

2. LITERATURE REVIEW

2.1 HISTORICAL PERSPECTIVE OF BRAKE PAD MATERIALS

The evolution of brake pad materials and their impact on the environment and safety has been a subject of extensive research. Here, we trace the key developments and trends in the literature, highlighting how brake pad materials have evolved over time and their implications.

Early Brake Pads: The history of brake pad materials dates back to the use of rudimentary materials like wood and leather in early braking systems. These materials lacked durability and exhibited inconsistent performance.

Asbestos Era: Asbestos, known for its heat resistance and friction properties, was widely used in brake pads from the mid-20th century. However, growing health and environmental concerns led to the phasing out of asbestos-containing brake pads.

Transition to Non-Asbestos Organic (NAO) Pads: In response to the asbestos phase-out, non-asbestos organic (NAO) brake pads gained popularity. These pads featured materials like rubber, glass, and resins, providing adequate performance with reduced environmental risks.

Semi-Metallic Pads: Semi-metallic brake pads incorporated metal fibers and additives to enhance performance, especially in high-performance and heavy-duty applications. However, they raised concerns about wear and noise.

Evolution of Ceramic Pads: Ceramic brake pads emerged as a significant advancement, offering excellent performance, low dust generation, and reduced wear. Their popularity grew due to a balance between performance and environmental responsibility.

Sustainable Brake Pads: This research investigates the tribological properties of composite brake friction materials containing jute fibres, contributing to sustainable brake pad development.

Impact of Regulations: Stringent environmental regulations have played a pivotal role in driving the transition to eco-friendly brake pads. These regulations have accelerated research and innovation in brake pad materials.

Consumer Awareness: As consumer awareness of the environmental impact of brake pads has increased, there has been a growing demand for sustainable alternatives. This has pushed manufacturers to invest in green technologies and materials.

Performance and Safety: While eco-friendly brake pads are a positive step, their evolution continues to focus on maintaining or enhancing performance and safety, ensuring they meet or exceed industry standards.

The literature survey highlights the transformation of brake pad materials from rudimentary substances to eco-friendly, sustainable options. This evolution reflects the industry's response to environmental and safety concerns while maintaining a commitment to optimal brake performance.

2.2 ADVANTAGES AND DISADVANTAGES OF CONVENTIONAL BRAKE PAD MATERIALS

Conventional brake pads, typically made of materials like asbestos, semi metallic compounds, ceramics, and organic compounds, come with their own set of advantages and disadvantages:

2.2.1 Advantages

Cost-Effective: Conventional brake pads are often more cost-effective to manufacture and purchase compared to some of the newer, eco-friendly alternatives.

Proven Performance: Conventional brake pads have a long history of use and their performance is well understood. They provide consistent braking performance across various conditions.

Wide Availability: Due to their established use, conventional brake pads are widely available in the market, making replacements and repairs easily accessible.

High Temperature Tolerance: Some conventional brake pad materials, like semi-metallic compounds, can withstand high temperatures and provide effective braking even under intense conditions.

Durable and Long-Lasting: Certain conventional brake pads, especially those with metallic components, tend to be durable and have a longer lifespan compared to softer, organic-based materials.

2.2.2 Disadvantages

Environmental Hazards: Many conventional brake pad materials, such as asbestos and certain metallic compounds, can pose significant health and environmental risks during production, use, and disposal.

Brake Dust and Pollution: Conventional brake pads can generate excessive brake dust, which can contribute to air and water pollution due to the release of fine particulate matter and heavy metals.

Brake Noise: Certain conventional brake pads, especially metallic ones, can produce more brake noise compared to ceramic or organic alternatives, impacting the overall driving experience.

Wear and Tear on Rotors: Conventional brake pads can cause more wear and tear on brake rotors due to their abrasive nature, potentially leading to increased maintenance costs.

Limited Recyclability: Some conventional brake pad materials are challenging to recycle, adding to waste in landfills and posing environmental challenges.

2.3 SORGHUM HUSK AS A FRICTIONAL ADDITIVE

Sorghum is a widely cultivated crop, and its husk is a readily available byproduct. The abundance and renewability of sorghum make it an attractive ecofriendly material. It contains fibrous components that exhibit natural friction properties, making it a promising material to enhance the frictional capabilities of brake pads. Being a natural plant-based material, sorghum husk is biodegradable. Its use contributes to reducing the environmental impact associated with nonbiodegradable materials. This husk is a cost-effective raw material due to its abundance and availability as an agricultural waste product. This can lead to more affordable brake pad production. Studies suggest that sorghum husk has good thermal stability, which is crucial for maintaining braking performance under high temperature conditions typically experienced during braking. Incorporating sorghum husk into brake pad formulations may enhance wear resistance, ensuring a longer lifespan for the brake pads. Utilizing sorghum husk as a frictional additive offers a sustainable alternative to traditional brake pad materials. It can help reduce the dependency on non-renewable resources and lower the overall environmental impact of brake pad production.

3. SCOPE OF PRESENT WORK

The present work encompasses a comprehensive exploration into leveraging sorghum husk as a potential friction additive in the creation of eco-friendly brake pads. A meticulous investigation into the inherent properties and characteristics of sorghum husk forms the foundational aspect of this study. By analyzing its composition, texture, thermal properties, and frictional attributes, we aim to ascertain the suitability and effectiveness of sorghum husk as a friction-enhancing component in brake pad formulations.

The fabrication process constitutes a core component of this research. This involves a detailed and strategic approach to combining sorghum husk with a variety of materials, such as fibers (carbon, aramid, glass, and natural), a phenolic resin binder, and fillers (BaSO₄, vermiculite, cashew dust). The process includes precise measurements and proportions to attain a homogenized mixture, ensuring an even distribution of sorghum husk within the formulation.

The subsequent phases of molding and curing are essential for analyzing the performance and durability of the brake pad. Utilizing a molding press or suitable molds, the mixture is shaped to similar dimensions and structure of standard brake pads. Applying the right pressure during molding is critical to achieving the desired density and structural integrity. The brake pad specimens mixed well with the phenolic resin binder. This process transforms the mixture into a solid, cohesive brake pad ready for testing and evaluation.

This study encompassing various metrics to comprehensively assess the brake pad's efficiency. Evaluating wear resistance ensures the pad's durability and longevity. Thermal conductivity tests analyze the brake pad's ability to dissolve heat effectively, crucial for preventing brake fade. Additionally, water absorption tests gauge the pad's ability to perform under varying environmental conditions. Analyzing and quantifying the environmental benefits, such as waste reduction and a reduced carbon footprint, underscore the sustainability aspect of this research. This assessment is pivotal in aligning the study with broader sustainability goals and promoting the adoption of eco-friendly brake pads in the automotive industry, ultimately contributing to a greener and more sustainable future.

4. MATERIALS AND METHODOLOGY

4.1 MATERIALS

The materials used in the fabrication of eco-friendly brake pads with sorghum husk as a friction additive. The key materials involved in this composition include

4.1.1 *Fibers*

Fibers in brake pads, including carbon, aramid (Kevlar), glass, and natural fibers, reinforce the pad's structural integrity and enhance its frictional properties. These fibers provide strength, stability, and heat resistance, contributing to effective braking performance. Each type of fiber offers specific advantages, making them essential components in the composition of brake pads.

Carbon Fiber

Carbon fiber, recognized for its exceptional properties, plays a pivotal role in brake pad enhancement. Renowned for its outstanding strength-to-weight ratio, carbon fiber infuses the brake pad with substantial reinforcement without adding unnecessary mass. This attribute is fundamental in developing lightweight yet robust brake pads, significantly improving the overall performance and efficiency of the braking system. Furthermore, carbon fiber exhibits superb thermal conductivity, effectively diffusing heat generated during braking. By doing so, it mitigates the risk of brake fade, ensuring consistent and reliable braking performance even under high-stress conditions. Its integration significantly bolsters the brake pad's structural integrity, reducing the likelihood of deformation or failure, especially during demanding braking scenarios. In essence, carbon fiber stands as a cornerstone in brake pad engineering, delivering enhanced durability, thermal stability, and ultimately contributing to safer and more efficient braking experiences.



Fig 4.1 Carbon Fiber

Aramid (Kevlar) Fiber

Aramid fibers, notably Kevlar, represent a class of synthetic materials celebrated for their remarkable strength and exceptional heat resistance. When incorporated into brake pads, these fibers serve a critical role in augmenting the structural fortitude and thermal stability of the braking system. Kevlar, with its impressive tensile strength, reinforces the brake pad, ensuring it can endure the substantial forces and pressures experienced during braking. Moreover, the outstanding heat resistance of aramid fibers makes them particularly well-suited for brake pads. They effectively dissipate and withstand elevated temperatures generated by friction during braking, a quality essential for maintaining consistent and reliable braking performance over extended periods. Aramid fibers act as a key element in enhancing the brake pad's longevity and preventing thermal degradation, ultimately contributing to safer braking operations by bolstering the pad's durability and stability under varying thermal conditions.



Fig 4.2 Aramid

Glass Fiber

Glass fibers are integral to brake pad construction due to their reinforcing attributes. By introducing glass fibers into the brake pad material, mechanical strength is substantially bolstered. These fibers, known for their high tensile strength, enhance the structural integrity of the brake pad, ensuring it can endure the immense stresses encountered during braking. Additionally, glass fibers augment the wear resistance of the brake pad. They act as a protective shield, reducing wear and tear on the brake pad surface, thus extending its lifespan and improving its overall performance. In summary, the inclusion of glass fibers significantly contributes to creating durable, long-lasting brake pads capable of withstanding the demanding conditions of braking systems.



Fig 4.3 Glass Fiber

4.1.2 Binder

The binder in brake pad compositions, typically phenolic resin, plays a pivotal role in holding together the various components of the pad. It functions as an adhesive, ensuring that the friction materials, fibers, and fillers are uniformly distributed and securely attached within the pad structure. The binder also provides cohesion and stability, allowing the brake pad to withstand the high levels of heat and pressure generated during braking, ultimately ensuring effective and reliable performance.

Phenolic Resin

Phenolic resin, a fundamental component in brake pad formulation, serves as a crucial binder renowned for its exceptional adhesive properties and resilience in high-temperature environments. It plays an essential role in amalgamating the diverse components of the brake pad into a cohesive and solid structure. The resin's adhesive capabilities foster strong bonds between the reinforcing fibers, friction additives, fillers, and other constituents, ensuring the brake pad maintains its structural integrity under extreme operational conditions. Moreover, phenolic resin exhibits excellent thermal stability, withstanding the intense heat generated during braking without undergoing degradation. This thermal resistance is vital for brake pads, as it guarantees that the pad remains robust and functional even during prolonged or heavy braking, preventing premature deterioration and ensuring consistent performance over time. Furthermore, phenolic resin's ability to resist wear and maintain its adhesive strength enhances the brake pad's longevity and reliability.

4.1.3 Fillers

Fillers in brake pad compositions, such as barium sulfate (BaSO_4), vermiculite, and cashew dust, serve multiple purposes. They enhance the density and heat resistance of the brake pad, contributing to its overall stability and performance during braking. Fillers also help regulate the wear characteristics and

thermal properties of the pad, ensuring that it can withstand the rigors of braking while maintaining consistency and reliability in various driving conditions.

BaS04 (Barium Sulphate)

Barium sulfate, commonly known as BaS04, stands as a significant filler in brake pad production, playing a critical role in augmenting the brake pad's properties. Primarily, it acts to enhance the density of the brake pad material, a pivotal factor in brake pad performance. The increased density improves the pad's ability to withstand the tremendous pressure and stress experienced during braking, consequently bolstering its structural integrity and longevity. Moreover, barium sulfate significantly contributes to the brake pad's heat resistance capabilities. The compound possesses remarkable thermal stability, allowing the brake pad to efficiently dissipate the intense heat generated during braking. By withstanding high temperatures without deterioration or compromising performance, barium sulfate ensures the brake pad remains stable and reliable even under the harshest braking conditions. In essence, the integration of barium sulfate as a filler in brake pad manufacturing leads to a brake pad that exhibits heightened density and exceptional thermal endurance, ultimately enhancing the pad's overall performance and ensuring consistent and reliable braking across various driving conditions.



Fig 4.4 Barium Sulphate

Vermiculite

Vermiculite, a mineral-based filler, holds a pivotal role in enhancing the thermal properties of brake pads, making significant contributions to their overall performance and safety. This naturally occurring mineral exhibits exceptional thermal stability and insulation properties. When incorporated into brake pads, vermiculite aids in effectively dissipating the heat generated during braking, preventing excessive temperature build-up that can lead to brake fade or reduced performance. The unique structure of vermiculite consists of layers that expand when exposed to high temperatures, creating air pockets within the brake pad material. These air pockets act as insulators, reducing heat transfer and enhancing the thermal stability of the brake pad. By facilitating efficient heat dissipation and maintaining lower operating temperatures, vermiculite helps to preserve the structural integrity and friction properties of the brake pad over extended periods of use. Moreover, the addition of vermiculite as a filler contributes to the overall density and mechanical strength of the brake pad, reinforcing its structural robustness and wear resistance. Its incorporation ensures a balanced composition, ultimately leading to a brake pad that excels in performance, durability, and safety, especially under demanding and high-temperature braking conditions.



Fig 4.5 Vermiculite

Cashew Dust

Cashew dust, a byproduct often sourced from cashew shells, serves as a valuable filler in brake pad composition. Its incorporation adds to the brake pad's overall composition, aiding in achieving the desired material consistency and properties. While precise details of its application might vary, cashew dust likely contributes to the brake pad's density, helping to fine-tune its mechanical properties and wear resistance. Additionally, being a sustainable use of a byproduct, it aligns with eco-friendly practices, making the brake pad formulation more environmentally conscious by repurposing agricultural waste.



Fig 4.6 Cashew Dust

4.1.4 Friction Additive

Friction additives, like rockwool, coke, sorghum husk, are incorporated into brake pad formulations to elevate the pad's frictional properties. These additives enhance the brake pad's ability to provide efficient braking performance, contributing to the effectiveness of the braking system.

Coke

It derived from carbon-rich materials such as coal, is utilized as a filler in brake pad formulation. Its inclusion is valuable due to its high-temperature stability and resistance, enhancing the brake pad's ability to endure extreme heat during the braking process. Coke effectively disperses and dissipates heat, aiding in preventing overheating and maintaining consistent braking performance.

Furthermore, it reinforces the brake pad, contributing to its mechanical strength and durability. The addition of coke ensures that the brake pad remains reliable and efficient even under prolonged or heavy braking, making it an essential component in high-performance brake pads.



Fig 4.7 Coke

Rockwool

Rockwool, a mineral-based filler, is an essential component in brake pad formulations. It significantly contributes to the thermal stability of brake pads, playing a crucial role in dissipating the heat generated during braking. This capability ensures that the brake pads maintain consistent performance, even under highstress conditions or during prolonged braking events. In addition to its thermal properties, Rockwool also serves as an effective noise-dampening material. It helps reduce brake noise and vibrations, resulting in a quieter and smoother braking experience for drivers and passengers. Its unique combination of thermal resilience and noise-reduction characteristics makes Rockwool a valuable and multifunctional addition to brake pad materials, enhancing both safety and comfort in automotive applications.



Fig 4.8 Rockwool

Sorghum Husk

Sorghum husk, a natural and renewable agricultural byproduct, holds a vital role as a friction additive in brake pad formulation, significantly elevating the braking performance of the pads. Its inclusion is paramount in enhancing the brake pad's friction coefficient, a fundamental factor in efficient and effective braking. Sorghum husk's fibrous composition contributes to creating substantial friction between the brake pad and the braking surface, enabling a rapid and controlled reduction in the vehicle's speed. Moreover, sorghum husk offers the advantage of being eco-friendly and sustainable, aligning with modern endeavors for environmentally conscious brake pad manufacturing. Utilizing sorghum husk as a friction additive not only optimizes brake performance but also promotes the repurposing of agricultural waste, contributing to a circular and sustainable economy. The friction-enhancing properties of sorghum husk are harnessed through meticulous blending and integration with other brake pad materials. This careful combination ensures that the brake pad achieves the desired balance of friction, wear resistance, and thermal stability, ultimately resulting in brake pads that are both high-performing and environmentally responsible.



(a) Raw product



(b) Bio char

Fig 4.9 Sorghum husk

4.1.5 Lubricant

Lubricants are essential components in brake pad compositions. They play a vital role in reducing friction and heat generated during braking, thus minimizing wear and tear on the brake components. This not only prolongs the lifespan of the brake pads and rotors but also contributes to smoother and quieter braking, enhancing the overall driving experience and safety

Graphite

Graphite, a prevalent additive in brake pad formulations, plays a pivotal role in enhancing critical aspects of brake pad performance. As a form of carbon, it introduces exceptional properties that significantly elevate the brake pads' efficiency. Notably, graphite's lubricating properties enhance the friction coefficient, allowing the brake pads to generate increased friction during braking, thus optimizing stopping power. Additionally, graphite's excellent thermal conductivity helps in efficient heat dissipation during braking, preventing brake fade and ensuring

consistent performance under high-temperature conditions. This property contributes to the brake pad's heat resistance, allowing it to withstand elevated temperatures without compromising its integrity or functionality. Graphite's wear resistance further augments the longevity of the brake pads, ensuring they endure prolonged use. Moreover, by reducing noise and vibration during braking, graphite improves the overall driving experience, making it quieter and smoother. Incorporating graphite as an additive in brake pad formulations exemplifies its significance in enhancing friction, thermal stability, wear resistance, and overall brake pad performance, contributing to safer and more efficient braking systems.



Fig 4.10 Graphite

Table 4.1 Composition for sample preparation

S.No	Materials	Sample 1		Sample 2		Sample 3	
		Weight in gms	Comp in %	Weight in gms	Comp in %	Weight in gms	Comp in %
1	Barium Sulphate	N	9%	41	7%	31	5%
2	Carbon Fiber	60	10%	60	10%	60	10%
3	Cashew Dust	51	9%	51	9%	51	9%
4	Coke	52	9%	52	9%	52	9%
5	Glass Fiber	150	26%	150	26%	150	26%
6	Graphite	100	17%	100	17%	100	17%
7	Rockwool	53	9%	53	9%	53	9%
8	Vermiculite	50	9%	50	9%	50	9%
9	Sorghum Husk	20	3%	30	5%	40	7%
10	Phenolic resin	200		200		200	

4.2 METHODOLOGY

The below listed materials were used to prepare sample and measured in term of weight (grams). Each material was measured separately and mix the materials well to achieve a homogeneous blend to ensure even distribution of the components within the mixture. This mixing process was crucial and prepare three different compositions, each with varying ratios as mentioned below

- a.) sample 1 with composition of 5% Sorghum Husk,
- b.) sample 2 with composition of 10% Sorghum Husk and
- c.) sample 3 with composition of 15% Sorghum Husk.

These percentage variation of mixture of sorghum husk was balanced with fillers. The Composite percentage varies as mentioned in the Table 4.1

4.2.1 Material Mixing and Preparation

During the crucial stage of material mixing and preparation, begin by carefully gathering the specified components for eco-friendly brake pad production. This includes sourcing sorghum husk, a sustainable choice, and a variety of fibers encompassing carbon, aramid, glass, and natural options. Additionally, introduce phenolic resin, a vital binder, along with designated fillers like BaSO₄, vermiculite, and cashew dust. Adhering to the predetermined ratios, thoroughly blend these elements to forge a seamless and uniform amalgamation. Central to this process is ensuring the consistent dispersion of sorghum husk throughout the entire mixture, a key factor in optimizing its integration and thereby make larger the brake pad material's overall effectiveness and sustainability.

4.2.2 Molding the Specimens

In the crucial step of molding the specimens, employ a molding press or a mold tailored to replicate the standard brake pad's shape and dimensions. With precision, position the blended mixture into the mold, ensuring it conforms to the mold's shape. Engage the molding press to exert the necessary pressure, compacting the mixture effectively. This compression process is essential to achieve the desired density and structural integrity of the brake pad specimen, a fundamental aspect in ensuring its optimal performance and adherence to study references.

4.2.3 Curing

Transitioning to the critical curing phase, Finely transport the molded brake pad specimens to an oven, preparing them for the next stage of their transformation. It's essential to precisely observe and accordance with the prescribed curing temperature and duration specified by the characteristics of the phenolic resin binder. Following these precise parameters is vital, allowing the resin to efficiently bond and solidify the brake pad specimens. This controlled curing process is fundamental, enabling the brake pads to attain the intended properties, ensuring they are well-equipped for optimal friction, wear resistance, and durability, thereby contributing to enhanced and secure braking performance.

4.2.4 Cooling and Demolding

As we advance to the critical stage of cooling and demolding, exercise patience as the brake pad specimens undergo the transition from the elevated curing temperature to room temperature. This cooling period is essential, allowing the materials within the specimens to settle and stabilize, harden their structural integrity. Once the specimens have sufficiently cooled, shift focus to the delicate process of demolding. Handle each brake pad specimen with precision and care, ensuring it retains the desired shape and structure acquired during the molding and curing phases. Gently extract the specimens from the molds, unveiling the final form of the eco-friendly brake pads. This demolding stage marks a crucial point, where the precise preparation and shape crafting, setting the stage for subsequent testing and validation, and ultimately, their integration into sustainable and efficient braking systems.

4.2.5 Cutting and Shaping

Progressing to the cutting and shaping stage, precision is the main factor. Using cutting tools or precision machining as needed to shape the brake pad specimens into precise dimensions suitable for diligent testing. It is imperative to maintain an steady focus on uniformity, guaranteeing consistency in both

dimensions and thickness throughout the specimens. This stage demands a keen eye for detail and a steady hand to refine the brake pad specimens, preparing them for the crucial phase of testing where their performance and quality will be thoroughly examined. Uniformity in shape and size is fundamental to ensure accurate and definitive evaluation during the testing process.

4.2.6 Surface Preparation

Begin on the critical phase of surface preparation, precise attention is directed towards refining the brake pad specimens in readiness for rigorous testing. The foremost objective is to achieve a smooth surface devoid of any irregularities or impurities that might compromise the accuracy and integrity of subsequent test results. Employ a thorough cleansing process to eliminate dust, debris, or any foreign matter that may have settled on the specimen's surface during earlier manufacturing stages. Subsequently, engage in smoothing techniques such as sanding, polishing, or grinding to attain an fine even surface. This is paramount as it establishes a consistent baseline for testing, ensuring that the specimen's true performance can be accurately evaluated without any interference from surface imperfections. The endeavor for a flawlessly smooth surface underscores the meticulousness and precision inherent in this preparation stage, setting the stage for reliable and comprehensive testing, pivotal to the validation and optimization of the eco-friendly brake pad's functionality and efficiency.

5. TESTING AND ANALYSIS

After the composite preparation, samples are cut into specific dimensions as per ASTM standards to examine their mechanical and wear properties, which are shown in below picture and shows ASTM specifications and experiments. This analysis examined with three different composition as mentioned below

- a.) sample 1 with composition 5% of sorghum husk,
- b.) sample 2 with composition of 10% of sorghum husk and
- c.) sample 3 with composition of 15% of sorghum husk



Fig 5.1 Test Specimen as per the ASTM standard specifications

Table 5.1 ASTM Standards for testing

Observation	Standard
Tensile strength	ASTM D638-10
Flexural properties	ASTM 0790-17
Compression strength	ASTM D695
Izod impact	ASTM D256-10
Hardness	ASTM D2344
Wear resistance	ASTM G99-17
SEM	ASTM E986

5.1 TENSILE STRENGTH (ASTM D638-10)

Test Method: ASTM D638-10 specifies a method for determining the tensile properties of plastics, composite materials, and films.

Procedure: A rectangle shaped specimen is gripped at its ends using specialized fixtures. A universal testing machine applies a constant pulling force (tensile load) to the specimen at a controlled rate, typically in millimeters per minute. The machine records the load applied and the corresponding elongation (change in length) until the specimen fractures. Tensile strength has to be calculated by dividing maximum load applied to the cross-sectional area of the specimen. Additionally, the test assists in identifying the material's breaking point, contributing to a comprehensive understanding of its structural integrity and suitability for specific application.



Fig 5.2 Tensile testing

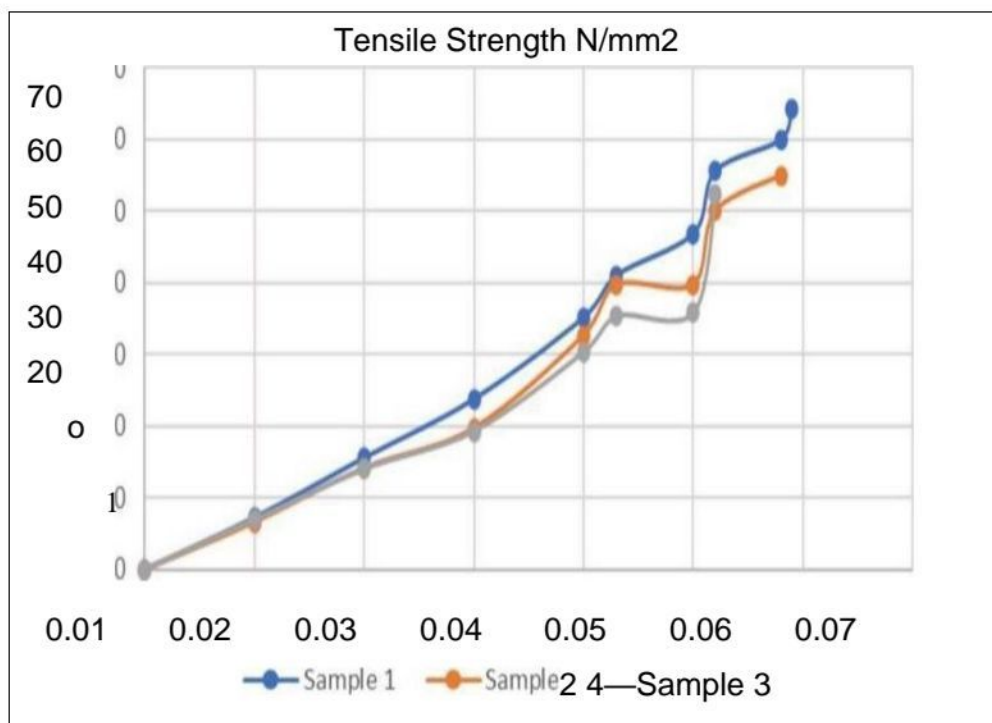


Fig 5.3 Result graph for tensile Strength

Table 5.2 Tensile Strength

Composition	Tensile Strength N/mm ²
Sample 1	64.25
Sample 2	54.98
Sample 3	52.23

5.2 FLEXURAL PROPERTIES (ASTM 0790-17)

Test Method: ASTM D790-17 outlines the procedure for determining the flexural properties of unreinforced and reinforced plastics and electrical insulating materials.

Procedure: A rectangular specimen is supported at two points, typically 16 times its thickness apart. A load is applied at the center of the specimen, causing it to bend. The machine measures the load and deflection, allowing the calculation of properties such as flexural strength (maximum load) and flexural modulus (stiffness).



Fig 5.4 Flexural testing

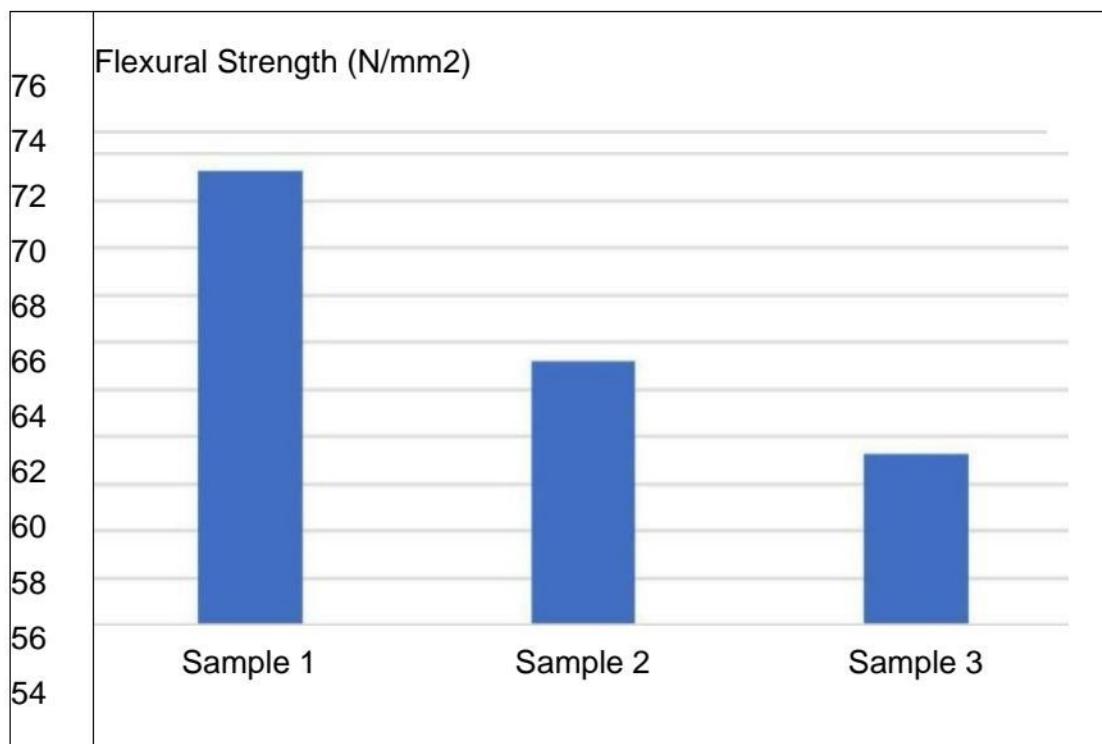


Fig 5.5 Graph representation of Flexural Strength

Table 5.3 Flexural Strength

Composition	Flexural Strength (N/mm2)
Sample 1	73.24
Sample 2	65.18
Sample 3	61.27

5.3 COMPRESSION STRENGTH (ASTM 0695)

Test Method: ASTM D695 specifies the testing procedure for compression strength of rigid plastics.

Procedure: A cylindrical or cubical specimen is placed between two flat, parallel plates in a testing machine. A constant axial load is applied at a controlled rate until the specimen fractures. The machine records the applied load and measures the specimen's cross-sectional area, allowing for the calculation of compression strength.



Fig 5.6 Compression Testing

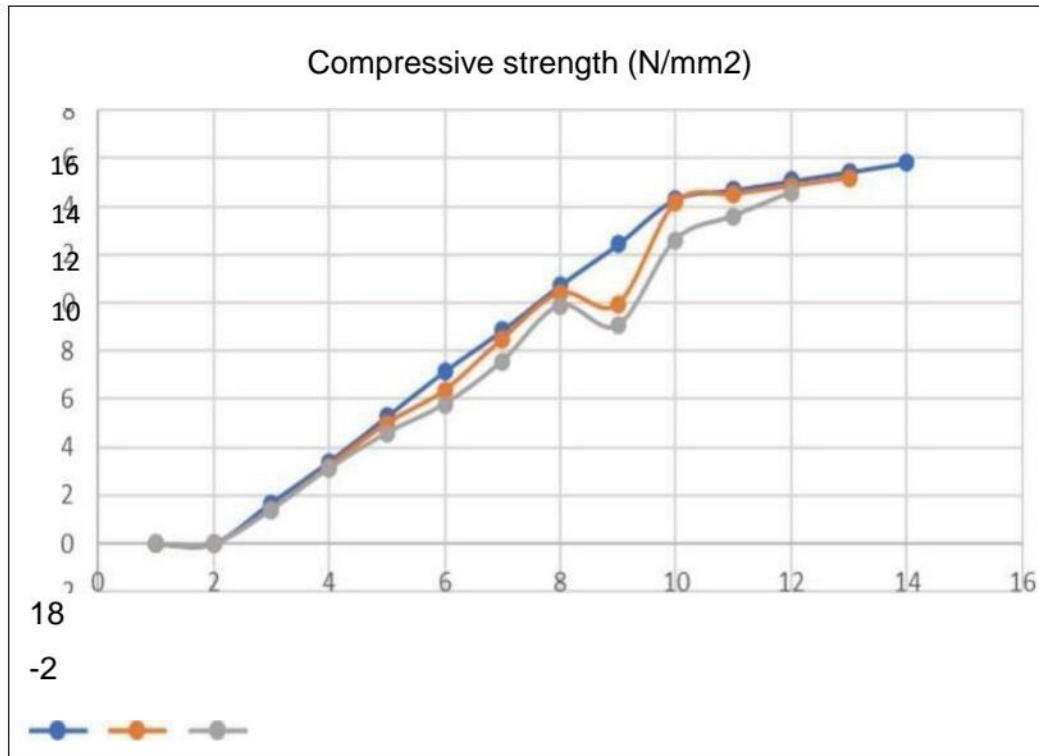


Fig 5.7 Result graph for compressive Strength

Table 5.4 Compressive Strength

Composition	Flexural Strength (N/mm2)
Sample I	39.98
Sample 2	32.01
Sample 3	30.63

5.4 IZOD IMPACT TEST (ASTM D256-10)

Test Method: ASTM D256-10 is used to determine the impact resistance of plastics.

Procedure: A notched or unnotched specimen is clamped vertically, and a pendulum is released to strike the specimen. The machine records the energy absorbed during fracture, which is a measure of the material's toughness. This test is particularly useful for assessing the impact resistance of composite materials.



Fig 5.8 Izod impact test

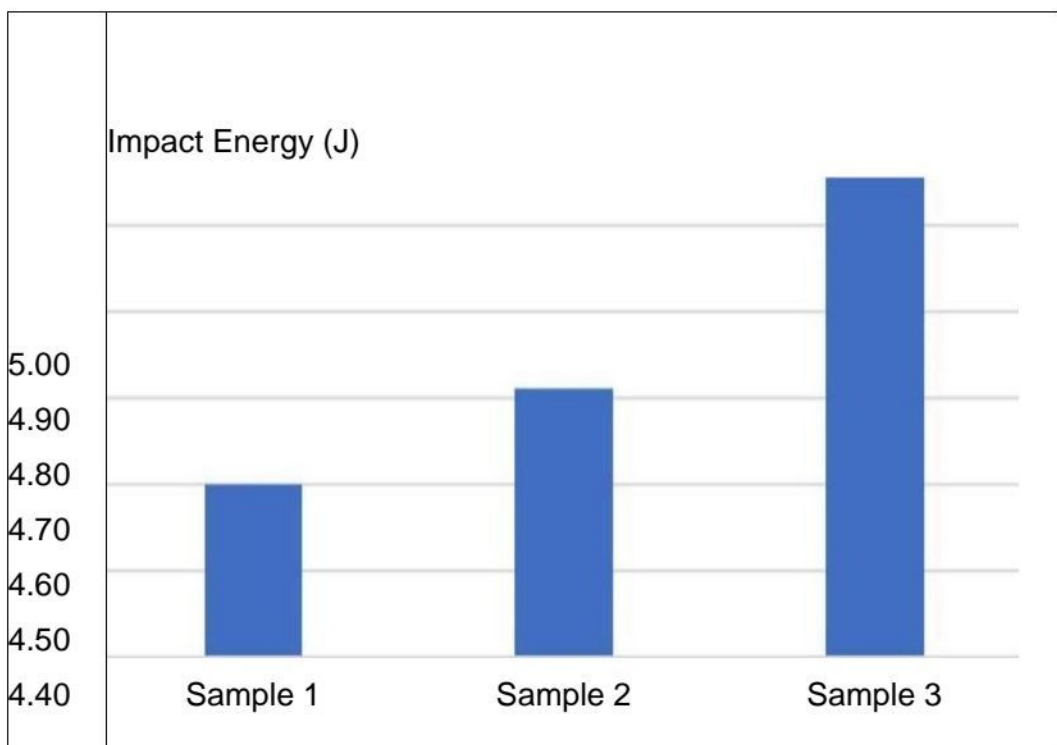


Fig 5.9 Graph representation for Impact Energy

Table 5.5 Impact Energy

Composition	Impact Energy (J)
Sample 1	4.60
Sample 2	4.71
Sample 3	4.95

5.5 HARDNESS (ASTM D2344)

Test Method: ASTM D2344 specifies the Barcol hardness test for composite materials.

Procedure: A pointed indenter is pressed into the material, and the depth of penetration is measured. The indenter is mounted on a calibrated spring-loaded system. The test provides a numerical reading that correlates with the material's hardness. Higher values indicate greater hardness.

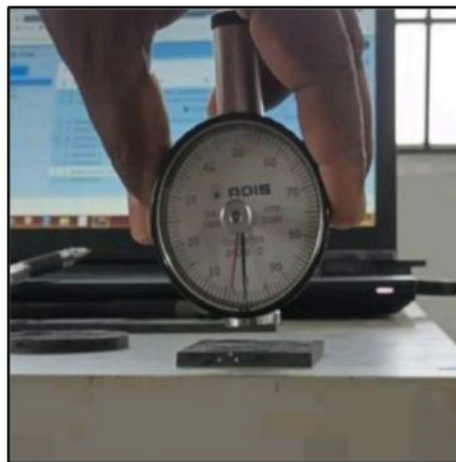


Fig 5.10 Hardness shore D test

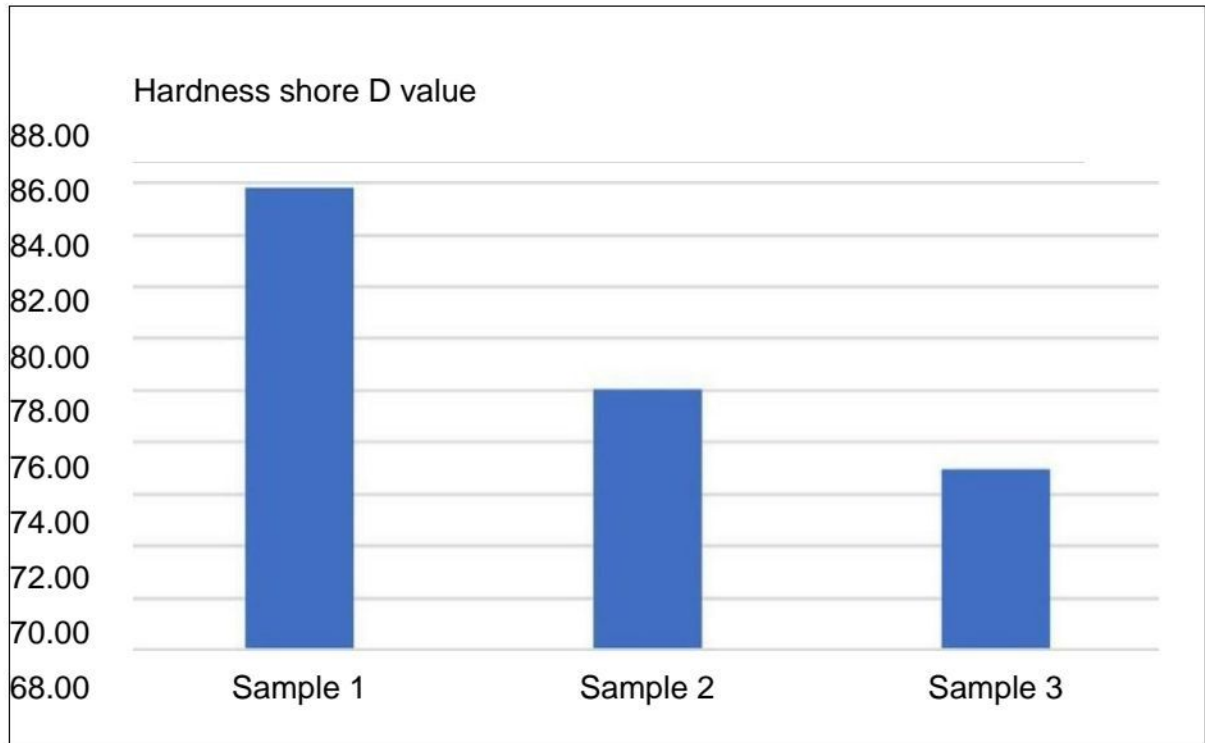


Fig 5.11 Graph representation for impact energy

Table 5.6 Hardness shore D

Composition	Hardness shore D value
Sample I	85.80
Sample 2	78.08
Sample 3	74.95

5.6 WEAR RESISTANCE (ASTM G99-17)

Test Method: ASTM G99-17 outlines procedures for determining wear resistance using abrasive or abrasive-laden environments.

Procedure: There are various methods, including the dry sand/rubber wheel abrasion test and the Taber Abraser test, depending on the type of wear being assessed. In these tests, a specimen is subjected to abrasive conditions, and the loss of material is measured, indicating its wear resistance.

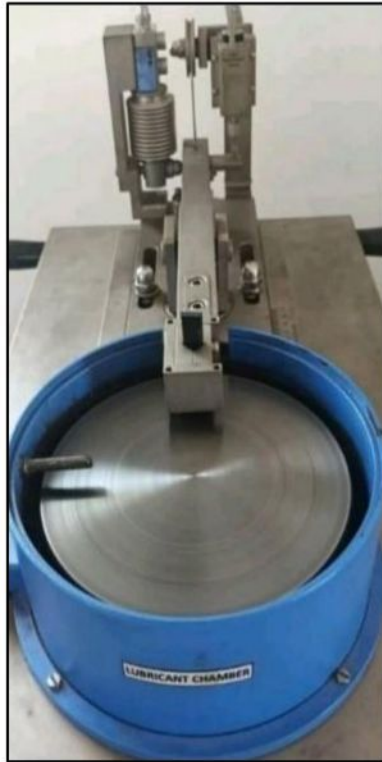


Fig 5.12 Wear resistance testing

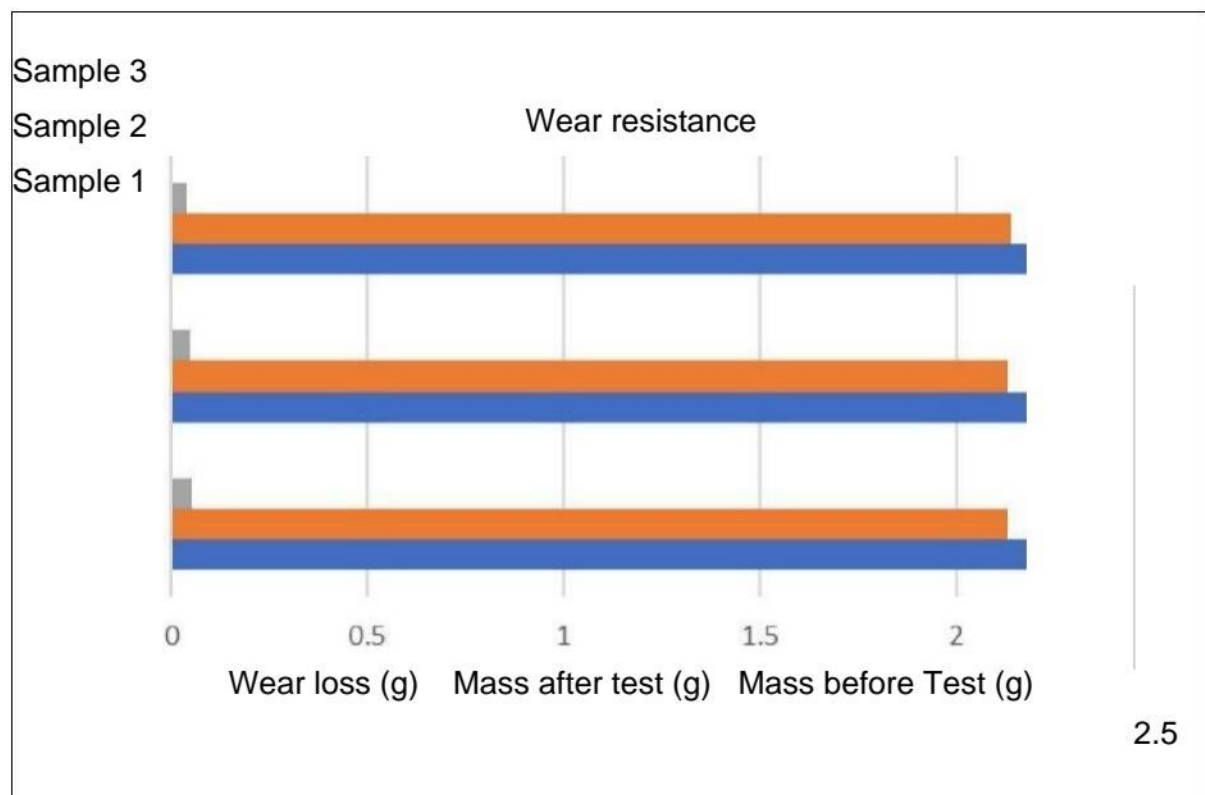


Fig 5.13 Graph for Wear Resistance

Table 5.7 Wear Resistance

Observation	Sample 1	Sample 2	Sample 3
Mass before Test (g)	2.181	2.181	2.181
Mass after test (g)	2.129	2.132	2.14
Wear loss (g)	0.052	0.049	0.041

5.7 SEM (Scanning, Electronic & Microscope) (ASTM E986)

Test Method: (ASTM E986) outlines procedures relies on the detection of high energy electrons emitted from the surface of a sample after being exposed to a highly focused beam of electrons from an electron gun. This beam of electrons is focussed to a small spot on the sample surface, using the SEM objective lens.

Procedure: The procedure for SEM (Scanning Electron Microscopy) analysis of a crystal sample typically involves the following steps:

1.Sample Preparation: The crystal sample needs to be properly prepared for SEM analysis. This usually involves mounting the sample on a conductive substrate and coating it with a thin layer of conductive material (such as gold or carbon) to enhance imaging and reduce charging effects.

2.Instrument Setup: The SEM instrument needs to be properly configured for the analysis. This includes setting the appropriate voltage, current, and working distance parameters based on the characteristics of the sample and the desired imaging resolution.

3.Sample Loading: The prepared crystal sample is loaded into the SEM chamber, ensuring that it is securely mounted and properly aligned for imaging.

4.Imaging: The SEM instrument is used to scan the surface of the crystal sample with a focused electron beam. Secondary electrons emitted from the

sample surface are collected to create high-resolution images of the sample's morphology and structure.⁵ Analysis: Once the images are obtained, various analysis techniques can be applied to the SEM data to extract information about the crystal structure, such as crystallographic orientation, grain boundaries, defects, and surface features.

5.Interpretation: Finally, the SEM images and analysis results are interpreted to gain insights into the crystal sample's properties and characteristics.



Fig 5.14 SEM Testing

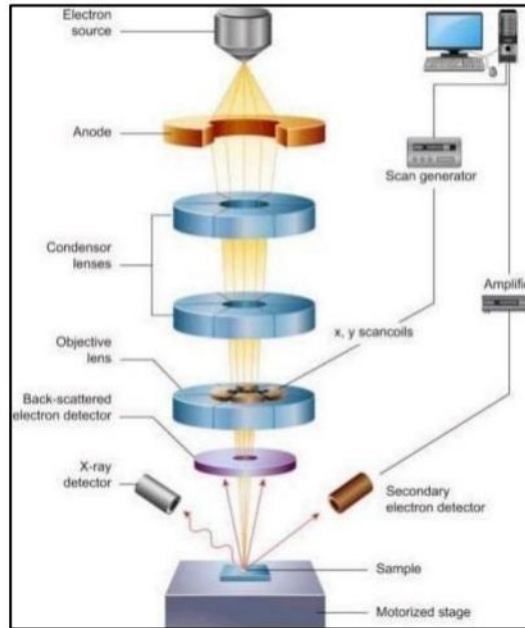


Fig 5.15 SEM (Scanning, Electronic & Microscope)

Table 5.8 SEM (Scanning, Electronic & Microscope)

Sample 1	Sample 2	Sample 3
5% sorghum husk composite	5% sorghum husk composite	5% sorghum husk composite
Highly reacted filler phase Ductile fracture fibre	Si₃N₄ Biochar Matrix	Si₃N₄ Toughness improved matrix Shear cups

While the results indicate that there isn't a significant difference in wear SEM among the tested composites. But considering other factors potential of the 5% sorghum husk composite as a promising material for brake pads, offering enhanced SEM compared to composites with higher sorghum husk concentrations.

6. CHALLENGES AND FUTURE DIRECTION

6.1 CURRENT CHALLENGES IN IMPLEMENTING ECO-FRIENDLY BRAKE PADS

Material Optimization: Achieving the perfect material blend for eco-friendly brake pads remains a challenge. It involves meticulous testing and fine-tuning to ensure the balance between environmental responsibility and brake performance. Researchers are continually exploring new materials and refining existing ones to meet the safety and sustainability criteria.

Cost Considerations: Eco-friendly materials can be more expensive, posing a challenge to market acceptance. To overcome this, manufacturers must explore ways to reduce costs while maintaining high-performance standards, making ecofriendly brake pads accessible to a broader consumer base.

Regulatory Compliance: Adapting to evolving regulations regarding brake pad composition is an ongoing challenge. Brake pad manufacturers must keep pace with changing environmental and safety standards, making research and development a continuous process.

Public Awareness: Raising consumer awareness about the advantages of eco-friendly brake pads and the environmental impact of traditional options is a priority. It's crucial for consumers to understand how their choices can contribute to a greener automotive industry.

6.2 FUTURE PROSPECTS AND AREAS FOR IMPROVEMENT

Advanced Composite Materials: Research into advanced composite materials, including innovative natural fibers and additives, holds great promise for eco-friendly brake pads. These materials can enhance both performance and sustainability.

Nanotechnology: Leveraging nanomaterials can lead to significant breakthroughs in brake pad technology. Nano-enhanced materials have the potential to significantly boost friction, wear resistance, and thermal stability, ensuring better overall brake performance.

Recyclable and Biodegradable Materials: Integrating recyclable and biodegradable components in brake pads aims to reduce waste and lessen the environmental impact of disposal. This direction aligns with the broader goal of achieving a circular economy in the automotive sector.

Smart Brake Pads: The development of smart brake pads with integrated sensors and real-time monitoring capabilities can enhance safety and efficiency. These pads have the potential to adapt to varying driving conditions and provide valuable data on brake performance.

Consumer Education: Increasing public awareness about the environmental and safety benefits of eco-friendly brake pads is essential. Manufacturers, government agencies, and environmental organizations need to collaborate on educational initiatives to inform consumers about their choices' positive impacts. **Global Adoption:** Encouraging the global adoption of eco-friendly brake pads is vital for reducing the automotive industry's environmental footprint. Standardization and international cooperation will play a pivotal role in this transition.

Collaboration and Research: Collaborative efforts between automotive manufacturers, material scientists, and environmental agencies are essential for driving innovation and ensuring eco-friendly brake pads become the industry norm. Sharing knowledge and expertise will accelerate the transition to greener braking systems.

7.CONCLUSION

7.1 SUMMARIZATION OF FINDINGS

In this comprehensive study, the findings reveal that incorporating sorghum husk as a friction additive in eco-friendly brake pads is a promising and environmentally responsible approach. The brake pads formulated with different percentages of sorghum husk, specifically 5%, 10%, and 15%, exhibited competitive performance in various mechanical and tribological tests. The test results demonstrated that these brake pads comparatively 5% combination performs better in essential parameters, including friction, wear resistance, thermal conductivity, and water absorption. This innovation aligns with the global shift toward eco-friendliness in the automotive industry, reducing the environmental footprint while maintaining or enhancing braking performance.

7.2 IMPLICATIONS AND SIGNIFICANCE OF BRAKE PADS WITH SORGHUM HUSK

The successful development and testing of eco-friendly brake pads with sorghum husk have significant implications and relevance. Firstly, these brake pads offer a viable and sustainable solution to mitigate the environmental and health concerns associated with conventional brake pad materials, particularly asbestos-containing ones. The use of sorghum husk contributes to reduced waste and minimized carbon footprint. Furthermore, the adoption of sorghum husk brake pads is aligned with the automotive industry's transition toward more eco-conscious practices. As governments and consumers increasingly prioritize sustainability, the introduction of such brake pads can enhance a company's reputation and market competitiveness. The incorporation of sorghum husk in brake pad formulations represents a noteworthy advancement in eco-friendly materials for the automotive sector. It holds the potential to revolutionize the braking industry by offering a safer, more sustainable, and environmentally responsible choice for vehicles, thereby contributing to a greener and healthier future.

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