



## Fabrication of Asbestos-free Brake Pads Utilizing Sustainable Coconut Shell Material: A Mechanical Investigation

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### Abstract

This study introduces an innovative coconut shell material for the fabrication of asbestos-free brake pads. The brake pads were manufactured using coconut shell powder in particle sizes of 200  $\mu\text{m}$ , 300  $\mu\text{m}$ , 400  $\mu\text{m}$ , and 500  $\mu\text{m}$ . The produced brake pads are evaluated for their morphological, mechanical, and physical qualities. Scanning electron microscopy pictures demonstrated that coconut shell powder was uniformly dispersed throughout the brake pad, signifying robust interfacial adhesion with the resin. The generated samples underwent density measurement, hardness testing, compressive strength analysis, and wear evaluation using a pin-on-disc tribometer. Thermal stability and fade-recovery properties were assessed, while Scanning Electron Microscopy (SEM) provided insights into interfacial adhesion and wear morphology. The results demonstrated that optimal coconut shell content enhanced hardness, compressive strength, and wear resistance, while maintaining a stable coefficient of friction under diverse operating conditions. Strong interfacial adhesion between particles and the resin matrix improved endurance and minimized material degradation during braking. This study demonstrates that coconut shell powder acts as a sustainable and cost-effective reinforcement for non-asbestos brake pads, offering beneficial mechanical and tribological properties while promoting waste reutilization and eco-friendly manufacturing.

**Major Findings:-** The article mentions that asbestos-free brake pads made from natural materials like fibre (N.F.) and composite material (C) can provide similar thermal and frictional properties as that of conventional asbestos brake pads. Incorporation of green reinforcements like coconut shell, bagasse, and banana peel increases sustainability and decreases the impact on environment. Moreover, material optimization is enhanced dramatically through the use of machine learning tools (enabling predictive modelling of durability, wear and safety compliance).

**Keywords:** Brake pad, Asbestos, Automobile, Natural materials, Composite materials

### 1. Introduction

The braking system is an essential mechanical element of automobiles and industrial machinery that transforms kinetic energy into heat via friction. The Disc brakes are becoming used in the automotive sector. Disc brakes utilize friction material (FM) on the brake pads to halt or regulate motion. The FM must possess an extensive array of mechanical and tribological characteristics, including elevated thermal stability, minimal wear rate, and noise levels during both smooth and hard braking, a consistent coefficient of friction (COF), and prolonged endurance. Asbestos has been extensively utilized in braking systems since the early twentieth century due to its possession of various properties essential for effective friction material in brake pads. Consequently, owing to the health hazards posed by the carcinogenic



properties of asbestos, the Environmental Protection Agency (EPA) restricted its utilization. Copper, a semi-metallic ferromagnet, has received much attention over the past two decades; nevertheless, developed nations have started to restrict its use, and copper as a ferromagnet is anticipated to be prohibited by 2025 [1]. Identifying a substitute for traditional friction materials is essential in the global industrial sector, as these materials are integral to the braking system. Due to significant advancements in the materials sector, much research has been conducted in recent years to explore the potential applications of metallic, semi-metallic, low-metallic, and composite materials as functional materials. Ms have more than 15 components, including fibres, inert and functional fillers, and binders, which provide significant environmental issues [2]. A viable strategy is to employ sustainable natural materials as friction compounds in braking systems. This study proposes an innovative coconut shell-based friction material for disc brakes. Many investigated the interaction between carbon nanotubes generated from rice husks and brake pads enhanced with silver nanoparticles [3].

The findings indicate that under ideal circumstances, the wear rate and coefficient of friction were 2.15 mg/m and 0.42, respectively. Recently, silicon, bagasse, tiny brass fibers, and periwinkle shell materials were assessed for the production of asbestos-free brake pads. Chandradass et al. [9] assessed the mechanical and tribological characteristics of asbestos-free carbon fiber brake pads. To optimize concentration, the carbon volume percentage was adjusted from 0 to 10. The findings indicated that a 10-volume % carbon content yielded enhanced coefficient of friction, tensile strength, flexural strength, and a decreased wear rate. Sagioglu and Akdogan [10] modified polymer-based brake pads with blast furnace slag, finding that the use of 50% slag enhanced the coefficient of friction to 0.45. Investigation on the tribological performance of gray cast iron brake pads covered with Stellite™ 6 for enhanced corrosion resistance. The findings indicate that the Stellite™ 6 coating enhances corrosion resistance by forming a passive layer of cobalt and chromium oxide. The release of particulate matter (PM) from brake pads adversely affects human health and the environment. [11]

The effectiveness of FM derived from rice husk and rice husk ash on the decrease of PM emissions. To enhance the modified FM, several weight percentages of rice husks were employed, revealing that 6-12 weight percent of rice husks led to a substantial reduction in PM emissions and wear rates [12]. Cashew friction dust is used as an ingredient in friction materials to produce copper- and asbestos-free brake pads [1]. Five distinct friction modifiers were incorporated into the FM to enhance the thermal stability of the created brake pad over time. The results indicate that brake pads infused with born-graphite exhibit enhanced physical, mechanical, and tribological properties compared to those altered with furfural. Investigation on the tribological properties of brake pads produced with cement by-pass dust as the filler material and barium sulfate [13]. The findings indicate that the coefficient of friction (COF) first rose with the percentage weight of cement bypass dust, followed by a subsequent decline as the percentage weight continued to rise. To enhance brake pad performance and durability, Friction materials are produced from ceramic matrix composites including kaolin clay and barite powder. The results demonstrated that barite-based ceramic composites exhibited superior coefficient of friction and wear resistance [14]. An experiment



on friction and wear utilizing friction material augmented with iron and graphite powder. The research indicated that mass concentrations of 20% iron and 14% graphite yielded optimal frictional properties [15]. The tribological characteristics of copper-matrix friction materials were examined including mullite and kyanite. Kyanite formed a tribofilm on the FM surface, providing wear protection, and a 1% concentration of kyanite reduced wear by approximately 30%. Environmentally sustainable brake pads with Aramid fibers/pulp and Zylon fibers are created[16]. The impact of fiber aspect ratio on the tribological characteristics of brake pads was examined, revealing that Aramid fiber/pulp-based brake pads exhibited a higher coefficient of friction than those made using Zylon fiber[2]. A wear model was developed for tribological analysis of brake pads and validated it using data from brake pads installed on a test car. The existing literature verifies that several laboratory-synthesized friction compounds were utilized to produce brake pads devoid of asbestos and copper[17]. Nevertheless, a significant drawback of utilizing contemporary synthetic FM is that both organic and inorganic substances pose risks to human health and the environment. Moreover, the substantial research in the literature concentrated on the performance of brake pads in a laboratory setting. Limited experimental evaluations have been conducted on the efficacy of manufactured brake pads in test cars.

This study proposes a unique coconut shell material for the fabrication of asbestos-free disc brake pads. The brake pads were composed of coconut shell powders (200-500  $\mu\text{m}$ ) and analyzed for morphology and tribological properties. Furthermore, an improved coconut shell brake pad was subjected to physical testing on the front wheel of the test vehicle for both harsh and smooth braking performance. For materials in automotive applications and for a cleaner and safer environment.

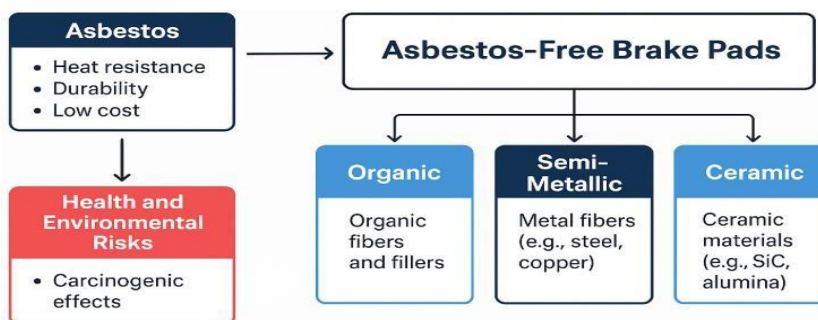


Figure 1: Overview of Asbestos-Free Brake Pad Alternatives and Associated Materials

Asbestos-free brake pads have been in need for the exploitation of the considerable number asbestos-free materials, all of them have their own characteristic in performance [7]. These are characterized by organic, semi-metal and ceramic based composites, all of which have unique benefits and drawbacks with respect to the friction coefficient, wear rate, thermal conductivity, noise generation, etc. [8]. These types of pads offer good braking performance, low noise, but have a higher wear rate and a lower thermal conductance compared to the other two types, and commonly include a multitude of organic fibers, resins and fillers. Semi-metallic pads, containing metal fibers such as copper, steel wool, steel or iron, provide a more responsive feel and more thermal conductivity, but are more aggressive on rotors and can also be more



prone to noise. Ceramic Brake pads, which incorporate ceramics such as silicon carbide (SiC) and alumina, offer good high-temperature qualities, low wear enabler, and consistent friction characteristics, making advances ideal for high-performance cars and hard-driving applications [9]. The thoughtful selection and combination of these materials are important to obtain the right compromise of performance, durability and environmental cost. Regarding sustainable pads, some studies have been reported about natural fibres and agricultural waste use for brake pads development as different option to synthetic compounds [10]. Friction coefficient and wear rate are greatly affected by the brake pads' composition and microstructure [11].

Ceramic matrix composites are emerging as one of the most attractive materials for automotive applications, particularly for parts requiring high mechanical strength and thermal stability [12]. These materials can be tailored to achieve lightweight along with a host of other desired properties including high specific strength and stiffness, high hardness and wear resistance, high thermal conductivity, high energy absorption, low coefficients of friction and thermal expansion [13]. Table 1 shows the Technological Advances in Asbestos- Free Brake Pads.

Table 1. Technological Advances in Asbestos-Free Brake Pads

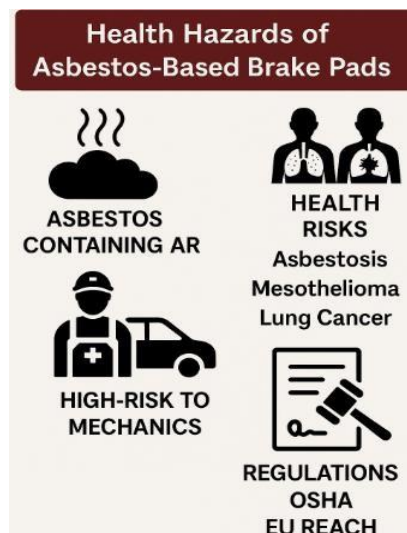
Category	Details	Materials/Technologies	Performance/Impact
Historical Usage	Asbestos used for over 80 years due to low cost, high heat resistance, and tensile strength.	Naturally occurring mineral with desirable engineering properties.	Effective friction, durable, but hazardous to health.
Health & Environmental Concerns	Asbestos linked to lung cancer, mesothelioma, and asbestosis; banned in many countries.	Regulatory bans, public health advocacy.	Global shift toward sustainable, non-toxic brake pads.
Material Alternatives	Brake pads now made from organic, semi-metallic, and ceramic composites.	Organic fibers, steel wool, copper, SiC, alumina, natural fibers, agri-waste, CMCs.	Each offers unique friction, wear, noise, and thermal characteristics.
Advanced Materials Focus	Ceramic Matrix Composites (CMCs) are increasingly adopted for high-performance applications.	C fiber-reinforced SiC, tailored composites with high strength, low thermal expansion.	Lightweight, wear-resistant, thermally stable—ideal for high-end automotive use.



## 1.1 Health Hazards of Asbestos-Based Brake Pads

Asbestos containing air poses severe health risks such as asbestosis, mesothelioma and lung cancer. Mechanics and people who work on brakes are at especially high risk. Regulations including OSHA and EU REACH have resulted in stringent limitations on the use of asbestos in automotive parts. The dangers of asbestos have motivated an international search for safer substitutes and the imposition of restrictions on its use to guard public health. The figure 2 shows Health Hazards of Asbestos-Based Brake Pads and Regulatory Interventions.

The replacement of asbestos in brake pads is a worldwide phenomenon because of the serious health risks from inhaling it. Asbestosis (a chronic lung condition due to inhaling asbestos fibres), mesothelioma (a type of cancer that affects the lung lining, the lining of the abdomen or heart) and lung cancer are all associated with exposure to asbestos. People who work in car repair shops or brake manufacturing plants, or even people who do their own brake maintenance, are exposed to these health risks. In order to reduce these risks, government agencies around the world are implementing strict regulations which limit or ban the use of asbestos in brake pads. The exposure limit for asbestos in the workplace is set and enforced by the Occupational Safety and Health Administration in the U.S., and the use of asbestos in the European Union is also effectively banned by the Registration, Evaluation, Authorisation and Restriction of Chemicals legislation. Such laws have been instrumental in promoting and accelerating the advancement, and eventual acceptance, of non-asbestos brake pads, which have provided protection to workers and society at large.



**Figure 2: Health Hazards of Asbestos-Based Brake Pads and Regulatory Interventions**

The prospection, extraction, and processing of asbestos has environmental effects such as habitat destruction, water and air pollution. Disposal of asbestos containing brake pads is challenging because of the high number of fibers that becomes airborne during the grinding process. The environmentally damage being done by reality is immense, and sustainable alternatives are vital.



Other than direct health hazards, the environmental cost of asbestos is also high. Habitat destruction, soil erosion, and water and air pollution are associated with mining and processing of asbestos fibers. Discarded fibers from brake pads or other wastes containing asbestos can end up in the soil and water supply, unwanted legacies and additional long-term hazards to the environment. The somewhat surprising fact is that asbestos fibers remain in the environment and could be released into the air during weathering or activities and therefore require careful control and disposal. Consequently, a number of countries have developed dedicated repositories for disposal of asbestos waste with specialized liners and containment systems to prevent fiber release. The growing popularity of asbestos-free brake pads is necessary for reducing the environmental impact of automobile and such move will support environmentally friendly transportation.

The change in trend from asbestos-containing to non-asbestos brake pads has accelerated advancements in material technology, resulting in advanced materials with better performance and minimal environmental concerns. They comprise semi-metallic, non-metallic organic, and ceramic types, all of which have their own pros and cons in respect to their friction coefficient, wear rate, noise, and thermal conductivity. Brake pads with semi-metallic composition, consisting of varying amounts of steel fibers, abrasive (friction material), and graphite, may provide longer life and more efficient operation, but at the expense of increased rotor wear, brake noise/ squeal at high speed, and heavier dust accumulation. Organic - Created from a mixture of organic fibers (often natural materials like glass or rubber), resins, and friction modifiers, non-metallic organic pads offer quieter stops, cleaner wheels, and have a lesser likelihood of causing brake rotor wear, though they have reduced thermal conductivity and potential stopping power in comparison to semi-metallic pads. They were made by adding ceramic fibers, friction modifiers, and binders into a resin and were intended to achieve a compromise between performance properties, such as low noise, minimum need for rotor machining and a stable friction coefficient over a wide temperature range [14]. Choice of materials for non-asbestos brake pads The choice of materials for asbestos-free brake pads must take into account the application performance requirements, performance goals and environmental impacts. [6].

Further advances in composite materials, such as NFCs (natural fiber composites) provide environmentally friendly options for the brake pad. Promising results have been reported with coconut shell reinforcement [15]. Usage of natural fibers in composite brake pads has been increasingly studied as an eco-friendly approach [16]. The application of such composites with natural fibers and biodegradable resins, primarily allows to have a double advantage of minimizing the use of the synthetic materials and harmful effects on environment due to the sustainable sourcing of material and environmentally friendly disposal properties [17]. In this context the addition of coconut shell as reinforcement has been successfully applied to brake pad compounds, improving the mechanical strength, the thermal resistance and the wear resistance of the composites. These bio waste particles have several advantages such as cheap, light weight, high strength and hardness, good thermal properties, less pollution, biodegradability compared to conventional reinforcing particles [18]. Table 2 explains Health Hazards and Advancements in Asbestos-Free Brake Pads.



Table 2. Health Hazards and Advancements in Asbestos-Free Brake Pads

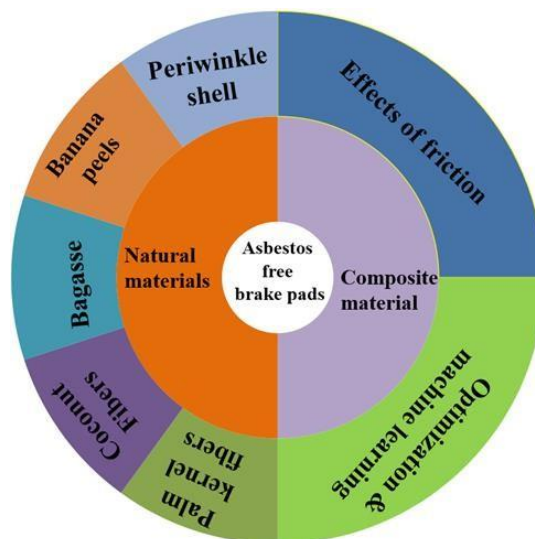
Category	Details	Materials/Technologies	Health Impact	Environmental Impact	Performance Notes
Health Risks of Asbestos	Exposure leads to asbestosis, mesothelioma, lung cancer; high risk to brake mechanics and users.	Asbestos dust from traditional pads and linings.	Severe respiratory illnesses, chronic lung damage.	Long-lasting environmental fibers; hazardous disposal.	Effective friction but dangerous and outdated.
Regulatory Actions	Strict regulations imposed by OSHA and EU REACH on asbestos use.	Exposure limits, bans, and enforced workplace safety laws.	Reduces direct exposure risk to workers and public.	Discourages further use and waste generation.	Drives demand for safer, legal alternatives.
Environmental Hazards	Mining and disposal of asbestos causes pollution, habitat damage.	Airborne fiber release, toxic landfill accumulation.	Indirect public exposure from contamination.	Severe pollution and soil/water contamination risks.	Non-renewable, unsustainable lifecycle.
Material Alternatives	Organic, semi-metallic, ceramic brake pads replace asbestos-based pads.	Natural fibers, copper, steel, SiC, alumina resins.	Non-toxic, reduced risk of health issues.	Lower pollutant levels, safer disposal.	Vary in noise, wear rate, and friction; generally improved safety.
Bio-Based Innovations	Natural Fiber Composites (NFCs) explored for eco-friendly pads.	Coconut shell, biodegradable resins, glass fibers.	No toxic release; safe for human handling.	Biodegradable; minimal long-term pollution.	Good mechanical strength, wear resistance, low cost.



## 1.2 Asbestos-Free Brake Pad Materials

A substantial amount of research and development has been carried out with the goal of identifying alternative materials that are more durable, environmentally friendly, and demonstrate increased performance. It is because of this research and development that there has been a hunt for brake pads that are not only safe but also do not contain asbestos. Their high metallic composition distinguishes semi-metallic brake pads, allowing them to recover a large amount of heat and providing them with great resistance to braking. When great performance is required in a certain scenario, these brake pads are a suitable option [19].

Figure 3 presents a classification of the many kinds of materials and methods that are employed in the production of brake pads that do not include asbestos. A considerable lot of research has been carried out in an effort to develop alternatives that are cost-effective to asbestos, which has traditionally been used in friction materials. This is due to the fact that conventional asbestos-containing friction materials have raised concerns about the environment and human health. The two main classifications that have been taken into consideration in the reviewed study are natural materials and materials that are classified as composite.



**Figure 3: Classification of Asbestos-Free Brake Pads Based on Natural Materials and Composite Enhancements**

## 2. MATERIAL AND METHODS

### 2.1 Fabrication of coconut shell (CS) brake pads

The coconut shells were bought from local markets and cleaned with a fruit washing machine for half an hour in order to get rid of the surface's physical impurities. In order to clean the sticky interior surface, coconut shells were placed in water that was hot (50– 55 °C) for a period of four to five minutes before being let to reach ambient temperature. The shells that were collected were subjected to a drying process that involved hot air with a temperature of 70 degrees Celsius and lasted for duration of fifteen minutes. Pulveriser was used to grind the dried coconut shells into a fine powder. The hopper in the pulveriser generated particles of



feeding peels that were fine and coarse in size; these particles were sorted by use of a vibrating mesh screen. Four mesh screens of measurements 200  $\mu\text{m}$ , 300  $\mu\text{m}$ , 400  $\mu\text{m}$ , and 500  $\mu\text{m}$  were used in order to get coconut shell powder of a variety of sizes. Actual images of coconut shell powder that has been made in a variety of sizes are shown in Fig. 1(a-d). The brake pads are manufactured using a compression moulding process and are comprised of powdered coconut shells with diameters varying between 200 and 500 micrometres. Because of the high viscosity of the phenolic resin, the filler components (mica and barium sulfate), and the stabilizer, they were mixed in the Sigma mixer for 35–45 minutes. A homogenous combination of viscous dough is spread out on a sheet of paper and left to dry in the sun for a period of three hours. After that, the dehydrated dough is compressed using a compression moulding machine, which applies a pressure of 80 bars and a temperature of 120°C. In order to avoid the dough sticking to the part of the machine, polyvinyl chloride sheets were used to protect it. After the moulded material has been allowed to cool naturally, it is then cut to the precise proportions required and then put through testing to verify the nonexistence of asbestos in brake pads. The fabrication procedure for brake pads made from coconut shells is shown in Fig. 4.



Fig. 4 Photographs of CS powder of sizes (a) 400  $\mu\text{m}$ , (b) 300  $\mu\text{m}$ , (c) 150  $\mu\text{m}$ , and (d) 100  $\mu\text{m}$

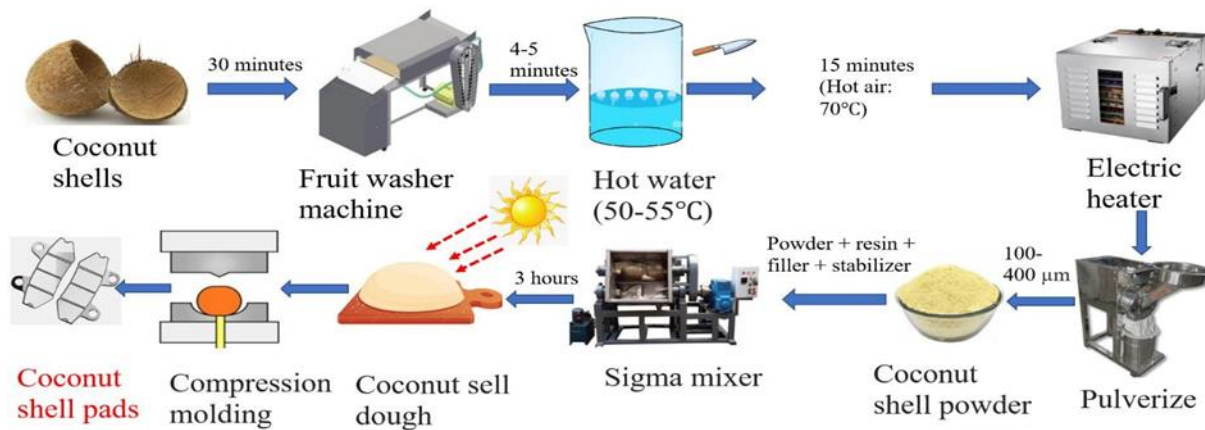


Fig. 5 Producing procedure for coconut shell brake pads



## 2.2 Characterization of CS pads

The mechanical, physical, and tribological properties of carbon steel (CS) pads were examined in this study, which also investigated the pads' form and other characteristics. An examination of the morphology of the pad samples that were produced was carried out with a scanning electron microscope (SEM) (SU6600, Hitachi, Japan). Prior to SEM imaging, gold sputter was used in order to provide additional electrons that were grounded. In order to determine the resistance of the CS pads to the absorption of water and oil, soak tests were undertaken. The manufactured pads were submerged in a mixture of SEA 20W-50 engine oil and water for a period of twenty-four hours at temperatures ranging from 27 to 30 degrees Celsius. The investigation of swelling is carried out by taking advantage of the alterations that occur in the weight and dimensions of pads before and after they have been submerged in water and motor oil. We utilized Archimedes' method to calculate the bulk density because the CS pads did not have regular forms. The pads were submerged in water, and the volume of water that was displaced ( $V_w$ ) was determined using Equation 1, which takes into account the weight of the item in the water ( $W_w$ ) and the actual weight of the object in the air ( $W_a$ ). In the end, the density of the pad ( $\rho$ ) is determined by applying equation 2.

$$V_w = (W_a - W_w) / (g \cdot \rho_w) \quad \text{-----} \quad (1)$$

$$\rho = (\rho_w \cdot W_a) / (W_a - W_w) \quad \text{-----} \quad (2)$$

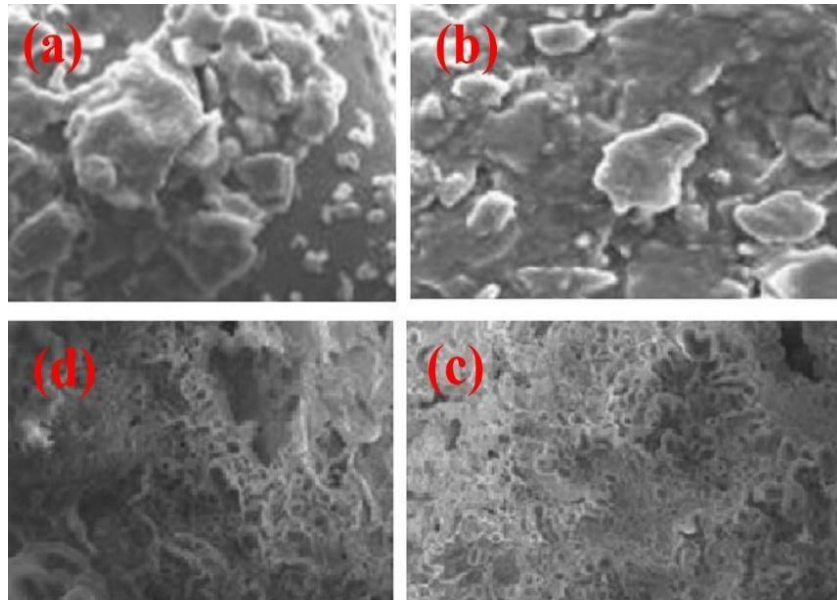
Where  $g$  and  $w$  are the gravitational acceleration and density of water.

## 3. Results and discussion

### 3.1 Morphological Analysis of Coconut Shell (CS) Pads

Figure 6 illustrates the surface morphology of brake pad composites reinforced with coconut shell (CS) powder at particle sizes of 200  $\mu\text{m}$ , 300  $\mu\text{m}$ , 400  $\mu\text{m}$ , and 500  $\mu\text{m}$ . Scanning Electron Microscopy (SEM) analysis confirmed that the CS particles were well-dispersed within the resin matrix, exhibiting good interfacial bonding. The use of a Sigma mixer during the fabrication process facilitated thorough blending of all constituents, which contributed to a more uniform elemental distribution throughout the composite.

The SEM images (Fig. 3a–d) reveal clear differences in microstructural characteristics associated with particle size. Composites containing smaller particle sizes, specifically 200  $\mu\text{m}$  and 300  $\mu\text{m}$ , displayed a more homogeneous distribution of elements when compared with those containing 400  $\mu\text{m}$  and 500  $\mu\text{m}$  powders. This uniformity in distribution can be attributed to the increased specific surface area of finer particles, which allows for enhanced interaction and adhesion between the CS particles and the resin matrix. The strong interfacial bonding observed in these samples contributes to improved mechanical properties, such as hardness and wear resistance, by reducing the likelihood of particle pull-out during frictional contact. In contrast, composites prepared with larger CS particle sizes (400  $\mu\text{m}$  and 500  $\mu\text{m}$ ) exhibited relatively less consistent dispersion, which could lead to weak bonding areas and localized stress concentrations. Such variations may adversely affect the tribological performance of the brake pads under operational conditions. Overall, the findings suggest that finer CS powder sizes (200  $\mu\text{m}$  and 300  $\mu\text{m}$ ) are more effective in achieving desirable microstructural characteristics for enhanced mechanical and tribological performance.

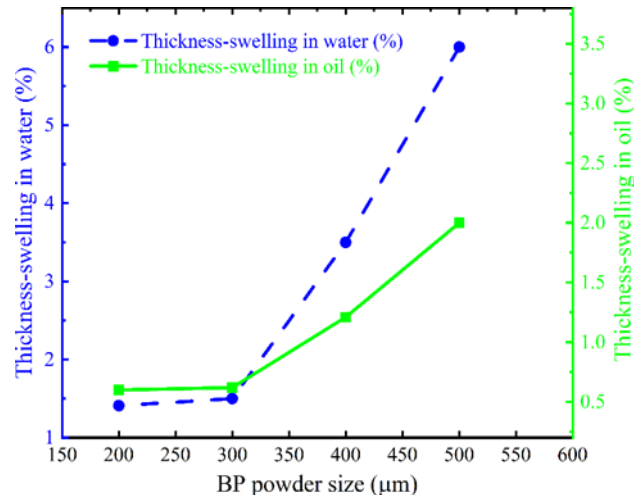


**Fig. 6 SEM pictures show CS pads with powder sizes of (a) 500  $\mu\text{m}$ , (b) 400  $\mu\text{m}$ , (c) 300  $\mu\text{m}$ , and (d) 200  $\mu\text{m}$ .**

### 3.2 Oil and Water Absorption Characteristics of CS Pads

An important factor that affects how well brakes work is how well brake pads don't soak up oil and water. Too much absorption causes swelling, which can make the dimensions less stable, lower the effectiveness of friction, and finally lower the effectiveness of brakes. To choose a good brake pad, it is important to look at how the thickness and thickening of the materials react in different media. Figure 7 shows how the thickness and growth of coconut shell (CS) brake pads with different particle sizes change when they are put in water and engine oil (SAE 20W-50). The results show that the amounts of oil and water absorption went down a lot when the particle size was lowered from 500  $\mu\text{m}$  to 200  $\mu\text{m}$ . This is because the interfacial bonding is stronger and the porosity is lower. This is because the smaller CS particles have a larger specific surface area, which helps them stick better to the resin matrix.

It's interesting that the 300  $\mu\text{m}$  particle size was better at resisting oil and water absorption than the bigger sizes. This made it the most effective reinforcement of all the ranges that were tried. The particles that were 200  $\mu\text{m}$  in size also had some good qualities, but the 300  $\mu\text{m}$  pads worked better all the time. This is probably because they had the best mix of particle packing density and glue bonding. The swelling seen during soaking is linked to the composite's ability to absorb water and the compression forces created during the moulding process. Notably, the manufactured CS pads only slightly swelled when exposed to water and engine oil. This shows that they can be used as long-lasting, shape-stable alternatives to traditional brake pad materials.



**Fig. 7 Thickness of coconut shell pad thickness in water and motor oil**

#### 4. Conclusion

1. This work suggests a unique coconut shell material for the development of asbestos-free brake pads to mitigate the health and environmental concerns associated with asbestos-based brake pads. The brake pads were composed of diverse materials.
2. Coconut shell powder sizes (500–200 μm) were evaluated for mechanical qualities. Additionally, both long-term and short-term evaluations were performed to determine the viability of the engineered brake pads. Significant findings from the experimental inquiry may be summarized as follows:
3. SEM scans revealed a uniform distribution of coconut shell powder within brake pads, indicating robust interfacial adhesion with the resin.
4. The mechanical qualities of oil and water resistance enhance when the particle size diminishes to 300 μm. The brake pad with a particle size of 300 μm was determined to be best.

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