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Experimental Analysis and Performance Evaluation of Advanced Composite Brake Pads for Automotive Applications

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Abstract

This research focuses on developing environmentally friendly materials for automotive brake pads. The goal is to create pollution-free brake pads that enhance performance, durability and reduce weight. This research work focuses on developing an innovative, eco-friendly material for friction pads, aiming to create pollution-free brake pads that enhance performance, durability, and reduce weight. The research evaluates the performance of glass fiber, jute fiber, and basalt fiber in brake pads, known for their ability to improve braking efficiency while maintaining stability, controllability, and a broad range of torque outputs. Using selected composite material samples (jute fiber, glass fiber, and basalt fiber), an experimental investigation was conducted to assess frictional behaviour under different loads, speeds, temperatures, wear conditions and deceleration performance in terms of stopping time. The results revealed that brake pad performance improved by 24.62% for jute fiber, 30.28% for glass fiber, and 34.20% for basalt fiber compared to traditional brake pads. Among the tested composites, basalt fiber exhibited the best stopping time and heat resistance.

Major Findings: *Research has demonstrated that adding basalt fibres to brake pads improves their wear resistance, mechanical characteristics and braking performance as compared to other composite materials, suggesting that basalt fibres are a suitable reinforcing material for automobile braking applications.*

Keywords: *Basalt Fiber, Glass Fiber, Jute Fiber, Performance of Automotive Brake Pad*

1.0 Introduction

Brake pads are particularly essential for regulating the speed of moving cars in automobiles as well as in various machinery of industrial and domestic use. Only by carefully combining specific components in the proper amounts can this be accomplished. However, because of environmental contamination and other health-related issues, not all brake pad materials are suitable for use in automobiles and other industrial settings[1]. Therefore, to minimise and eliminate additional harm, it becomes vital to produce materials that are both significantly appropriate and energy-efficient. Brake pads are crucial parts of any car with disc brakes. They are made of steel backing plates with friction material affixed to the side that faces the brake disc. Drum brakes and disc brakes are the two main categories into which braking systems fall. Whereas disc brakes use a metal disc that revolves inside a calliper, drum brakes use shoes inside a drum for the braking action. Brake pads are essential disc components in automobiles, consisting of steel plates with friction materials bonded to the surface[2]. To

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continually clamp and hold the wheels and slow down or halt their motion, they are positioned in the wheel assembly and attached to the surface facing the brake disc. Their main job is to regulate a moving vehicle's speed by using friction to transform kinetic energy into thermal energy and then releasing the heat into the environment.

The majority of car brake pads in the market today can be divided into three groups: Non-Asbestos Organic (NAO), semi-metallic, or metallic materials. The components of friction materials include fillers, binders, structural materials, and frictional additives. Materials that include metal powders are classified as semi-metallic, while those containing asbestos are called asbestos friction materials[3]. Non-asbestos friction materials are asbestos-free brake pads which are free from asbestos. Brake pads are typically made using materials such as graphite, brass, and ceramics[4]. This study focuses on developing a suitable friction material that balances cost, performance, and environmental considerations. As a result, non-toxic and environmentally friendly materials are becoming more useful. Recent researchers have welcomed the idea of using environmentally acceptable natural fibers to replace asbestos in a control composition with other additives in the manufacturing of brake pads[5].

Although asbestos particles contained in a polymeric matrix and several other components are typically found in brake pads, their carcinogenic nature has rendered them unacceptable. As a result, new asbestos-free brake pads are being created using preferred natural fibers which are affordable, easily accessible and recyclable[6]. This paper presents the different fiber materials used for brake pads in different brake systems with their performance in terms of mechanical and thermal properties.

2.0 Composite Materials

Over time, brake friction materials have undergone tremendous changes. Asbestos has given way to organic and semi-metallic compositions. Regarding wear, noise, stopping power, and environmental friendliness, each of these materials has demonstrated pros and cons. To improve human health and technological efficiency, numerous studies have been conducted and are still being conducted to design asbestos-free brakes as well as less heat-generating pads made up of innocuous materials.

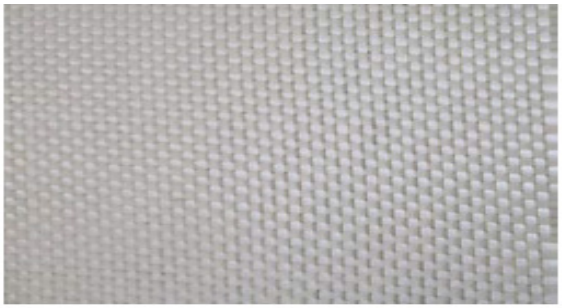


Figure 1. Schematic glass fiber

2.1 Glass Fibre

Glass fibres are modern materials widely utilised in mechanical and production industries are manufactured using advanced techniques. In addition to the fundamental fibre qualities like strength, flexibility and stiffness, they provide outstanding performance, including hardness, transparency, stability, inertness, and chemical resistance[7]. Structural composites, printed circuit boards, etc., are frequently made up using glass fibres. A schematic representation of glass fiber is illustrated in Figure 1.

2.2 Basalt Fibre

Basalt bars and other basalt-based products, such as chopped basalt fibre strands, continuous filament wires, and mesh, are derived from basalt rock. These basalt composites have numerous potential applications, including bulletproof vests, soil stabilisation, bridges and highways, industrial flooring, polymer reinforcement, structural retrofitting and rehabilitation, as well as heat and sound insulation for residential and commercial buildings[8]. Figure 2 shows a schematic diagram of basalt fiber.



Figure 2. Schematic of basalt fiber

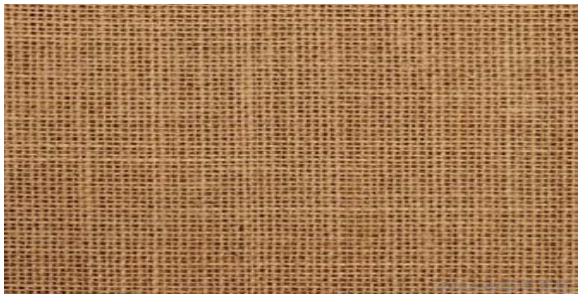


Figure 3. Schematic jute fiber

2.3 Jute Fibre

Jute is a significant natural fibre crop in India, ranking second only to cotton. In commerce, jute and mesta crops are collectively referred to as raw jute due to their similar applications. An important part of the country's economy is raw jute. It was first mostly used in the packaging and agricultural industries[9]. However, it has since become a versatile material with applications in various fields, including textile and paper industries, construction and automotive sectors, soil conservation, and as decorative and furnishing materials. As a biodegradable and annually renewable resource, raw jute is considered an eco-friendly crop that supports environmental sustainability and ecological balance. Its natural fiber properties offer distinct advantages, making it a valuable resource for diverse uses. Figure 3 shows a schematic diagram of jute fiber.

3.0 Method of Production

Typically, brake pads were made of asbestos fibers embedded in a polymeric matrix along with a few additional chemicals. However, due to the carcinogenic properties of asbestos, its use is no longer permitted. As a result, new asbestos-free brake pads are being developed using preferred natural fibres that are cost-effective, readily available, and recyclable[10].

Natural fibers are typically defined as those derived from minerals, plants, vegetables, animals and agricultural waste that can be converted into non-woven textiles. Numerous naturally occurring fibres that are currently suitable for industrial use include kapok, sisal, coconut, jute, bamboo, bagasse, hemp, nut shell, rice husk and many more. High-strength natural fibers, including basalt, kenaf, sisal, jute, and glass, are embedded in a polymer matrix to create natural fiber polymer composites. Research has shown that varying fiber types, sources and moisture conditions result in different natural fiber composite characteristics.

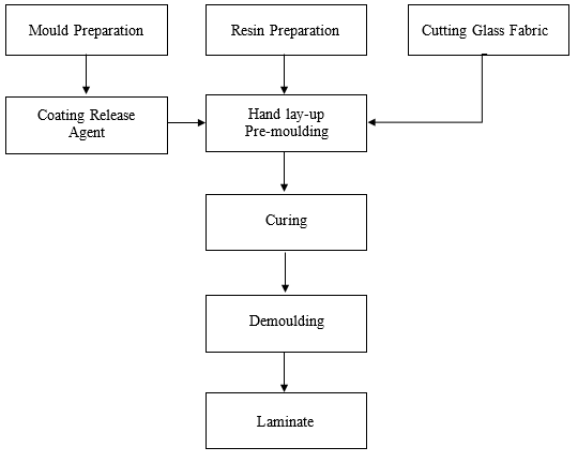


Figure 4. Production flowchart of brake pad.

In this investigation, the friction material specimens were made using a typical NAO formulation[10]. These specimens included a fiber modifier. Brake pad production involves several unit procedures, such as mixing, cooling, post-curing, hot and cold pressing, and finally finishing. The blended material is placed in a mould to shape the brake pad. A pre-pressing step compacts the material into a semi-finished product, ensuring uniform density and alignment of fibres. The production method of the selected material is illustrated in Figure 4.

While the techniques involved in producing jute, basalt, and glass fibre brake pads are identical, the selection of fibres affects material handling and end performance. Basalt and Jute brake pads are excellent in durability and wear resistance, making them perfect for demanding applications. Jute brake pads are also economical and environmentally beneficial.

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4.0 Experimental Testing of Material

The friction material specimens for this experiment were produced using a standard NAO formulation,

incorporating a fibre modifier[12]. To ensure uniform mixing and proper curing during the manufacturing process, surface hardness distribution was evaluated using a Rockwell hardness tester. The measured surface hardness of the friction material ranged from 80±5 HRs on the Rockwell S-scale. Metal fibres accounted for 20% by volume of the friction material, while the proportions of the other ingredients remained unchanged.

4.1 Hardness Test

The hardness test is conducted to assess a material's resistance to indentation or deformation under an applied force, providing crucial insights into its strength, wear resistance, and durability[13]. In this study, a Brinell hardness tester was used for the evaluation. The procedure involved applying a controlled force to the specimen using a hard steel or tungsten carbide ball for a specified dwell time, typically 10 seconds. After the load was removed, the diameter of the indentation was measured, and the Brinell Hardness Number (BHN) was determined using the following formula:

$$BHN = 2F / (D (D - (\pi D - d)^{1/2})$$

Where: F = Force in *Kgf*
D = Indenter ball diameter in *mm*.
d = Indentation diameter in *mm*.

Figure 5 illustrates the hardness testing of brake pads, which was used to evaluate the hardness of the selected composite materials. Table 1 shows the hardness value of the composite materials, which increases with their density and hardness number. Hardness is a critical property of brake friction materials, significantly impacting their performance and behaviour.

4.2 Wear Test

The wear test evaluates the material's ability to withstand mechanical deterioration and abrasion under continuous use[14]. The wear rate of the samples was determined by operating a pin-on-disc machine over a cast iron surface at loads of 10N and 20N, sliding speeds of 125 and 250 rev/min and sliding distances of 2000 and 4000 meters[15]. At room temperature, every test was carried out. An electronic weighing machine with a single pan and an accuracy of ±0.01 g was used to determine the samples' initial weight. Pin samples were held and inserted



Figure 5. Hardness test of brake pad.

Table 1. Hardness test result

Brake Pad Material	Hardness Number (*BHN*)	Hardness Value (*MPa*)
Jute Fiber	4.83	47.36
Glass Fiber	8.12	79.62
Basalt Fiber	14.43	141.50

Table 2. Surface wear test result

Brake Pad Material	W_0 (*gm*)	W_1 (*gm*)	Time (*min*)	Wear Rate (*gm/min*)
Jute Fiber	5.182	5.14	20	0.005
Glass Fiber	5.367	5.298	20	0.00335
Basalt Fiber	6.123	6.024	20	0.0021

vertically into the rotating, hardened cast iron disc using a strain gauge that was connected to a friction-detecting arm. The samples were taken out, washed with acetone, dried and weighed to calculate the weight loss from wear after they had run through a predetermined sliding distance. Sample wear is determined by comparing the weight measurements taken before and after tests.

The surface wear test results for various brake pad materials are shown in Table 2. W_0 and W_1 represent the initial and final weight of the brake pad respectively. Brake friction materials experience significant mechanical wear during braking. The material's hardness is closely associated with its wear resistance. Higher hardness generally implies better resistance to abrasive forces, leading to reduced wear and enhanced durability of the brake pads.

4.3 Thermal Test

In this test, when a brake pad is subjected to high temperatures during braking, its performance, stability and longevity are assessed. This test is essential to comprehending how the material of the brake pads reacts to the heat produced by friction[16,17]. Important components of the thermal test are the material's wear resistance, friction performance, heat resistance and thermal stability. This test monitors how the temperature affects the composite materials. Table 3 shows that the colour changes as the pad temperature increases for Jute Fibre, Basalt Fibre, and Glass Fibre.

The thermal test's findings establish the brake pad's maximum temperature and its capacity to maintain reliable performance in a varying range of circumstances. These findings provide valuable insights for optimising the material composition or design to enhance durability and heat resistance[18]. Additionally, the test results confirm the brake pads' capability to safely and reliably meet the thermal demands of a moving automobile.

4.4 Tensile and Compressive Test

The tensile test verifies that the brake pad material can withstand delamination and remain cohesive while in use. Compressive test verifies that the brake pad can sustain significant compressive forces during braking, guaranteeing dependability and safety[19].

Table 3. Thermal test result

Brake Pad Material	Temp 1 (°C)	Temp 2 (°C)	Temp 3 (°C)
Jute Fibre	150 (Colour Changed)	200 (Edge Burned)	300 (Fully burned)
Basalt Fibre	150 (No Change)	200 (Colour Changed)	300 (Edge burned)
Glass Fibre	150 (Edge Colour Changed)	200 (Colour turned into dark)	300 (Fully burned)

Table 4. Tensile test result

Brake Pad Material	Tensile Stress (N/mm^2)
Jute Fibre	134.34
Glass Fibre	248.57
Basalt Fibre	172.38

Table 5. Compressive test result

Brake Pad Material	Compressive Stress (N/mm^2)
Jute Fiber	132.45
Glass Fiber	252.54
Basalt Fiber	175.72

Using a Universal Testing Machine (UTM) with tensile testing fixtures, the sample was positioned between the machine's clamps or jaws. Proper alignment was ensured to prevent uneven loading. During testing, tensile force was gradually applied at a constant strain rate, as per the relevant standards. The applied force and elongation were recorded until the specimen failed. Afterward, the maximum tensile strength was measured. Table 4 showcases the results of the tensile test of different composite materials.

For the compressive test, the brake pad specimen is cut into a rectangular shape by the test standards, making sure the top and bottom surfaces are flat and parallel. The specimen is positioned centrally on the lower plate to ensure even loading with strain gauges to monitor deformation. A compressive load is gradually applied at a constant rate until the specimen fails or reaches the predetermined deformation limit. Finally, the force related to the displacement during the test is recorded. The measured values from the compressive test are presented in Table 5.

4.5 Deceleration Test

The test is conducted on a brake pad test rig, maintaining a constant brake pedal force and brake pad contact pressure while varying the rotational motor shaft speed between 200 to 500 RPM. This enables the rotating brake disc, in contact with the brake pad, to gradually slow down and come to a complete stop[20]. During the test, a constant force is applied to the brake pad, and measurements of stopping time are recorded. The recorded readings are shown in Table 6.

5.0 Results and Discussions

5.1 Hardness Test Performance

Figure 6 illustrates the hardness values and hardness number for different brake pads. It showcases that the Basalt fiber-based pads exhibit higher hardness values

Table 6. Deceleration test result

Description	Speed (*rpm*)	Time to Stop (*Sec*)	Braking Force (*Kg*)
Jute Fibre	200	30	10
	300	32	10
	400	36	10
	500	45	10
Glass Fibre	200	24	10
	300	27	10
	400	31	10
	500	35	10
Basalt Fibre	200	20	10
	300	22	10
	400	25	10
	500	31	10

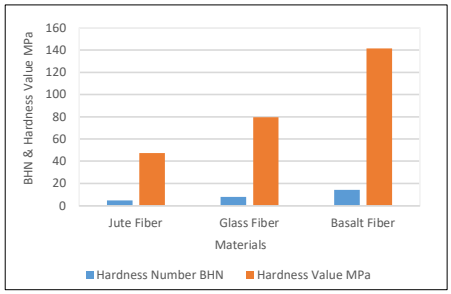


Figure 6. Hardness test of composite brake pads.

(141.5*MPa*) and hardness number (14.43), which indicates better resistance to wear, maintaining their hardness over time more effectively. Jute fiber pads provide a good balance of performance and environmental friendliness, though they typically have lower hardness[21]. Glass fiber brake pads have BHN values that fall between those of jute and basalt fibre pads, offering a compromise between durability and environmental benefits.

5.2 Wear Test Performance

The wear rate of various brake pads at maximum load conditions is shown in Figure 7, which shows that a higher wear rate is caused by an increase in load. The wear rate of the Basalt fibre brake pads was lower than that of the other two. Material transfer happens on both surfaces during wear in friction materials, making it a complicated event with many interactions and mechanisms. Pressure, speed and interface temperature are some of the variables

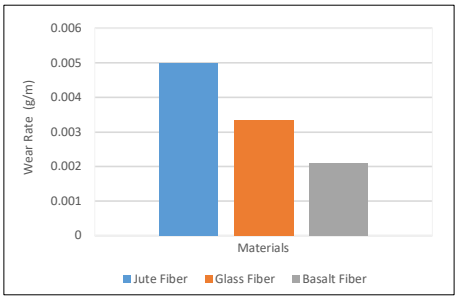


Figure 7. Wear rate of composite brake pads.

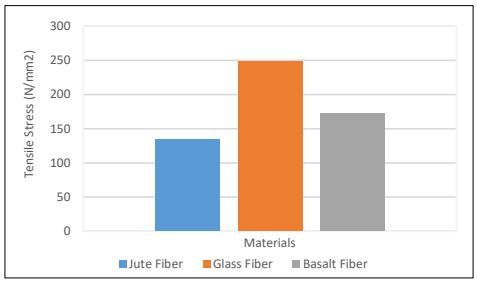


Figure 8. Tensile strength of composite brake pads.

that further impact the composition of the contacting surfaces, including the tribo-layer, which affects the dynamic behaviour of composite materials.

Jute fibre composites deteriorate more quickly at higher temperatures, because their organic components are less thermally stable, leading to increased wear[22]. On the other hand, greater hardness improves wear resistance by increasing resistance to penetration. The jute and glass fibre composite exhibits this phenomenon, with improved wear performance resulting from decreased strength and thermal stability. Jute fibres deteriorate quickly, particularly when subjected to high loads and temperatures. Glass fibres are more thermally stable and have superior load-bearing qualities, which causes them to provide increased wear resistance. Figure 7 showcases the maximum wear resistance in the case of basalt fibre with a wear rate of 0.002 g/m because of its exceptional mechanical strength and resilience to heat.

5.3 Tensile Stress Performance

When evaluating the strength, durability of composite materials reinforced with glass, basalt and jute fibres, tensile stress performance is a crucial consideration. Here is an in-depth comparative performance of jute, glass basalt fibre plotted in Figure 8.

Compared to glass and basalt fibre, jute fibre has a lower tensile stress of 125 N/mm^2 but a moderate strength. It is the cause of the reduced rigidity. During braking application, it deforms more under stress loading. Basalt fiber is less strong than glass fiber and more robust than jute, based on tensile stress of 160 N/mm^2 of basalt fiber. During braking applications, it offers good resistance to deformation and moderate stiffness. It has good tensile qualities and strikes a balance between sustainability and performance. Glass fiber has a higher tensile strength of 250 N/mm^2 than jute and basalt fiber, as seen in Figure 8. It is perfect for high-performance brake pad applications because it offers the best tensile strength, stiffness and elongation[23].

5.4 Compressive Test Performance

A material's compressive strength is an essential characteristic for brake pad applications in vehicles. It establishes how much axial load material can bear before deforming or failing[23]. A comparative study of glass, basalt and jute fibers' compressive strengths is presented in Figure 9. Jute fiber has the lowest modulus and compressive strength, it is only appropriate for lightweight applications with low compressive stress (approximately 130 N/mm^2) and brittleness.

The basalt fiber has 170 N/mm^2 is an excellent compressive strength, somewhat lower than glass but better than jute. Because of its ability to balance strength and flexibility, it is perfect for medium-load applications in brake pads. The glass fiber with the highest compressive strength, 250 N/mm^2, provides exceptional resistance to deformation when used in brake pads. Greatest stiffness and compressive strength, making it ideal for high-performance and high-load applications[24].

5.5 Deceleration Performance of Brake Pad

Braking effectiveness is measured with deceleration, which refers to how efficiently a brake system can reduce

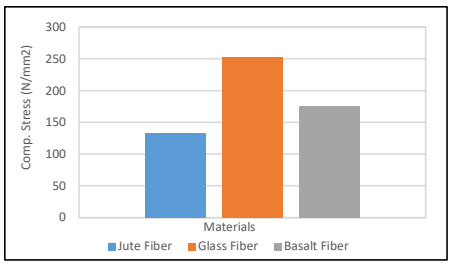


Figure 9. Compressive strength of composite brake pads.

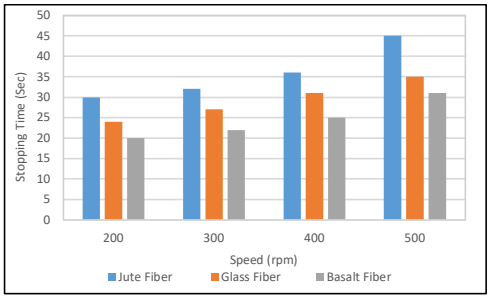


Figure 10. Deceleration performance of brake pads.

the speed of a vehicle or bring it to a complete stop. Braking effectiveness improves with higher deceleration rates[25,26]. Brake pads that generated more friction with the same applied force resulted in faster deceleration. This highlights the significant influence of the brake pad's material and design on the vehicle's stopping power. Figure 10 presents a plot of the average stopping time for the three types of composite brake pads under varying speed conditions, with a constant pedal force of 98.1 N and a contact pressure of 0.82 MPa.

From the graph, it is clear that at any given speed of the brake pad, the Jute fibre brake pad takes a longer time to stop compared to other brake pads due to lower friction and heat resistance. While the basalt brake pad has the shortest stopping time while the glass fibre brake pad has a moderate stopping time between jute and basalt fibre brake pad. For all the brake pads, under the application of a constant force on the brake pedal, the stopping time increases as the speed of the brake disc rises.

The basalt brake pad has the shortest stopping time. This is because brake pads made from basalt typically offer a better coefficient of friction and thermal stability, leading to faster braking and more efficient heat dissipation compared to the other two types of composite brake pads.

6.0 Conclusion

Composite brake pads were developed using fibres as filler materials, and their mechanical and tribological properties were thoroughly evaluated. The findings indicated that these newly fabricated composite brake pads met the necessary performance standards, exhibiting satisfactory levels of temperature resistance, hardness, tensile strength, compressive strength, and wear resistance. Notably, brake pads reinforced with glass

and basalt fibres demonstrated superior performance compared to traditional asbestos-based materials.

The experimental results demonstrated that the developed basalt fibre-reinforced brake pad provided a highly reliable and precise assessment of cooling efficiency, temperature rise and stopping time of composite brake pads. This suggests that basalt fibre reinforcement can enhance the performance characteristics of brake pads, offering improved thermal management 25.34 and braking efficiency 32.60%.

The study revealed that brake pads reinforced with glass and basalt fibre demonstrated superior performance compared to traditional asbestos-based materials. Specifically, the glass and basalt fibre brake pads exhibited enhanced temperature resistance, hardness, durability, compressive strength, and wear resistance. These improvements contribute to an increased lifespan, enhanced braking efficiency, and greater braking power, making glass and basalt fibres effective replacements for asbestos in brake pad applications.

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