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Research Article

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Preparation and Evaluation of Low-cost Asbestos Free Brake Pad Material Using Mustard Husk Additives

Tushar Rai and S.J. Pawar*

Department of Applied Mechanics, Motilal Nehru National Institute of Technology Allahabad, Prayagraj, U.P., India

***Correspondence to:**
S.J. Pawar
Department of Applied Mechanics,
Motilal Nehru National Institute of Technology
Allahabad, Prayagraj, U.P., India.
E-mail: sjpawar@mnnit.ac.in

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Abstract

This study assessed the performance of vehicle brake pads made from the mustard husk, silicon carbide, aluminum oxide, graphite, and epoxy resin binder. The mustard husk is used as a replacement for asbestos because asbestos is toxic and hazardous; additionally, it causes several health problems like lung cancer, asbestosis, and mesothelioma. In this study, the mustard husk is used as filler material, silicon carbide is used as heat dissipating material, aluminum oxide is used as abrasive material, graphite is used as lubricating material, and epoxy resin is used as binding material. The produced brake pad samples were put through different tests like microhardness test, compressive strength test, pin on disc wear test, and water and oil absorption test. The wear of brake pads has been tested at different speeds. The results revealed that the sample having 40% mustard husk in the composite as a filler content has high microhardness, high compressive strength, low water, and oil absorption, and low wear rate. This study shows that mustard husk is a possible alternative to asbestos in brake pad materials.

Keywords

Asbestos free, Brake pad, Friction coefficient, Mustard husk, Wear rate

Introduction

Automobiles and other vehicles and machines utilize brake pads in their braking systems to control speed by transforming the kinetic energy of the vehicle into heat that is released into the environment. The brake pad has a steel backing plate with a surface facing the disc that is bonded with a friction substance [1, 2]. For stopping a moving vehicle, brake pads are a crucial component in a disc brake. To minimize heat fade and enhance brake responsiveness, brake pad material is used in the disc brakes [3]. A brake pad needs a steady friction coefficient, less wear, and proper heat conductivity [4]. High temperatures should not affect the coefficient of friction with the brake discs; they show a consistent and constant friction coefficient with the brake disc [1].

Asbestos is generally a good heat absorbing material that is used in brake pads since the 1920s. Normally, asbestos fibers are reinforced in brake pads along with numerous other constituents in a polymeric matrix. The asbestos fibers due to wear and tear of the brake pad dislodge tiny particles (grit and fine dust) in the surrounding along with microscopic fibers that became trapped in the brake housings, which are highly carcinogenic. In recent years, different studies were rigorously experimented with to investigate the usage of natural fiber as a replacement for the fibers in brake pad composite. The advantages of naturally occurring fibers include less density, less cost, greater flexural modulus, good impact strength, good specific strength, non-corrosive, and ease of fabrication. They are used widely in the automotive sectors, aerospace sectors, and transportation sectors because of their biodegradability [5]. The creation of alternative non-asbestos friction materials for brake pads using environmentally friendly methods, such as the use of agricultural waste byproducts like rice husk, maize husk, mustard husk, and others [6]. Asbestos causes cancer and can lead to lung tumors and other health problems; it is restricted from being used nowadays. Another friction material like graphite, glass fiber, and Kevlar was created to use in the brake pad composite [5]. Disc brakes and drum brakes are the two most common types of car brakes [7]. The brake shoes are housed inside a drum in drum brakes. The brake shoe is pushed outward and presses against the drum when the brakes are engaged [8]. Drum brakes tend to be enclosed, whereas disc brakes tend to be exposed to the atmosphere. This is one of the main differences between the two types of brakes [9].

The main objective of the current work is to develop an asbestos-free brake pad made from mustard husk as a filler material. Along with, silicon carbide as a heat dissipating material, aluminum oxide as an abrasive material, graphite as a lubricating material, and epoxy resin (matrix) as a binding material. A total of three brake pad compositions have been developed in this current work. Vickers hardness test is used to determine the hardness, universal testing machine (UTM) is used to determine the compressive strength, and pin on disc wear apparatus is used to determine wear rate and coefficient of friction. Additionally, water and oil absorption tests were also carried out.

Materials and Methods

Materials

Mustard husk powder

The mustard husk is acquired from the local area of Uttar Pradesh which is shown in figure 1a. First, the mustard husk has been dried in a hot air oven at 70 °C for nearly 3 hours to remove moisture. Then it is crushed to disintegrate into small pieces. Further, a mixer and grinder machine was used to grind it to make it less than 100 μm in size.

Other additives

Graphite is used as a lubricating material; it can primarily provide lubrication. It can also withstand a higher temperature which is shown in figure 1b. To dissipate heat quickly, silicon carbide is used as a heat-dissipating material which is shown in figure 1c. Aluminum oxide is used as an abrasive material because it helps to maintain the friction coefficient which is shown in figure 1d. The used particle size for silicon carbide, graphite, and aluminum oxide is 20 - 25 μm [10, 11]. The grade of epoxy resin LY556 is used to bind the material which is shown in figure 1e and the grade of hardener HY951 is used to cure the epoxy resin.

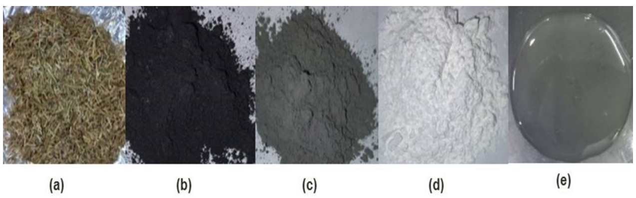

Figure 1: Materials **(a)** Mustard husk, **(b)** Graphite, **(c)** Silicon carbide, **(d)** Aluminum oxide, and **(e)** Epoxy resin.

Preparation of brake pad composite

Several unit processes, such as mixing, cold pressing, cooling, curing, and finishing are involved in the preparation of brake pad composites. Composite with volume fractions of different materials is shown in table 1. Aluminum oxide, silicon carbide, and graphite are mixed, and various percentages of the mustard husk (100 μm) are added. Ball milling is used to mix these powders to get a homogeneous mixture. After getting a homogeneous mixture, epoxy resin and hardener are taken in a ratio of 10:1. Epoxy resin and hardener have taken in a separate container and stirred properly for 10 minutes to get a uniform mixture. Then this mixture is poured into the homogeneous mixture of the friction material and mixed properly to get a homogeneous paste.

Table 1: Different composition of samples.

S. No.	Materials	Sample 1	Sample 2	Sample 3
1.	Mustard Husk	40 g	45 g	50 g
2.	Graphite	5 g	5 g	5 g
3.	Silicon Carbide	26 g	21 g	16 g
4.	Aluminum Oxide	15 g	15 g	15 g
5.	Epoxy Resin + Hardener	14 g	14 g	14 g

The homogeneous mixture of each of the formulations is separately filled into the 25 mm diameter die and with the help of a punch. 70 kN load is applied by a UTM to get the desired shape of brake pad composite. The produced brake pad composite is cured at 135 °C in the oven for 2 hours and 30 minutes to get proper bonding between the materials and to increase the strength of the composite. Samples for a compression test, hardness test, and water and oil absorption test are shown in figure 2. Samples for the wear test are shown in figure 3.

Methods

Micro-hardness test

Vickers hardness testing is used to assess the hardness of brake pad composites. This testing uses a diamond indenter and a small load to produce an indentation on the brake pad composites. The specimen hardness value is calculated from the depth of indentation. The specimen surface is polished, and both the upper and lower surfaces are level and parallel

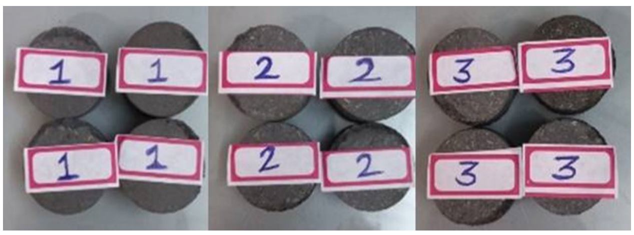

Figure 2: Cured sample for a compression test, hardness test, and water and oil absorption test.

Figure 3: Cured sample for the wear test.

to each other. For 20 seconds, a weight of 200 g is applied to the surface. A minimum of 4 to 5 indents are taken at various locations on the specimen surface for accurate measurement and the average is calculated.

Compressive strength test

A UTM is used to evaluate the compressive strength of samples. The compressive strength of a material is determined as the maximum compressive stress that it can survive without getting fractured. The tests are performed at ambient temperature (300 K) with a constant crosshead speed of 1 mm per minute. ASTM D3410 is preferred for the compressive strength test. Compressive strength mainly depends upon the particle size, bonding between particles, and porosity in the sample. If porosity in the sample is higher, then more deformation is observed with little increase in load. Porosity is minimized by the compaction load and curing temperature. A total of 9 samples of three types are tested and the average result is reported.

Water and oil absorption test

The brake pad composites are first dried at 100 °C to 120 °C in an oven to ensure moisture elimination. After drying, the weights of composites are taken, and if the weight variation was less than 5%, it is considered dry. The brake pad compacts of various compositions are immersed in a beaker filled with oil and water for 24 hours at room temperature. After 24 hours, samples are taken out from the beaker and the final weight is noted. The following equation 1 is used to determine the amount of water absorbed and oil absorbed (in percentage).

$$\text{Water and oil absorption in percent} = \frac{M_2 - M_1}{M_1} \times 100 \qquad (1)$$

Where, M_1 and M_2 are the mass of dry samples, and the mass of wet samples (in g), respectively.

Pin on disc wear test

Wear rate/mass loss (mg/mm), and coefficient of friction are the purposes of the wear test. According to the ASTM G99 standard test technique, the prepared brake pad samples are put through wear testing on Pin on Disc apparatus. In this test 10 N load and different speeds are used to conduct the experiment. The counter discs are constructed to slide against 12 mm diameter pin-shaped wear specimens. In this test, a track diameter of 115 m is taken, and a sliding distance of 2000 m is taken to calculate the wear rate and coefficient of friction. The following equation 2 is used to calculate the wear rate.

$$\text{Wear rate} = \frac{w_1 - w_2}{\text{Sliding distance}} \qquad (2)$$

Where, w_1 and w_2 are the mass of samples before the wear test and the mass of samples after the wear test respectively.

Results and Discussion

Micro-hardness

Table 2 shows the micro-hardness values of each composition of different samples. It shows that micro-hardness values are decreased as the weight percentage of mustard husk is increased and silicon carbide is decreased. This may be caused by the low hardness of the mustard husk. Silicon carbide has good hardness compared to the mustard husk, but silicon carbide is less in amount. Maximum hardness (57.43 VHN) is given by composition 1 which contains minimum mustard husk (40 g) and maximum silicon carbide (26 g) in brake pad composite. Micro-hardness values of all samples are shown in table 2. In the comparison of all the samples, the successive percentage decrease in the micro-hardness values from sample 1 to sample 3 are 2.681% (from sample 1 to sample 2) and 4.258% (from sample 2 to sample 3), respectively. It can be concluded that by increasing the mustard husk content, there is a decrement in the micro-hardness values which restricts the use of more mustard husk in the composite.

Table 2: Micro-hardness test values of all samples.

Composition	Micro-hardness values (VHN)	Average values
Sample 1 (S1)	58.01	57.43
	56.98	
	57.32	
Sample 2 (S2)	56.38	55.89
	55.20	
	56.10	
Sample 3 (S3)	53.32	53.51
	54.23	
	52.98	

Compressive strength

Figure 4 shows the compressive strength of brake pad composite with various compositions. It shows that the compressive strength decreases as the percentage by weight of mustard husk is increased and silicon carbide is decreased. This is due to an increase of mustard husk content in the composite. If the mustard husk is more in the composite, it makes the composite more porous/less dense which decreases the compressive strength of the brake pad. When the mustard husk is more, epoxy resin is not enough to bind composite material properly. This might be the one region of low compressive strength. Maximum compressive strength (48.03 MPa) is given by composition 1 which contains minimum mustard husk (40 g) and maximum silicon carbide (26 g). Minimum compressive strength (42.12 MPa) is given by composition 3 which contains maximum mustard husk (50 g) and minimum silicon carbide (16 g).

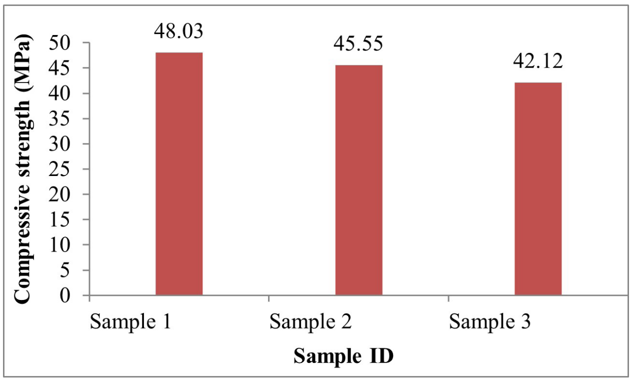

Figure 4: Compressive strength of brake pad composite with different compositions.

Sample 1 with 40% of mustard husk shows the highest load of 23.57 kN and by observing different data sample 1 shows less deformation than sample 2 and sample 3. It means sample 1 has less porosity and sample 3 has more porosity in the composite. Sample 3 with 50% mustard husk shows a minimum load of 20.67 kN and maximum deformation. After analyzing different data, sample 1 is the most suitable friction material composite for brake pad application. In comparison, an asbestos-based brake pad has a compressive strength of 110 MPa which is higher than a mustard husk-based brake pad [7]. Mustard husk-based brake pad has lower compressive strength which may decrease the life and other properties.

Water absorption

The samples containing 40%, 45%, and 50% mustard husk are tested by weighing the samples in dry condition and followed by dipping them in water for 24 hours and then calculating the percentage of water absorption. In table 3, the absorption percentage of water is shown in different samples. Figure 5 shows that the absorption percentage of water increases as the percentage by weight of mustard husk is increased and silicon carbide is decreased. Due to decreased interfacial bonding between the epoxy resin and other additives like mustard husk, silicon carbide, aluminum oxide, and graphite. Epoxy resin plays an essential role to decrease porosity and increase the density of the sample. It has been noticed that the 40% mustard husk sample has the least absorption percentage of water which is 8.951%. Water absorption of the sample mainly depends upon the porosity in the sample. If the porosity is less or density is more than the water absorption percentage is less. So, to decrease the porosity of composite proper compaction load is required.

In the comparison of all the samples, the successive percentage increase in the water absorption values from sample 1 to sample 3 are 5.574% (from sample 1 to sample 2) and 12.592% (from sample 2 to sample 3), respectively. It can be concluded that by increasing the mustard husk content, there is an increment in the water absorption values which restricts the use of more mustard husk in the composite. Water absorption in asbestos-based brake pads is 0.90% which is lower than the mustard husk-based brake pad composite [7]. More water absorption in the mustard husk-based composite may decrease the life of the brake pad.

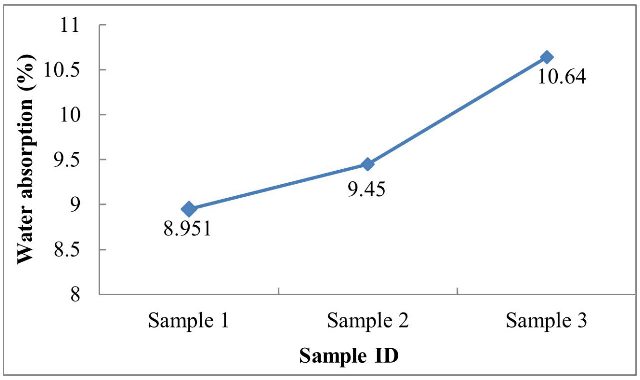

Figure 5: Variation in water absorption with different compositions.

Table 3: Absorption percentage of different samples in water.

Sample Description	Mass of dry sample (g)	Mass of wet sample (g)	Increase in mass (g)	Absorption (%)
Sample 1	10.646	11.599	0.953	8.951
Sample 2	9.121	9.983	0.862	9.450
Sample 3	10.911	12.072	1.161	10.64

Oil absorption

Figure 6 shows that the absorption percentage of oil increases as the percentage by weight of mustard husk is increased and silicon carbide is decreased because interfacial bonding decreases. From figure 6 it has been observed that sample 1 shows the least value of oil absorption which is 6.805% and sample 3 (50% mustard husk) shows the highest value of oil absorption (9.501%). Table 4 contains the mass of the dry sample, the mass of the wet sample, and the absorption percentage of each sample. If we compare water ab-

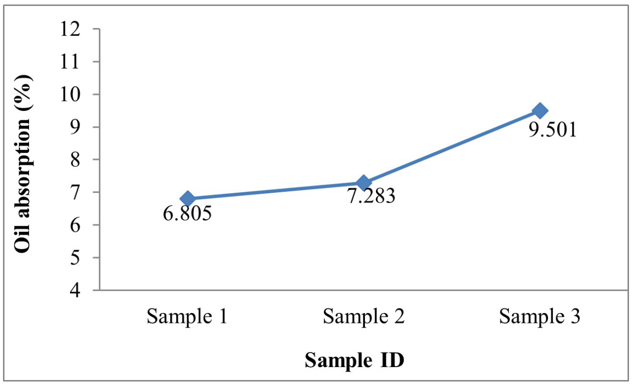

Figure 6: Variation in oil absorption with different compositions.

Table 4: Absorption percentage of different samples in brake oil.

Sample Description	Mass of dry sample (g)	Mass of wet sample (g)	Increase in mass (g)	Absorption (%)
Sample 1	7.391	7.894	0.503	6.805
Sample 2	10.352	11.106	0.754	7.283
Sample 3	9.567	10.476	0.909	9.501

sorption and oil absorption, water absorption is more in the brake pad composite than oil absorption because oil is a thicker fluid than water. Thicker fluid like oil needs more porosity to penetrate into the composite that's why the oil absorption percentage is less in every sample. Oil absorption is increased by the percentage of 7.024% from sample 1 to sample 2 and oil absorption is increased by the percentage of 30.454% from sample 2 to sample 3. By this, a rising tendency in oil absorption is noticed.

In the comparison of all the samples, the successive percentage increase in the oil absorption values from sample 1 to sample 3 are 7.024% (from sample 1 to sample 2) and 30.454% (from sample 2 to sample 3), respectively. It can be concluded that by increasing the mustard husk content, there is an increment in the oil absorption values which restricts the use of more mustard husk in the composite. Oil absorption in asbestos-based brake pads is 0.30% which is lower than the mustard husk based brake pad composite [7]. More oil absorption in the mustard husk-based composite may decrease the life of the brake pad.

Coefficient of friction

Variation in brake friction coefficient with respect to speed is an essential problem because drivers anticipate the same amount of frictional force under different circumstances and as the speed changes, the coefficient of friction of the material frequently changes. Figure 7 shows the coefficient of friction with respect to speed for mustard husk-based brake pad and commercial brake pad [1].

The commercial brake pad shows a constant friction coefficient (0.316) with respect to a different speed [1]. At a lower speed friction coefficient of the mustard husk-based brake pads is lower than the commercial brake pad but with increasing speed a slight increase in the friction coefficient was observed, which is shown in figure 7. Sample 1 gives a better coefficient of friction with respect to speed. The sample contains less mustard husk gives a better coefficient of friction which restricts the use of more mustard husk in the brake pad composite.

Wear rate

Figure 8 shows the wear rate variation with speed for brake pad materials made from the mustard husk. Commercial brake pad wear rate is also shown with respect to speed in figure 8. For all of the produced samples and the commercial brake pads, it is found that wear rate increased as speed increased. Due to varying additive and their weight percentage, the wear rate varied for different formulations. The increasing speed causes an increase in contact load between the brake pads, which promotes wear. Sample 1 gives almost the same value with respect to the commercial brake pad. Figure 8 shows that sample 2 and sample 3 give more wear than the commercial brake pad. It is clear that the epoxy resin used in the brake pad composite gives a stronger bonding of the brake pad materials that resist wearing rates. The minimum values of wear rate generated from the produced brake pad sample may be linked to the type of binder applied. Different values of sample 3 and the commercial brake pad are shown in figure 8.

The micro-hardness, compressive strength, water absorption, oil absorption, coefficient of friction, and wear rate for the three samples have been obtained experimentally. It can be concluded from the results that among all the samples, sample 1 showed better mechanical and tribological properties and can be a replacement for the asbestos-based brake pad. However, its performance is not as good as the expected performance of other commercial brakes. More studies are recommended for the proper composition of the asbestos-free mustard husk brake pad. Asbestos has a higher cost than mustard husk. The mustard husk is an agricultural waste that gives low-cost brake pad composite.

Conclusions

The study and preparation of mustard husk-based brake pad materials are determined. Sample 1 exhibited maximum hardness which contains 40% mustard husk in the composite, revealing that the brake pad has a longer life span. Sample 1 with the composition of 40 g mustard husk, 5 g graphite, 26 g silicon carbide, 15 g aluminum oxide, and 14 g epoxy resin showed the highest compressive strength than other samples which makes the brake pad stronger. The least water absorption percentage and oil absorption percentage are exhibited by sample 1 which contains 40% mustard husk after immersion of the sample in water for 24 hours. The low value of water and oil absorption percentage is desirable because the absorption properties of the brake pad may be different. Water and oil absorption mainly depend on the porosity and compaction load in the brake pad composite. The coefficient of

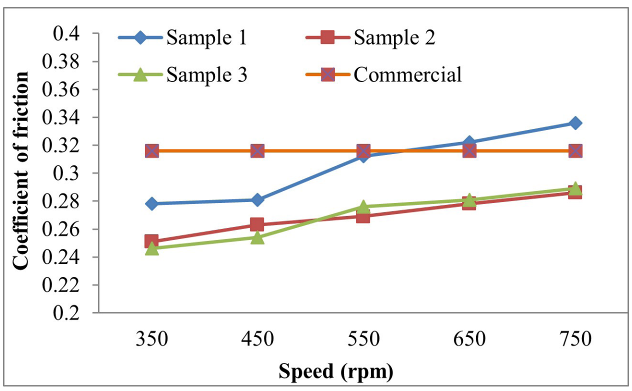

Figure 7: Variation of coefficient of friction with respect to speed.

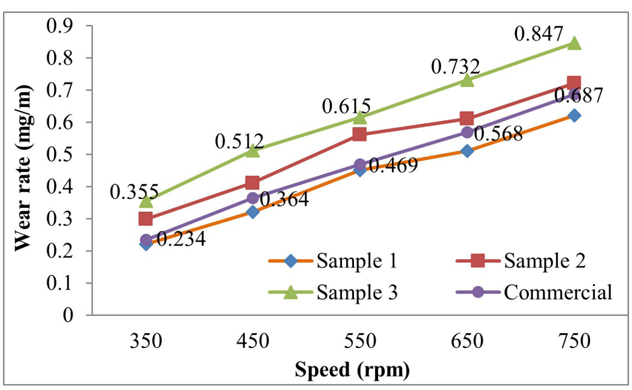

Figure 8: Variation of wear rate with respect to speed.

friction mainly depends on surface temperature, speed of the disc, and material composition, and the coefficient of friction is independent of the contact area. The wear rate largely depends on the bonding between different materials and particle size of materials. Sample 1 shows a minimum wear rate of 0.45 mg/m and sample 3 shows a maximum wear rate of 0.61 mg/m.

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Conflict of Interest

The authors declare no conflict of interests that are relevant to the content of this article.

Credit Author Statement

Tushar Rai: Conceptualization, Study design, Experimentation, Data analysis, Writing - original draft preparation, Writing - review and editing; S.J. Pawar: Conceptualization, Study design, Writing - original draft preparation, Writing - review and editing. All the authors read and approved the manuscript.

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