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PAPER

Investigation of Caryota urens fibers on physical, chemical, mechanical and tribological properties for brake pad applications

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Abstract

The idealization of this research work is to extend the utilization of the naturally available fibers as a key ingredient in the development of a non-asbestos free brake pad. The fibers used in this work are *Caryota urens,* which is found all over the Asian regions and abundantly available. The compression molding machine was used to develop the non-asbestos free brake pad. The fibers were added in weight percentages of 5, 10 and 15. The various physical, chemical, and mechanical properties were evaluated. Chase test rig was used to evaluate the tribological properties. The combination of *Caryota urens* fiber with the barytes had a more significant influence on the tribological properties. The brake pad composites with ten weight percent of *Caryota urens* fibers based brake pads possessed a good coefficient of friction values with less fade values and less fluctuations. Increasing the weight percentage of *Caryota urens* fibers in the brake pad formulation had a decreasing trend in the wear performance but increased recovery properties.

1. Introduction

The purpose of brake is to stop or slow down the vehicle at the required period. The stopping of vehicles takes place due to the frictional surfaces between two mating services. Frictional and wear resistance are the important parameters of the brake pad for better operation [1]. The brake pad generally consists of 13–15 ingredients that are used to satisfy the required frictional properties [2, 3]. They are generally classified as binders, fillers, friction modifiers (abrasives and lubricants), and reinforcements. Fillers are used further classified as inert and functional. Initially the era of brake pad started by using the asbestos as the predominant material. Later it was identified as carcinogenic, so replacement of asbestos came into existence. Owing to the concern about eco-friendliness many researchers are showing interest towards the natural fibers which are available and present abundantly. Due to its unique advantages as excellent mechanical properties, lightweight, low cost and high strength it has been selected as the best alternative for various synthetic fibers. In recent years many natural fibers were used in multiple applications such as automobile, household appliances, textile industries, aerospace industries, etc. The various natural fibers used for various applications are jute, kenaf, bamboo, hemp, flax, cotton, areca, *Tridax procumbens, Cardiospermum Halicababum* etc [4–7]. These natural fibers are selected based on the ease of availability and its effectiveness in its applications. It is used in different applications by changing the physical, chemical properties and biocompatibility nature [8, 9]. The different types of fibers were used, such as short fiber, long fiber and chopped short fiber for its applications. To have better wear resistant the short random fiber is appropriate. Though natural fibers have many advantages it also has various other disadvantages on the other hand such as decreased mechanical property, stiffness and varying strength which is enhanced using various techniques like chemical treatment [10, 11]. Suryarajan *et al* [12] investigated the fade and recovery performance of the silane treated, alkali-treated and untreated *Prosopis juliflora* fibers based brake pads using

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Table 1. Designation of brake pads and its weight percentage.

Sl. No	Ingredients of the Composites		Designation of developed brake pads CUB1	CUB2	CUB3
1	Varying Ingredients	CUS fibers	5	10	15
2		Barytes	35	30	25
3	Parental ingredients	60	60	60	

Table 2. Sequential Procedure Followed in developing composites [16–20].

Procedure	Conditions
Sequential mixing in plough shear (lodige) mixer	Total duration 20 min, shovel and chopper speed: 140 and 2800 rpm. 1 kg mix was prepared. Mixing sequence is fibers (10 min), friction modifiers & fillers (6 min), binders (4 min).
Curing in hydraulic cure press	Compression Moulding machine with six mold cavities was used, Die temperature was set to 145 °C; Compression Pressure 13 MPa; Each cavity filled with 80 grams of mixture; Curing Time: 7 min; Five intermittent breathings for removing volatile gases evolved during curing
Post curing	5.5 h at 160 °C in a hot air oven
Finishing	Grinding of the baked pad in the belt grinder

Chase test as per SAE J661a. It was found that silane treated *Prosopis juliflora* fibers based brake pads with five weight percent performed better tribological performance. Saikrishnan *et al* [13] developed various weight percentages of areca sheath fiber-based brake pads for automobile applications. It was found that brake pads with five weight percent of areca sheath fibers showed excellent tribological properties compared to other brake pads. Tej Singh *et al* [14] investigated the various weight percentages of ramie fibers on the tribological performance of brake friction composites using Chase test rig. The test results showed that five weight percent of ramie fibers based brake pads performed better in the tribological testing compared to other developed composites.

The CUS fibers are commonly called solitary fishtail palm, toddy palm, wine palm, or jaggery palm. It belongs to Arecaceae family and found in regions of South India and South Asia countries. It can grow up to a medium-sized of 20 m tall like palm which has branched and having an extension at internodes. The study on mechanical properties of the CUS fibers in the polyester composites was already explored. The current study is to investigate the CUS fiber as reinforcement in brake pad applications. The percentage of fibers were chosen based on the previous literature [15]. The brake pads were developed as per standard practice. The developed brake pads were analyzed for physical, chemical, mechanical and tribological properties as per industrial standards.

2. Materials and methods

2.1. CUS fiber extraction and brake pad development

The CUS fiber used in this work was sourced locally from Chennai, Tamilnadu, India. The extraction of fibers was done using water retting process. After extraction, the fibers which were at the inner side were again separated from the outer sheath manually. The CUS fibers were again thoroughly washed, and the moisture content was removed by heating in a hot air oven at 50 °C for 5 h. Then the brake pads were developed using a friction material formulation possessed 15 parental ingredients namely fibers with additives (11 weight%): acrylic fiber, rock wool fiber, steel fiber, hydrated lime, binders with additives (16 weight%): phenolic resin, NBR, crumb rubber, $CaCO_3$, frictional modifiers (18 weight%) graphite, silicon carbide, and fillers of (15 weight%) mica, friction dust, tin powder. The barytes, CUS Fibers are the varying ingredients and its formulation weight percentage are given in table 1. The conventional method was used to develop the brake pad, and its details are given in table 2 [16–20]. The developed brake pad is shown in figure 1.

2.2. Characterization of the developed brake pads

2.2.1. Physical, chemical and mechanical characterization of the developed brake pads

The physical and mechanical properties of the developed brake pad composites were assessed by using industrial standards and the details are given in table 3 [21–25].



Figure 1. Developed Brake Pads.

Table 3. Measurement procedure of various Physical, Chemical And Mechanical properties [21–25].

Composite	Property	Procedure/Standard
CUS Brake Pad (CUB)	Density (Machine: Digital density measurement apparatus)	The test was performed as per IS 2742 Part 3 based on Archimedes principle
	Acetone extraction (Machine: Soxhlet extraction apparatus)	The test was performed as per IS 2742 Part 3 was the uncured resins percentage was found
	Ash content(Machine: Muffle furnace)	The test was performed as per IS 2742 Part 3 where the brake pads samples of 10 grams were placed in a muffle furnace for 2 h at 800 °C
	Hardness (Machine: Rockwell hardness tester)	The test was performed as per IS 2742 Part 3. K scale was considered in which the ball indenter was made of steel having dia 3.125 mm, the load applied was 1500 N at ten different portions. Average values were reported
	Porosity	This test was performed as per JIS D 4418. The samples were dipped in SAE 90 oil heated for 24 h and the weight was noted. Then it was wiped out with filter paper to remove the oil. Then the weight was noted. The difference was noted.
	Shear strength	Test carried out based on ISO-6312 at room temperature conditions. In this test, the developed brake pad with the backplate was placed in the shear testing fixture. A side load was applied to the brake pad surface while another load was applied in a perpendicular direction using a rammer. The load was applied gradually until failure.

2.2.2. Estimation of the tribological performance by using Chase test rig

The Chase test rig was used to determine the tribological properties of the developed brake pads. The IS2742 part 4 was followed for evaluating the tribological performances. Initially, the burnishing was carried out. In order to make good contact between the samples and drum burnishing was done. It was done at the standard 308 rpm for 20 min time until the saturation temperature reaches 93 °C. After completing burnishing process the baseline cycle was initiated. A temperature between 82 to 104 °C was maintained. It was done as per the procedure at 411 rpm and a load of 660 N. After that the speed and the load were kept constant, fade, and recovery were measured. The detailed procedure is presented in table 4 [13, 25, 26]. Finally the wear loss was calculated as per the change in weight observed in the digital weighing balance.

3. Results and discussions

3.1. Physical, chemical and mechanical properties of CUS fibers based brake pads

The physical, chemical and mechanical properties of the CUS fibers based brake pads are evaluated and given in table 5. The CUB1 has the highest density of 2.39 g cc^{-1} which is higher compared to the other two composites. This is mainly due to the higher density of the barytes which is 4.1 g cc^{-1} that is higher than the natural fibers. This is in tandem with the literature findings of Lenin Singaravelu *et al* 2019 [27] where crab shell powders were replaced by synthetic barytes in the brake friction formulation. The increase in CUS fibers decreased the hardness which is due to the presence of barytes in less weight percentage that doesn't fill the pores that are essential for effective braking. Similar results were seen in the literature findings of Lenin Singaravelu *et al* 2019 [18]. The better curing is seen in the CUB3 composite due to the less hardness that enables effective heat penetration during curing. This effect can be seen from the lower acetone extraction value. Ash content shows

Table 4. Experimental procedure of the Chase test as per IS2742-Part-4.

Cycles	Speed (rpm)	Temperature (°C) min	Temperature (°C) max	Load (N)	On time min	On time sec	Off time sec	No. of Applications	Heater	Blower
Burnish	308	—	93	440	20	—	—	1	Off	Off
Initial Baseline	411	82	104	660	—	10	—	20	Off	Off
Fade-I	411	82	289	660	10	—	—	1	On	Off
Recovery-I	411	261	93	660	—	10	—	1	Off	On
Wear	411	193	204	660	—	20	10	100	Off	Off
Fade-II	411	82	345	660	10	—	—	1	On	Off
Recovery-II	411	317	93	660	—	10	—	1	Off	On
Final Baseline	411	82	104	660	—	10	20	20	Off	Off

Table 5. Physical, Chemical and Mechanical characteristics of the developed friction composites.

Properties	Unit	Standard	CUB1	CUB2	CUB3
Density	g cc^{-1}	IS 2742 Part-3	2.39	2.32	2.28
Hardness	No Unit		105	97	91
Acetone Extraction	%		1.204	1.195	1.183
Ash Content	%		83.26	81.79	79.21
Porosity	%	JIS D 4418	4.3	5.24	5.57
Shear Strength	N mm^{-2}	ISO 6312	442.3	451.2	456.2

the decreasing trend value with increase in the fiber content. This is attributed due to the thermal stability of the barytes compared to the natural fibers [28]. It is a postulate that higher the density, hardness then there will be lower porosity [29, 30]. Similar behavior is seen in the current study, where the baryes being smaller in size fill the space thereby reducing the porosity in the case of CUB1, while the natural fibers which increase the volume show higher porosity as in the case of CUB3. The shear strength for CUB3 is higher compared to other two composites which are mainly due to the better adhesion of friction materials layer with the backplate caused by effective curing of the composite. These can be inferred from the literature findings of Vijay *et al* 2019 and Ganesh Babu, 2019 [19, 31].

3.2. Tribological properties of the developed CUS fibers based brake pads

The tribological properties of the developed brake pad composites are done with the help of the Chase test rig and the output graphs of fade and recovery are given in figure 2. Among the tested brake pads, CUB1 showed the constant frictional values till 177 °C and later got decreased. After this a gradual reduced is observed, and then it went down at the end of the test without much difference for the CUB2 composites. Thus there is the marginal difference among the composites. CUB3 showed increased frictional value till 149 °C and later it decreased down marginally. During the first fade rate the all the developed brake pads showed drastically μ decrease, whereas during the second fade rate all the brake pad composites had a high frictional value at the temperature above 250 °C and decreased slowly. Further, a slight decrease in the frictional values is observed above the 280 °C for all the three composites. In the second recovery, frictional values are higher till a temperature of 289 °C. CUB1 showed a marginal decrease in the frictional value above 260 °C, whereas the composites with CUB3 decreased vigorously. All the frictional values are within the industrial range (0.3 to 0.55) as per the literature [28]. The fade and recovery showed similar trends. Out of all the three composites the CUB1 and CUB2 had a slight decrease in the values above 260 °C whereas CUB3 showed a phenomenal reduction in the frictional values above 205 °C. This is mainly due to increase in μ during fade cycles is due to the least thermally stable natural fibers compared to more thermally stable barytes in the frictional formulation. But the trend got reversed in the recovery cycles since the porosity of the brake pads helped to regain the friction value drastically by removing the heat at the interface thereby sustaining the brake pads from transfer film formation by pyrolysis and other abrasive mechanisms. This is tandem with the literature findings of Manoharan *et al* 2019 and Vijay *et al* 2019 [23, 28].

3.2.1. Frictional performance parameters

The frictional behavior of all the developed composites is observed and given in figure 3. All the developed composites μ are well within the industrial range as specified in the literature [23]. The μ hot values will be lesser

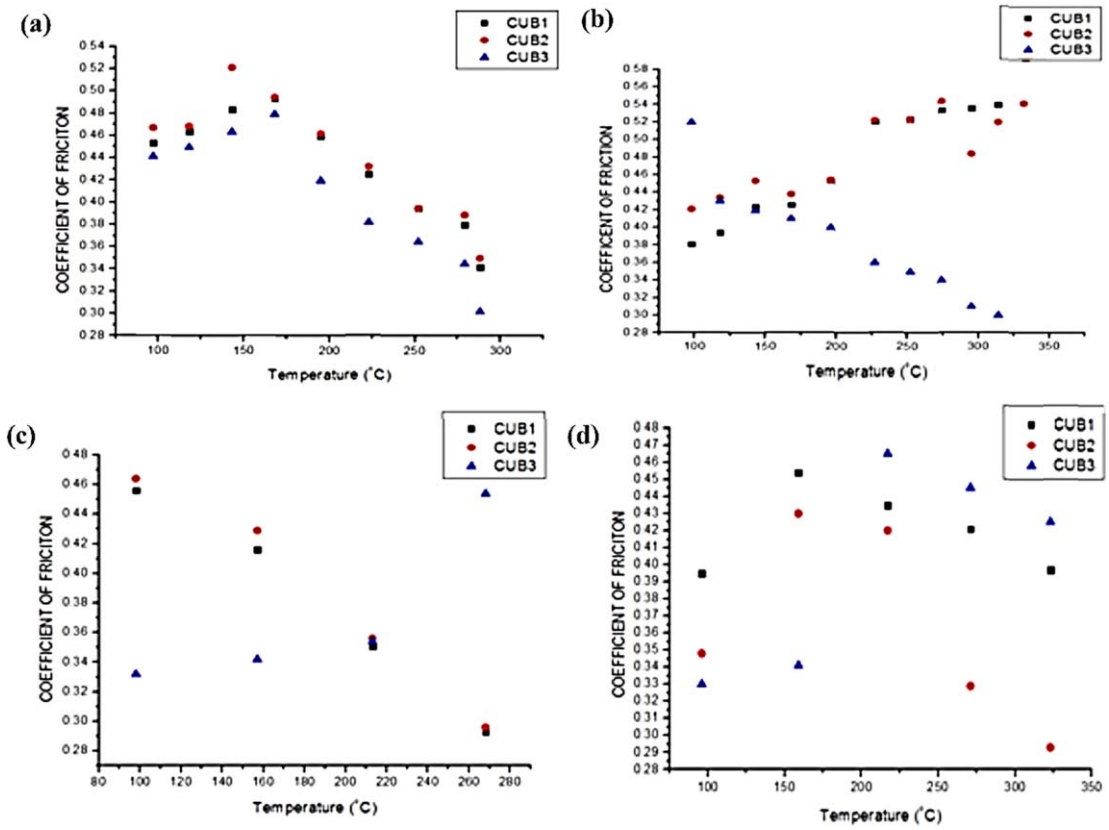


Figure 2. Response in friction during (a), (b) fade 1&2 ; (c), (d) recovery 1&2 cycles.

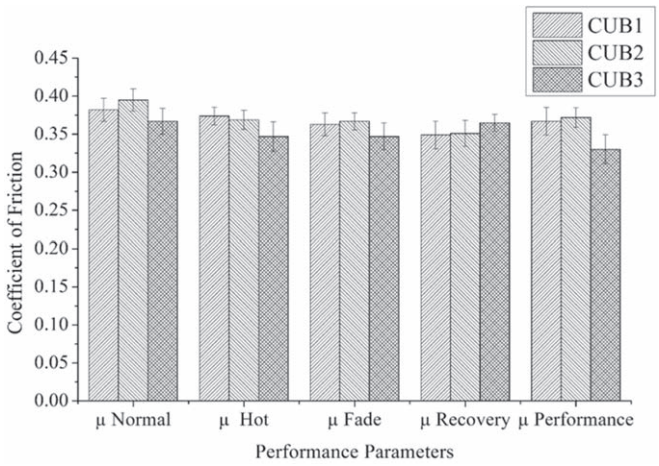


Figure 3. Friction performance parameters of the developed brake pads.

than μ normal values as per the literature [22] similar trend is also seen in the current study. μ Performance was measured by taking the average of both fade and recovery test runs. The minimum coefficient of friction was taken from both the fade cycles and highest coefficient of friction was obtained recovery cycles. The μ performance and μ Fade are between 0.33–0.370 and 0.345–0.365 respectively and it showed decreasing trend on increasing the CUS fiber, and it is presented in the figure below. This is mainly due to degradation of least stable ingredients at higher temperatures. From figure 3, it is witnessed that the performance coefficient of friction and fade possessed increasing values for CUB1 and CUB2; later on it decreased by increasing the fiber content and reduction in thermally stable barytes [28]. This thermally stable barytes also plays a vital role in film formation that protects the braking interface prone to further degradation of least stable ingredients and contact plateaus

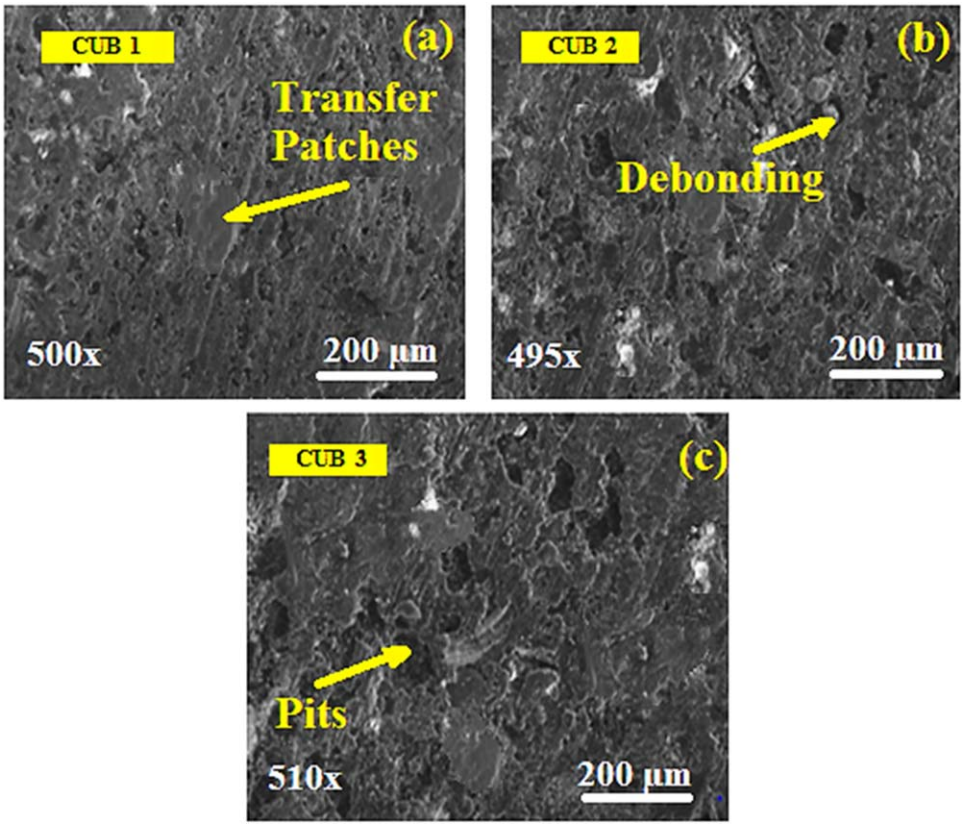


Figure 4. SEM images of Chase tested brake pads (a) CUB 1; (b) CUB 2; (c) CUB 3.

from further disintegration. The μ recovery showed an increasing trend due to the better porosity which helped to prevent degradation causing pyrolysis [29, 30, 32].

3.3. Wear performance and worn surface morphology of the brake pads

The wear performance is a combination of different mechanisms that are thermally activated. In this work increasing the content of the CUS fibers increased the wear rate. The wear for all the composites remains in the range between 1.29 for CUB1 and 1.39 for CUB2 and 1.57 for CUB3. The increase in the wear is attributed due to the increasing content of the CUS fibers with the reduction in thermally stable barytes [28]. Thus optimal percentage of CUS fibers has beneficial effects on the wear performance. It can also be due to the more amount of CUS fibers that were added in CUB3, caused fibers agglomerated and peeled off, thereby increasing the wear rate. Higher the hardness increases the wear resistance in certain cases for brake pads; similar behavior is also seen in this study [31].

The worn surface analysis of the Chase tested brake pads are analyzed and discussed below in figures 4(a)–(c). The wear debris and small pits, groves are observed in all the tested brake pads. It is formed due to the scattered particles. The formation of contact plateaus and transfer patches are mainly due to the fibers, thermally stable, and least stable ingredients which in turn control the tribological properties of the brake pads. The wear debris also depends on these fibers. The transfer patches are seen in all the composites but more in CUB3. This is due to the reduced wear resistance of CUB 3 when compared to CUB1. Thus CUB3 SEM images 4(c) shows a lot of wear debris and severe damages on the tested surface. While in the case of CUB1 as shown in figure 4(a), there exist transfer patches and film formation which helps to prevent the pyrolysis and further degradation of ingredients leading to good wear resistance. CUB2 as shown in figure 4(b) performed slightly lower than CUB1.

4. Conclusions

Caryota urens fibers based brake pads were fabricated by compression molding technique and physical, chemical mechanical and tribological properties were evaluated. The following conclusions were drawn.

- The density, hardness, ash content got decreased with an increase in *Caryota urens* fibers in the brake pads while the shear strength, porosity got increased.

- The brake pads with 10 weight percent of *Caryota urens* fibers showed better frictional performance especially in the fade, performance, and normal μ, while the 15 weight percent *Caryota urens* fibers showed better recovery μ.
- The wear performance was better in the case of 5 weight percent *Caryota urens* fibers based brake pads compared to the other two developed brake pads. This behavior can be seen from worn surface images that shows film and transfer patches.

Thus *Caryota urens* fibers can be optimally used in the brake friction materials formulation as a reinforcement.

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