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Comparative Study of the Effects of Treatment Techniques on the Mechanical Properties of Kenaf (Hibiscus Canabinus) Fibre Reinforced Brake Pads

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Abstract
Asbestos fibre has been used as the traditional base material in brake pads manufacture, but due to its health hazard, non-renewability, cost, non-biodegradability and difficulty in processing, its replacement has been sought. This paper reports the effects of some fibre treatment techniques namely: mercerization, acetylation and semi-carbonisation on the performance of Kenaf fibres. The treated kenaf fibres which are considered biodegradable, cost effective, renewable and user friendly have been used as a possible base friction material for brake pad production. results indicated that they all the four kenaf brake pad samples behave differently during performance evaluation. Of all the samples studied, Mercerized kenaf brake pad samples exhibited high values of Rockwell hardness of 101$\pm$1.379 HR and an Impact strength of 20.86$\pm$0.704KJ/cm^2 on the average. Compressibility test indicated that Acetylated fibre based samples also show high compressive strength of 0.86$\pm$0.058KN/mm^2 as compared to Crude, mercerised and semi-carbonised fibre based kenaf brake pads.
Keywords: treatment techniques, kenaf fibre, comparative study, brake pads

1. Introduction

Brake pad for an automotive brake system is friction complex composites because they contain numerous ingredients that are diverse in physical, mechanical and chemical properties. These brake pads or friction composites comprise many disparate ingredients such as binders, fibres and fillers. According to Marthur *et al (*2004), asbestos fibres, which occurred naturally as mineral, have been used as traditional fibrous ingredient to reinforce the constituents in the friction material or to provide mechanical strength and also to inhibit catastrophic failure of the structure. However, due to its non-biodegradability, non-renewability, difficulty in processing, high cost, high density and most especially its risk of causing cancer, asbestos – based friction materials were banned and the search for safer and cheaper alternative sources started as reported by NICNAS (1999) and Warren (1992). Several treatment techniques intended to improve the natural fibre-matrix adhesion in brake pad composites were reported in literature. Some of the techniques considered in this paper are mercerisation, acetylation and semi-carbonisation of kenaf fibre as compared to using the crude. The objectives of this study is to compare the effects of these fibre treatment techniques on the mechanical properties such as Rockwell Hardness(HR), Impact Strength (JK/cm^2) and Compressive Strength (KN/mm^2) of Kenaf Brake Pad samples.

2. Materials and Methods

2.1 Materials for kenaf brake pad production

The materials used in this study include binder or polyester, fillers (rubber crumbs, fine grain iron filings, graphites, barium sulphate), rolls of decorticated kenaf fibre, sodium hydroxide, ammonium oxalate, hydrochloric acid, hydrogen peroxide, tools and equipment include; furnace, oven, drier, hardness tester, compression moulding rig, friction test rig, impact tested, digitizer, camera fitted light microscope, microtome, stop watch, weighing balance and intsrone machine.

2.1.1 Binder

The Unsaturated Polyester Binder that was used was obtained from the Northern Scientific Laboratory Located here in Yola.Ten litres of this binder were purchased for the purpose of this research.

2.1.2 Fillers

2.1.2.1 Rubber crumbs

These are the other black particles that are seen in commercial brake pads. They are produced from scrap rubber from used tires of 50 μm and are relatively inexpensive. The low specific weight of rubber was an advantage in the final product. In this work 500 g of rubber crumbs was ground to 0.5 mm particle size and was used.

2.1.2.2 Fine grained metal iron

Fine grain metal iron or iron powder was used in this research as an abrasive. About 1.5 kg of fine-grain metal iron was sieved which was obtained as waste from Machine Shops in Jimeta, Yola. This was sieved into fine grain of 2 μm size

2.1.2.3 Graphite
Graphite occurs naturally in places like Gayama village in Taraba State, Nigeria. From this village, which is about 289 km from the state capital, Jalingo, 1.2 kg of graphite stone was mined or dug from the deposit for the purpose of this study. Thereafter, it was milled and the product, which is a fine powder, was sieved through a 200 mesh (75 um).

2.1.2.4 Barium sulphate
Like graphite, Barium Sulphate also called barite was obtained locally from the mines at Lau village of Taraba State. This filler was ground into powder by means of a plate mill; thereafter it was sieved through a 345 mesh (5 µm). A Total of 1.5 kg of this material was used in this study.

2.1.3 Kenaf fibre
Ten rolls of decorticated Kenaf fibre were used in this study, it was procured from Jimeta Market, Yola. These fibres have been decorticated, dried and packed in form of rolls. The material represents a matured fibre and the best of its type available in the locality. These fibres were purified and transformed into better fibre through some innovative chemical treatments discussed previously. Using a plate mill, I kg each of the four fibre Treatments was ground and sieved into an average length of 2 - 4 mm and an average diameter of 12 ɥm. According to Jang *et al* (2001and 2005); Marthur *et al* (2004), 10 % - 20% fibre reinforcement was used in brake padding (Pre trials to determine the fibre volume fraction were also carried out). Thereafter, 15% by weight of kenaf fibre was considered adequate for reinforcement in this study.

2.2 Methods
2.2.1 Surface modification by semi – carbonization or heat treamtent
Crude fibre having been retted and bleached was semi-carbonised using a laboratory oven as shown on Figure 5a, b, and c. An equal weight of 0.300 g of the above kenaf fibre sample was weighed. And using a heating rate of 2.21 ^{0}C/min, each batch was heated to temperatures of 100^{0}C 150^{0}C, 200^{0}C, 250^{0}c and 300^{0}C respectively. It was then soaked for 5 mins at each temperature threshold as was done by Rowell *et al* (1995).

2.2.2 Production of kenaf brake pads
2.2.2.1 Experimental design
The experiments were of the randomised 1 x 3 x 3 factorial design for four different types of kenaf fibre at 15 % weight each.. Table 1 shows the outline of the experimental design for the four types of kenaf fibers with three levels of polyester binder and filler.

Main treatment: **T_1** (Untreated fibre); **T_1** (Mercerized fibre); **T_1** (Acetylated fibre); T_1 (Semi – Carbonized fibre) at 15 % weight each. **Sub-treatmen**ts: **S_1** (15 % polyester (Binder)); **S_2** (20% polyester); **S_3**(25% polyester), then filler at **R_1** (60 %), **R_2** (65 %), and **R_3** (70 %) by weght

Treatment combination = for the four types of fiber treatments = 1 Level of fibre × three levels of binder (Polyester) x three levels of Filler = 1 x 3 x 3 = 9 (T1S1R1, T1S1R2, T1S1R3, T1S2R1, T1S2R2, T1S2R3, T1S3R1, T1S3R2 and T1S3R3)

Total experiments conducted = 9 treatments x 4 Fibre Types × 5 replications = 108 experiments.

T, S and **R** were mere letters chosen to represent fibre treatment, binder (polyester) and Filler, respectively The numbers 1, 2, 3 were used to denote the levels of the factors. This exercise was done this way for convenience only.

Table 1 Experimental design for kenaf brake pad samples

		Treatment			
S/N	Sample code	Kenaf Fibre Type (1 level)	Polyester (3 levels)	Filler (3 levels)	Replications
1.	T1S1R1	1	1	1	5
2.	T1S1R2	1	1	2	5
3.	T1S1R3	1	1	3	5
4.	T1S2R1	1	2	1	5
5.	T1S2R2	1	2	2	5
6.	T1S2R3	1	2	3	5
7.	T1S3R1	1	3	1	5
8.	T1S3R2	1	3	2	5
9.	T1S3R3	1	3	3	5
10	Control (commercial sample)	NA	NA	NA	NA

NA = Not Available

1 Kg of rubber crumbs, 1 Kg of iron filings, 1 Kg of barium sulphate and 1 Kg graphite
to give 4 Kg of Fillers.

Total Raw Materials used in this study = 100g x 1 treatment x 5 replications = 500g

Where the treatment combination does not give exactly 500g, calcium carbonate was used as a space filler to adjust the remaining percentage during replications as was done by Marthur *et al* (2004). Then the materials used in this study is approximately, 500g x 9 Treatments x 4 Fibre Types = 18,000g

2.2.2.2 Mixing of raw materials

In order to assist fiber dispersion, kenaf fibres were fiberized in a double-bladed kitchen blender for 8 mins. The fiberized kenaf fibers were dried at 60^{0}C for 24 h and stored in a desiccator, prior to compounding. A total of 9 samples with five replicates for each formulation of the four fibre treatments were mixed batch by batch.

The mixing was done at a temperature of 38^{0}C, mixing time of 5 mins, and rotor speed of 600 rpm as was done by Jang *et al* (2001). The first treatment mixing was carried out in this manner: the binder resin (unsaturated polyester (15 % of the Total weight) was first added inside the mixing chamber then another 15 % by weight of the fibre type was added, and finally 70 % by weight of the last component (filler) was also added. The mixer containing 100 g of kenaf fibre, polyester and filler was started and run for 5 mins until the three components were mixed. Thereafter the mixed material was removed for the next process.

2.2.2.3 Compression moulding

The mixed material was molded on a Hydraulic press into pads with dimensions of 6 cm x 4 cm x 2 cm. The mold was first preheated to raise the temperature to175 ^{0}C. As shown in Figure 1 and Figure 2, the mixed material was then placed in the mould and heated for 1 min under a constant pressure of 32.5 MPa; thereafter the moulded material was removed and cooled at room temperature for 8 mins as outlined on Figure 2a-d.

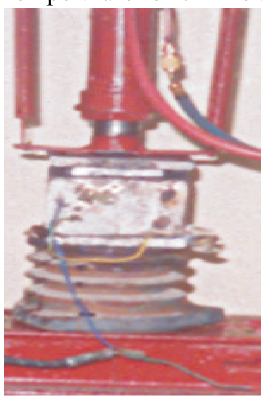

Figure 1 Compression moulding process using the CMR Equipment

The pressed samples were then cured in an Oven for 8h, therafter it was finished and prepared for performance properties (Booker., 1992 and Jang *et al.*, 2001)

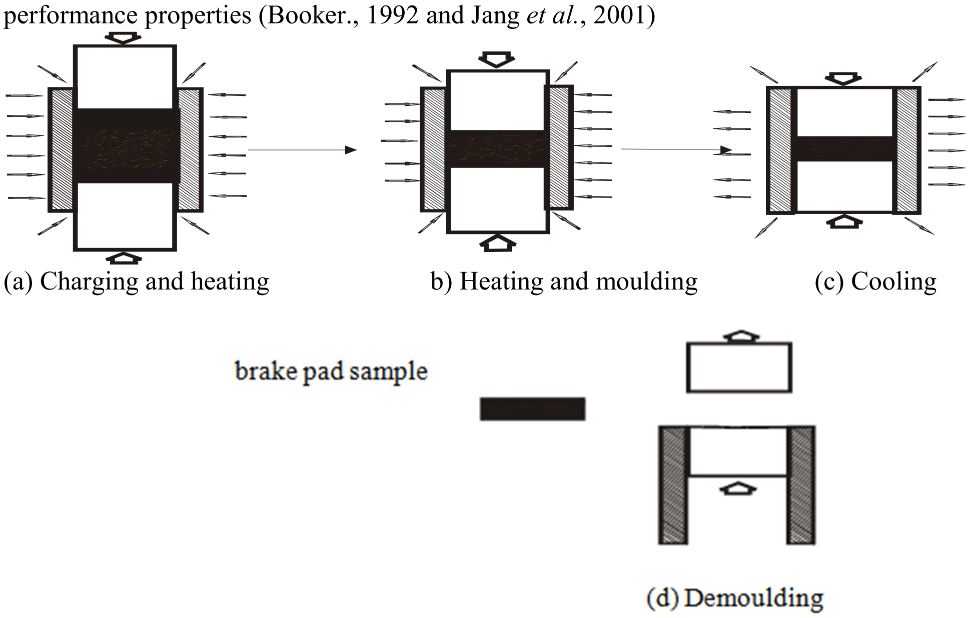

Figure.2 a, b, c and d. Compression Molding process for kenaf brake pad

Plate 1 Kenaf brake pad samples

3.3.2 Testing for mechanical properties of kenaf brake pads

The mechanical properties investigated in this research for the purpose of characetrising the brake pads were hardness and impact resistance.

3.2.1 Rockwell hardness of brake pads

Rockwell hardness measurements were performed according to ASTM D2240-77 (ASTM 1999). The Rockwell hardness tester consists of a Pressure foot, an indenture, and an indicating device. The test was carried out by first placing a specimen on a hard, flat surface. The pressure foot of the instrument was pressed on to the specimen, making sure that it was parallel to the surface of the specimen of 2 cm x 2 cm x 4 cm. The Rockwell hardness was read within 1 s after the pressure foot was in firm contact with the specimen. Each specimen was subjected to five Rockwell hardness readings; the results obtained from this experiment was statistically analysed.

3.3.2.2 Impact resistance of kenaf brake pads

The Impact properties of the polymeric materials are directly related to the overall toughness of the material. The impact strength test was developed to overcome the deficiencies of flexural tests. Impact energy is the energy required to break a standard impact specimen in tension by a single swing of a standard calibrated pendulum under a set of standard conditions. The impact strength test was conducted according to ASTM (1995) which was briefly stated as follows, The specimen was clamped into the impact tester fixture with the notched side facing the striking edge of the pendulum. The pendulum was raised and released and the impact energy was determined, recorded for all the specimens in all group of brake pad samples and their average was calculated and recorded.

4. Results and Discussion

4.1 Evaluation for mechanical properties of kenaf brake pads reinforced with crude kenaf fibre.

The results of the evaluation of mechanical properties of kenaf brake pads reinforced with crude fibres is as presented on Table 2.

Table 2: Evaluated mechanical properties of crude samples

		Treatment			Mechanical properties		
S/N	Sample code	Crude Fibre (1 level)	Polyester (3 levels)	Filler (3 levels)	Rockwell Hardness HR	Impact strength KJ/cm^2	Compressive strength KN/mm^2
1.	T1S1R1	1	1	1	55.628$\pm$ 1.293	4.966$\pm$ 0.180	0.616$\pm$ 0.045
2.	T1S1R2	1	1	2	54.734 $\pm$ 1.778	6.890$\pm$ 0.310	0.612$\pm$ 0.033
3.	T1S1R3	1	1	3	55.810 $\pm$ 2.072	7.312$\pm$ 0.308	0.530$\pm$ 0.038
4.	T1S2R1	1	2	1	57.096 $\pm$ 1.549	10.030$\pm$ 0.320	0.572$\pm$ 0.058
5.	T1S2R2	1	2	2	58.218 $\pm$ 0.845	14.452$\pm$ 0.391	0.530$\pm$ 0.054
6.	T1S2R3	1	2	3	67.498 $\pm$ 1.885	15.558$\pm$ 0.508	0.566$\pm$ 0.028
7.	T1S3R1	1	3	1	67.498 $\pm$ 1.885	16.010$\pm$ 0.419	0.466$\pm$ 0.025
8.	T1S3R2	1	3	2	59.452 $\pm$ 1.254	17.140$\pm$ 0.337	0.454$\pm$ 0.027
9.	T1S3R3	1	3	3	60.070 $\pm$ 0.879	18.272$\pm$ 0.439	0.454$\pm$ 0.011
10	Control	NA	NA	NA	110.60 $\pm$ 4.04	14.53 $\pm$ 0.81	0.395 $\pm$ 0.021

NA = Not Available

From Table 2, it is clear that the average values of Rockwell Hardness (HR) in crude samples which ranges from 55.628 HR in T1S3R3 sample code to as high as 67.498 HR in T1S2R3. Impact resistance (kN/cm^2) also range between 4.966 in T1S1R1 to a much higher average value of 18.272 in T1S3R3. The same trend follows in Compressibility (KN/mm^2) where highest value 0.616 occurred in T1S1R1 and T1S3R3 having the lowest value of 0.454 KN/mm^2.

4.2 Evaluation for mechanical properties of kenaf brake pads reinforced with mercerised kenaf fibre.
The results of the performance evaluation of mercerized kenaf brake pad samples is as presented on Table 3 below.

Table 3: Evaluated mechanical properties of brake pads reinforced with Mercerised kenaf fibre

		Treatment			Mechanical properties		
S/N	Sample code	Mercerised Fibre (1 level)	Polyester (3 levels)	Filler (3 levels)	Rockwell Hardness HR	Impact strenght KJ/cm^2	Compressive strength KN/mm^2
1.	T1S1R1	1	1	1	76.154 $\pm$ 0.640	10.348$\pm$ 0.588	0.806 $\pm$ 0.061
2.	T1S1R2	1	1	2	75.010$\pm$ 0.402	12.014 $\pm$ 0.268	0.904 $\pm$ 0.041
3.	T1S1R3	1	1	3	73.466$\pm$ 0.538	12.984 $\pm$ 0.525	0.906 $\pm$ 0.039
4.	T1S2R1	1	2	1	99.822$\pm$ 4.738	19.462 $\pm$ 0.433	0.454 $\pm$ 0.036
5.	T1S2R2	1	2	2	101.866 $\pm$ 1.379	20.862 $\pm$ 0.704	0.482 $\pm$ 0.034
6.	T1S2R3	1	2	3	96.870 $\pm$ 0.838	22.410 $\pm$ 0.708	0.536 $\pm$ 0.052
7.	T1S3R1	1	3	1	90.650 $\pm$ 0.458	24.326 $\pm$ 0.452	0.598 $\pm$ 0.025
8.	T1S3R2	1	3	2	91.130 $\pm$ 0.894	16.200 $\pm$ 0.570	0.622 $\pm$ 0.025
9.	T1S3R3	1	3	3	85.464 $\pm$ 0.412	15.332 $\pm$ 0.561	0.696 $\pm$ 0.031
10	Control	NA	NA	NA	110.60 $\pm$ 4.04	14.53 $\pm$ 0.81	0.395 $\pm$ 0.021

NA = Not Available

From Table 3, one can observe that the average values of Rockwell hardness (HR) in mercerised samples ranges from 76.154 HR in T1S1R1 sample code to as high as 101.866 HR in T1S2R2. Impact resistance (kN/cm^2) also range between 10.348 in T1S1R1 to a much higher average value of 24.326 in T1S3R1. Compressibility (KN/mm^2) of mercerised kenaf brake pads have the highest value of 0.906 in T1S1R3 which occurred and T1S2R1 having the lowest value of 0.454.

4.3 Evaluation for mechanical properties of kenaf brake pads reinforced with acetylated kenaf fibre.
Table 4 shows the evaluated mechanical properties of brake pads reinforced with Acetylated kenaf fibre. The average values of Rockwell Hardness (HR) of acetylated samples range from 67.376 HR in T1S1R1 sample code to as high as 74.112 HR in T1S3R2. Impact resistance (kJ/cm^2) also range between 8.176 in T1S3R1 to a much higher average value of 21.526 in T1S1R1.And in Compressibility (KN/mm^2), T1S1R3 has highest value 0.866 KN/mm^2 with the lowest value occurring in T1S3R1(0.466 KN/mm^2) as shown on Table 4.

Table 4: Evaluated mechanical properties of brake pads reinforced with Acetylated kenaf fibre

		Treatment			Mechanical properties		
S/N	Sample code	Acetylated Fibre (1 level)	Polyester (3 levels)	Filler (3 levels)	Rockwell Hardness HR	Impact strenght KJ/cm^2	Compressve strength KN/mm2
1.	T1S1R1	1	1	1	67.376 $\pm$ 1.471	21.526$\pm$ 0.924	0.856$\pm$ 0.058
2.	T1S1R2	1	1	2	66.504 $\pm$ 2.673	21.060$\pm$ 0.806	0.864$\pm$ 0.049
3.	T1S1R3	1	1	3	69.162$\pm$ 1.224	20.890$\pm$ 0.071	0.866$\pm$ 0.130
4.	T1S2R1	1	2	1	70.306 $\pm$ 0.671	21.302$\pm$ 0.418	0.672$\pm$ 0.103
5.	T1S2R2	1	2	2	72.682 $\pm$ 0.961	18.292$\pm$ 0.504	0.580$\pm$ 0.075
6.	T1S2R3	1	2	3	71.428 $\pm$ 1.065	16.244$\pm$ 0.502	0.566$\pm$ 0.063
7.	T1S3R1	1	3	1	67.740 $\pm$ 4.490	8.176 $\pm$ 4.248	0.466$\pm$ 0.008
8.	T1S3R2	1	3	2	74.112 $\pm$ 0.752	12.072$\pm$ 0.215	0.540$\pm$ 0.039
9.	T1S3R3	1	3	3	72.262 $\pm$ 0.455	14.850$\pm$0.375	0.508$\pm$ 0.052
10	Control	NA	NA	NA	110.60 $\pm$ 4.04	14.53 $\pm$ 0.81	0.395 $\pm$ 0.021

NA = Not Available

4.4 Evaluation for mechanical properties of kenaf brake pads reinforced with semi-carbonised kenaf fibre.
The results of evaluation of mechanical properties of brake pads reinforced with Semi-carbonized kenaf fibre are presented on Table 5 below.

Table 5: Evaluated mechanical properties of brake pads reinforced with Semi-carbonised fibres

		Treatment			Mechanical properties		
S/N	Sample code	Semi-carbonised Fibre (1 level)	Polyester (3 levels)	Filler (3 levels)	Rockwell Hardness HR	Impact strength KJ/cm^2	Compressive strength KN/mm^2
1.	T1S1R1	1	1	1	87.184$\pm$0.757	20.488 $\pm$ 0.835	0.510$\pm$ 0.012
2.	T1S1R2	1	1	2	86.580$\pm$ 0.740	19.868 $\pm$ 0.625	0.476$\pm$ 0.005
3.	T1S1R3	1	1	3	86.492$\pm$1.349	18.890 $\pm$ 0.521	0.514$\pm$ 0.005
4.	T1S2R1	1	2	1	90.600$\pm$0.798	14.434 $\pm$ 0.701	0.472$\pm$ 0.016
5.	T1S2R2	1	2	2	90.448$\pm$ 1.147	14.884 $\pm$ 0.842	0.530$\pm$ 0.007
6.	T1S2R3	1	2	3	90.314$\pm$ 0.546	14.618 $\pm$ 0.631	0.554$\pm$ 0.008
7.	T1S3R1	1	3	1	74.288$\pm$ 0.686	14.062 $\pm$ 0.501	0.532$\pm$ 0.004
8.	T1S3R2	1	3	2	73.330$\pm$ 0.565	14.522 $\pm$ 0.952	0.516$\pm$ 0.015
9.	T1S3R3	1	3	3	71.822$\pm$ 0.949	14.872 $\pm$ 0.414	0.526$\pm$ 0.005
10	Control	NA	NA	NA	110.60 $\pm$ 4.04	14.53 $\pm$ 0.81	0.395 $\pm$ 0.021

NA = Not Available

From the Table above, the average values of Rockwell Hardness (HR) in semi-carbonised samples which ranges from71.822 HR in T1S3R3 sample code to as high as 90.600 HR in T1S2R1. Impact resistance (kJ/cm^2) also range from14.062 in T1S3R1 to a much higher average value of 20.488 KJ/cm^2 in T1S1R1. The same trend follows in Compressibility (KN/mm^2) where the highest value of 0.554 KN/mm^2 occurred in T1S2R3 and T1S2R1 having the lowest value of 0.472 KN/mm^2

5. Conclusion

From the results obtained it is clear that Mercerised kenaf brake pad samples have high hardness with an average value of 101HR. this means that this particular treatment technique increases the hardness property of brake pads. From literature, the harder the brake material the faster the brake discs wear.

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