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COMPARATIVE STUDY OF THE EFFECTS OF TREATMENT TECHNIQUES ON THE THERMAL AND FRICTIONAL PROPERTIES OF KENAF (*Hibiscus canabinus*) FIBRE REINFORCED BRAKE PADS

Namessan, N.O.[1], Maduako, J.N.[2] and Iya, S.[2]

[1]Department of Agronomy, Taraba State University, P.M.B 1167 Jalingo, Nigeria

[2]Department of Agricultural and Environmental Engineering,
Modibbo Adama University of Technology, Yola

Email address: naneekee@yahoo.com

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 the four kenaf brake pad samples behave differently during during performance evaluation. semi-carbonized samples had high thermal conductivity with an average value of 0.6215 W/m. K than all the samples investigated in this study.

Keywords: *treatment techniques, kenaf fibre, comparative study, brake pads, thermal properties*

INTRODUCTION

Brake pads for an automotive brake system are 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 physical properties (namely; density, water absorption and porosity) of Kenaf Brake Pad samples.

Materials and Methods

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.

Fillers

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.

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

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).

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.

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 μm. 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.

Methods

Acetylation of kenaf fibre.

To 1 g of mercerized fibre, 5.5 cm^3 of acetic acid; 2.5 cm^3 acetic anhydride 0.65 cm^3 conc. H_2SO_4 were added. The content was warmed gently to 45 ^{0}C for 1 h. 0.65 cm^3 of H_2SO_4 was again added and stirred using a magnetic stirrer at 43-45 ^{0}C for another 1 h. The dark colored solution was poured into 50 cm^3 of water and allowed to stand for 48 h. The precipitate was dried and the yield determined. The water absorptions characteristics was conducted on the acetylated fibre samples

Surface modification by mercerization.

About five batches of 1.0 g each of 10% treated ammonium oxalate and 10% hydrogen peroxide and bleached samples of cellulose fibre were immersed in beakers containing 10%, 15% 18%, 22% and 25% sodium hydroxide concentrations. The temperatures in these beakers were kept at 5^{0}C by means of ice blocks for a period of 45 mins. Thereafter mercerized samples were washed very thoroughly in 5% solution of acetic acid. The water absorptions characteristics was conducted on the mercerised fibre samples

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).

Production of kenaf brake pads

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

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

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.

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

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 60^0C 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.

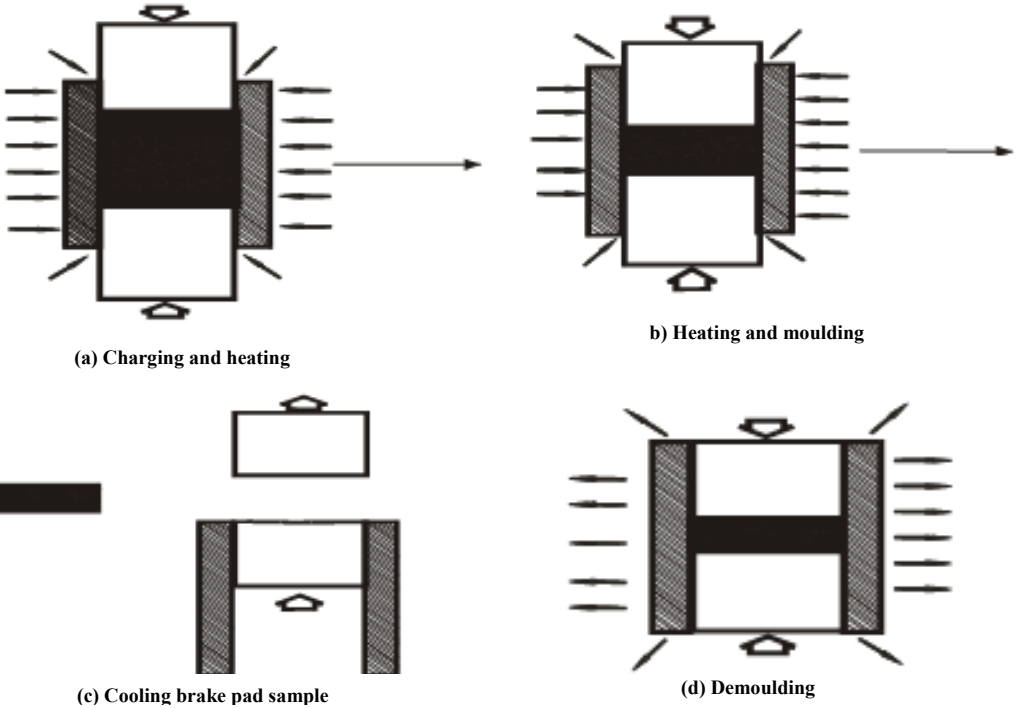
The mixing was done at a temperature of 380C, mixing time of 5 mins, and rotor speed of 600 rpm as was done by Jang et al (2001). The first treatment mixing was carried out in this manner: the binder resin (unsaturated polyester (15 % of the Total weight) was first added inside the mixing chamber then 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.

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 0C. 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.

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

Figure 1 Compression moulding process using the CMR Equipment



(a) Charging and heating

b) Heating and moulding

(c) Cooling brake pad sample

(d) Demoulding

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

Plate 1 Kenaf brake pad samples

Thermal conductivity of kenaf brake pads

Test specimens of 0.002 m^2 and thickness of 0.01m were cut from their respective mother samples as was done by Ugheoke *et al* (2006). The test specimens were tested one after the other. Each specimen was fixed in the space provided within the thermal conductivity apparatus fabricated by the Mechanical Engineering Department. A conical flask containing 50 ml of water was placed directly above and in contact with the specimen. A cork having a thermometer passing through it was used to cork the mouth of the conical flask. The thermometer read the temperature changes of the water in the flask. The test section was then closed and the initial water temperature was noted. A second thermometer with the aid of a cork was inserted into the steam outlet pipe offset to monitor the steam temperature so as to ensure constant base temperature of 100 ^{0}C

The boiler water outlet valve was closed while 5 litres of water was measured and poured into the boiler cover remaining opened. The boiler was switched on. Immediately the water started boiling, the boiler, cover was closed, while the steam inlet valve was fully opened with all the remaining valves closed. Timing commenced with the aid of a stopwatch immediately the steam inlet valve opened.

The testing was timed in each case for 10 mins and final temperature of the water in the beaker was noted at the end of time. Each specimen was tested twice and a mean temperature value was obtained. At the end of each experiment, the steam outlet valve was opened to release steam. The water in the boiler was refilled to maintain 5 litres and the experiment was repeated as stated above for other specimens

The values of the Thermal Conductivity, K for each of the specimen was determined using the formular as suggested by Ugheoke *et al* (2006).

$$K = 2.303\ MCL/A\ [\log(\Theta_1/\Theta_2)]/t \quad (1)$$

Where

k = thermal conductivity of the specimens
Θ_1 = initial temperature of the water in the conical flask (^{0}K)
Θ_2 = Final temperature in the conical flask (^{0}K)
C = specific heat capacity of water in conical flask {J/kg},
A = specimen are, (m^2)
M = mass of water in conical flask {kg}
t = Time (mins)

Testing for static coefficient of friction

Coefficient of Static friction is tangent of the friction angle of the material, which is the angle at which the material starts moving down the inclined plane with minimum resistance. This was carried out as was done by Kabri (2002). In his method, the sample whose friction angle is to be measured was placed on the inclined plane (galvanized sheet) surface of the friction test device lined with dry steel sheet. The inclined plane was raised gently with the help of the screw until material started to slide

down the device. The angle at this point was noted from the protractor attached on the device. The procedure was repeated five times and the corresponding readings were noted and calculated from the following formula.

$$\mu = \tan \Phi \quad (2)$$

Where

μ = coefficient of static friction
Φ = angle recorded when the material started to slide (^{0})

Testing for dynamic coefficient of friction

Dynamic friction tests on the kenaf brake pads were carried out using the laboratory scale friction and wear test rig, FTR as shown on Figure 2 and the data generated is presented in Appendix D. This equipment, which was designed and constructed in the course of this work, is equipped with a brake assembly of a medium size passenger car (Mazda Model). Using a continuous sliding test (ASTM G99) method as was done by Marthur et al (2004), when the brake was applied, a brake pressure of 3.5 g/cm2 was delivered to the calliper(Pcal) and the the force on the calliper (Fclamp) was calculated as in equation 3, the torgue and the friction force(Ffriction) were calculated from equation 5.

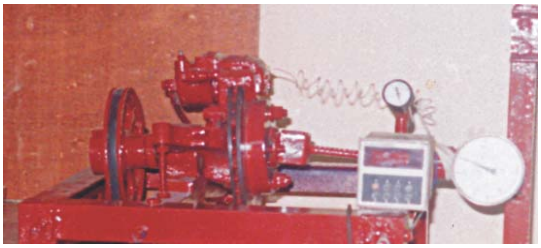


Figure 3. Experimental set up of the Friction Test Rig (FTR)

Thereafter, the coefficient of dynamic friction was calculated from equation 7. For every fresh experiment 5 min 'running-in' period was allowed for the FTR to allow the fresh test samples to bed very well, the reason being that the dynamic coefficient of friction changes significantly during the initial stages of testing and only becomes relatively stable after running in.

The rotational speed of 1500 rpm and a contact time of 1 s were maintained for the rotor or brake disc through out the experiment, the changes in the speed of the rotor after brake application and the power delivered to the rotor was used to determine the torgue on the brake disc. Also, temperature of the rotor surface was measured using a temperature sensor.

$$Fcal = Pcal \times Acal \quad (3)$$

$$Fclamp = Fcal \times 2 \text{ (back plates)} \quad (4)$$

$$Tr = Pem \times \omega r \quad (5)$$

$$F_{friction} = \frac{T_r}{R_{eff.rotor}} \quad (6)$$

$$\mu_{bp} = \frac{F_{friction}}{F_{clamp}} \quad (7)$$

Where

T_r = Torque on rotor radius (Nm),

P_{cal} = brake pressure delivered to the calliper (kg/cm2),

P_{em} = Power delivered to the rotor by the electric motor (hp)

ω_r = angular velocity (rad/s),

$F_{friction}$ = force of friction generated by the brake pads opposing the rotation of the rotor (N),

$R_{eff.\ rotor}$ = effective radius of the rotor(cm),

F_{clamp} = force generated by the clamp (Nm), μ_{bp}= coefficient of dynamic friction of kenaf brake pads, F_{cal}= the one sided force generated by the calliper (Nm),

A_{cal} = effective area of the calliper hydraulic pistons (cm^2)

Testing for thermal stability (wear loss) of kenaf brake pads

The wear tests were performed on the designed and constructed test rig, using a grey cast iron rotor disc of a passenger car. The friction test rig delivers 2.0 hp to the rotor rotating at 1500 rpm. A pair of test sample of 4 cm x 6 cm x 2 cm was bonded on both sides of the disc as required in SAE J – 661a test method and reported by Marthur *et al* (2004).

Figure 4.Worn samples of Kenaf Brake Pads fitted on back plates

The rig was allowed to run for some time to allow the samples to bed-in to allow at least 80% of the conformal contact, which was confirmed through visual inspection of the rubbed surface (Figure 4) prior to every experiment. The braking load of 3.5 kg/cm^2 was applied once the required speed (1500 rpm) of the disc was attained; the change in speed was recorded as well as temperature. This was done for 10, 20 and 30 braking

cycles of 10 seconds each; and using a venier calliper measurements were recorded, afterwards the wear loss was obtained by the following expression:

$$W_{loss} = T_1 - T_2 \quad (8)$$

Where

W_{loss} = thickness loss (mm),

T_1 = initial material thickness (mm)

T_2 = final thickness of the material (mm)

RESULTS AND DISCUSSION

Evaluation for thermal properties of kenaf brake pads reinforced with crude fibres

Table 2 shows the average values of thermal conductivity of crude brake pads which range from 0.298 W/m. ^{0}K in T1S1R1 sample code to as high as 0.424W/m. ^{0}K in T1S3R1. The percentage weight loss evaluation in crude brake pad samples revealed an almost close range of 31.080 % in T1S3R1 to a much higher average value of 32.672 % in T1S3R3. Thermal conductivity values also range from 0.298 W/m. ^{0}K in T1S1R1 and rises to a higher value of 0.424 W/m. ^{0}K in T1S3R1 crude kenaf brake pad formula. This value of thermal conductivity falls short by about 33 % of the value obtained in the commercial sample (control).

Evaluation for thermal properties of kenaf brake pads reinforced with mercerised fibres.

The average values of thermal conductivity and percentage weight loss of mercerised brake pads is presented on Table 3.These values range from 0.408 W/m. ^{0}K in T1S1R3 sample code to as high as 0.510 W/m. ^{0}K in T1S2R3. The percentage weight loss evaluation in crude brake pad samples revealed an increase of 18.890 % in T1S3R1 to a much higher average value of 22.298 % in T1S1R2.

Evaluation for thermal properties of kenaf brake pads reinforced with acetylated fibres

Table 4. shows the average values of thermal conductivity of acetylated brake pads which range from 0.394 W/m. 0K in T1S1R2 sample code to as high as 0.430 W/m. 0K in T1S2R3. The percentage weight loss evaluation in acetylated brake pad samples range from 14.948 % in T1S1R1 to a much higher average value of 16.820 % in T1S3R2.

Table 2. Thermal Properties of brake pads reinforced with crude kenaf fibre

		Treatment			Thermal properties	
S/N	Sample code	Crude Fibre (1 level)	Polyester (3 levels)	Filler (3 levels)	Thermal conductivity W/m. ^{0}K	Percentage Weight Loss
1	T1S1R1	1	1	1	0.298± 0.013	31.562± 1.583
2	T1S1R2	1	1	2	0.306± 0.045	32.344 ± 1.228
3	T1S1R3	1	1	3	0.310± 0.022	31.928 ± 2.058
4	T1S2R1	1	2	1	0.3400± 0.05	31.760 ± 1.639
5	T1S2R2	1	2	2	0.394± 0.023	31.854 ± 2.021
6	T1S2R3	1	2	3	0.400± 0.015	33.228 ± 1.886
7	T1S3R1	1	3	1	0.424± 0.034	31.080 ± 1.231
8	T1S3R2	1	3	2	0.408+ 0.0342	31.434 + 1.296
9	T1S3R3	1	3	3	0.418+ 0.043	32.672 + 1.679
10	Control	NA	NA	NA	0.68 ± 0.01	13.43 ± 1.04

NA = Not Available

Table 3. Thermal Properties of brake pads reinforced with Mercerised kenaf fibre

		Treatment			Thermal properties	
S/N	Sample code	Mercerised Fibre (1 level)	Polyester (3 levels)	Filler (3 levels)	Percentage Weight Loss	Thermal conductivity W/m. 0K
1	T1S1R1	1	1	1	21.804 ± 0.654	0.412 ± 0.063
2	T1S1R2	1	1	2	22.298 ± 1.030	0.430 ± 0.045
3	T1S1R3	1	1	3	21.870 ± 0.919	0.408 ± 0.047
4	T1S2R1	1	2	1	21.068 ± 0.324	0.490 ± 0.035
5	T1S2R2	1	2	2	21.316 ± 0.585	0.498 ± 0.025
6	T1S2R3	1	2	3	20.222 ± 0.813	0.510 ± 0.023
7	T1S3R1	1	3	1	20.154 ± 1.1683	0.424 ± 0.045
8	T1S3R2	1	3	2	20.550 ± 0.3474	0.434 ± 0.040
9	T1S3R3	1	3	3	18.890 ± 0.734	0.430 ± 0.041
10	Control	NA	NA	NA	0.68 ± 0.01	13.43 ± 1.04

NA = Not Available

Table 4. Thermal Properties of brake pads reinforced with Acetylated kenaf fibre

		Treatment			Thermal properties	
S/N	Sample code	Acetylated Fibre (1 level)	Polyester (3 levels)	Filler (3 levels)	Thermal conductivity W/m. ^{0}K	Percentage Weight Loss
1	T1S1R1	1	1	1	0.400 ± 0.010	14.948 ± 0.223
2	T1S1R2	1	1	2	0.394 ± 0.011	15.042 ± 0.565
3	T1S1R3	1	1	3	0.400 ± 0.010	15.280 ± 0.468
4	T1S2R1	1	2	1	0.402 ± 0.016	16.044 ± 0.240
5	T1S2R2	1	2	2	0.406 ± 0.018	16.048 ± 0.412
6	T1S2R3	1	2	3	0.422 ± 0.031	16.264 ± 0.427
7	T1S3R1	1	3	1	0.406 ± 0.020	16.450 ± 0.418
8	T1S3R2	1	3	2	0.414 ± 0.018	16.820 ± 0.340
9	T1S3R3	1	3	3	0.430 ± 0.037	16.506 ± 0.720
10	Control	NA	NA	NA	0.68 ± 0.01	13.43 ± 1.04

NA = Not Available

Evaluation for thermal properties of kenaf brake pads reinforced with semi-carbonised fibres

The results of evaluation of thermal properties of brake pads reinforced with semi-carbonised fibres is presented on Table 5. The average values of thermal conductivity of crude brake pads which range from 0.568 W/m. ^{0}K in T1S1R1 sample code to as high as 0.676 W/m. ^{0}K in T1S3R3.

The percentage weight loss evaluation in crude brake pad samples revealed an almost close range of 13.870± 0.565 % in T1S3R2 to a much higher average value of 15.672± 0.156% in T1S3R2.

Evaluation for tribological properties of kenaf brake pads reinforced with crude fibres

Table 6 shows the average values of Static and Dynamic coefficient of friction and Wear behaviour of crude brake pad samples. Static coefficient of friction of crude samples ranges from 0.410 in T1S1R1 sample code to as high as 0.426 in T1S2R1. Dynamic coefficient of friction also ranges from 0.312 in T1S1R1 to a much higher average value of 0.372 in T1S1R1. Also, Wear behaviour of crude brake pad samples range with the lowest value of 2.377mm occurring in T1S3R1 and T1S2R1 having the highest value of 3.353 mm.

Table 5. Thermal Properties of brake pads reinforced with Semi-carbonised kenaf fibre

		Treatment			Thermal properties	
S/N	Sample code	Semi-carbonised Fibre (1 level)	Polyester (3 levels)	Filler (3 levels)	Thermal conductivity W/m. 0K	Percentage Weight Loss
1	T1S1R1	1	1	1	0.568 ± 0.008	15.076 ± 0.223
2	T1S1R2	1	1	2	0.580 ± 0.008	15.672± 0.156
3	T1S1R3	1	1	3	0.606 ± 0.011	15.516± 0.448
4	T1S2R1	1	2	1	0.620 ± 0.010	14.502 ± 0.447
5	T1S2R2	1	2	2	0.612 ± 0.008	14.402 ± 0.346
6	T1S2R3	1	2	3	0.614 ± 0.005	14.156± 0.374
7	T1S3R1	1	3	1	0.652 ± 0.008	14.124± 0.400
8	T1S3R2	1	3	2	0.664 ± 0.008	13.870± 0.565
9	T1S3R3	1	3	3	0.676 ± 0.005	14.018± 0.134
10	Control	NA	NA	NA	0.68 ± 0.01	13.43 ± 1.04

NA = Not Available

Table 6 Evaluated tribological properties of brake pads reinforced with Crude kenaf fibre

		Treatment			Triobological properties		
S/N	Sample code	Crude Fibre (1 level)	Polyester (3 levels)	Filler (3 levels)	Static Coeff of friction	Dynamic coeff. of friction	Wear Loss (mm) at 30Braking cycles
1	T1S1R1	1	1	1	0.410 ± 0.040	0.312± 0.037	3.353± 0.257
2	T1S1R2	1	1	2	0.420 ± 0.033	0.338± 0.032	3.006± 0.112
3	T1S1R3	1	1	3	0.418 ± 0.040	0.330± 0.028	3.113± 0.092
4	T1S2R1	1	2	1	0.426 ± 0.023	0.348± 0.030	2.422± 0.107
5	T1S2R2	1	2	2	0.416 ± 0.024	0.354± 0.034	2.512± 0.016
6	T1S2R3	1	2	3	0.410 ± 0.027	0.342± 0.027	2.475± 0.162
7	T1S3R1	1	3	1	0.414 + 0.028	0.356+ 0.020	2.377+ 0.044
8	T1S3R2	1	3	2	0.422± 0.022	0.372± 0.021	2.967± 0.170
9	T1S3R3	1	3	3	0.416 ± 0.031	0.340± 0.015	2.514± 0.137
10	Control	NA	NA	NA	0.380 ± 0.084	0.398 ± 0.081	1.434 ± 0.026

NA = Not Available

Evaluation for tribological properties of kenaf brake pads reinforced with mercerised fibres

The results of Static and Dynamic coefficient of friction and Wear behaviour of mercerised brake pad samples is presented on Table 7. Static coefficient of friction of mercerised samples ranges from 0.386 in T1S1R1 sample code to as high as0.417 in T1S3R3.

Evaluation for tribological properties of kenaf brake pads reinforced with acetylated fibres

Table 8 shows the average values of Static and Dynamic coefficient of friction and Wear behaviour of Acetylated brake pad samples. Static coefficient of friction of Acetylated samples ranges from 0.388 in T1S3R2 sample code to as high as 0.404 in T1S1R2. Dynamic coefficient of friction also ranges from 0.354 in T1S1R1 to a much higher average value of 0.388 in T1S3R2. Also, Wear behaviour of Acetylated brake pad samples range with the lowest value of 2.130 mm occurring in T1S3R3 and T1S2R1 having the highest value of 3.248 mm.

Evaluation for tribological properties of kenaf brake pads reinforced with semi-carbonised fibres

The results of Static and Dynamic coefficient of friction and Wear behaviour of semi-carbonised brake pad samples is presented on Table 9. Static coefficient of friction of semi-carbonised samples ranges from 0.402 in T1S3R3 sample code to as high as 0.410 in T1S1R1. Dynamic coefficient of friction also ranges from 0.378 in T1S2R3 to a much higher average value of 0.416 in T1S1R1. Also, Wear behaviour of semi-carbonised brake pad formulae range with the highest value of 1.814 mm in T1S1R1 while lowest value of 1.588 mm occurred in T1S3R2.

Table 7. Evaluated tribological properties of brake pads reinforced with Mercerised kenaf fibre

	Treatment				Triobological properties		
S/N	Sample code	Crude Fibre (1 level)	Polyester (3 levels)	Filler (3 levels)	Static Coeff of friction	Dynamic coeff. of friction	Wear Loss (mm) at 30Braking cycles
1	T1S1R1	1	1	1	0.386+ 0.018	0.364+ 0.293	2.2300+ 0.324
2	T1S1R2	1	1	2	0.398+ 0.019	0.360 + 0.046	2.462+ 0.148
3	T1S1R3	1	1	3	0.401+ 0.010	0.352 + 0.046	2.562 + 0.043
4	T1S2R1	1	2	1	0.385+ 0.016	0.352 + 0.029	3.098 + 0.042
5	T1S2R2	1	2	2	0.345+ 0.029	0.352 + 0.038	3.344 + 0.034
6	T1S2R3	1	2	3	0.394+ 0.010	0.340 + 0.038	3.324 + 0.073
7	T1S3R1	1	3	1	0.394+ 0.022	0.366 + 0.037	2.540 + 0.095
8	T1S3R2	1	3	2	0.413+ 0.014	0.360 + 0.033	2.322 + 0.003
9	T1S3R3	1	3	3	0.417+ 0.028	0.370 + 0.033	2.722+ 0.076
10	Control (commercial sample)	NA	NA	NA	0.380 + 0.084	0.398 + 0.081	+ 0.026

NA = Not Available

Table 8. Evaluated tribological properties of brake pads reinforced with Acetylated kenaf fibre

	Treatment				Triobological properties		
S/N	Sample code	Crude Fibre (1 level)	Polyester (3 levels)	Filler (3 levels)	Static Coeff of friction	Dynamic coeff. of friction	Wear Loss (mm) at 30Braking cycles
1	T1S1R1	1	1	1	0.400± 0.024	0.354± 0.040	3.248 ± 0.023
2	T1S1R2	1	1	2	0.404± 0.015	0.356± 0.020	3.016± 0.0 17
3	T1S1R3	1	1	3	0.394± 0.021	0.362± 0.017	2.964± 0.056
4	T1S2R1	1	2	1	0.394± 0.016	0.378± 0.021	3.202± 0.062
5	T1S2R2	1	2	2	0.394± 0.027	0.382± 0.016	3.170± 0.037
6	T1S2R3	1	2	3	0.394± 0.013	0.384± 0.008	3.192± 0.0 43
7	T1S3R1	1	3	1	0.394± 0.015	0.386± 0.011	2.538± 0.050
8	T1S3R2	1	3	2	0.388± 0.019	0.388± 0.008	2.962± 0.005
9	T1S3R3	1	3	3	0.394± 0.015	0.382± 0.008	2.130± 0.031
10	Control	NA	NA	NA	0.380 ± 0.084	0.398 ± 0.081	1.434 ± 0.026

NA = Not Available

Table 9. Evaluated tribological properties of brake pads reinforced with Semi-carbonized kenaf fibre

		Treatment			Triobological properties		
S/N	Sample code	Semi-carbonised Fibre (1 level)	Polyester (3 levels)	Filler (3 levels)	Static coeff of friction	Dynamic coeff. of friction	Wear Loss (mm) at 30 Braking cycles
1	T1S1R1	1	1	1	0.410± 0.007	0.416± 0.005	1.814 ± 0.021
2	T1S1R2	1	1	2	0.408± 0.003	0.416 ± 0.008	1.716 ± 0.084
3	T1S1R3	1	1	3	0.406± 0.005	0.406± 0.008	1.638 ± 0.043
4	T1S2R1	1	2	1	0.404± 0.011	0.404 ± 0.005	1.68 ± 0.023
5	T1S2R2	1	2	2	0.406± 0.005	0.378 ± 0.010	1.714± 0.015
6	T1S2R3	1	2	3	0.406± 0.005	0.378 ± 0.013	1.686 ± 0.049
7	T1S3R1	1	3	1	0.404± 0.005	0.386 ± 0.005	1.670± 0.004
8	T1S3R2	1	3	2	0.404± 0.005	0.384 ± 0.008	1.588± 0.078
9	T1S3R3	1	3	3	0.402± 0.008	0.386 ± 0.005	1.654± 0.002
10	Control	NA	NA	NA	0.380 ± 0.084	0.398 ± 0.081	1.434 ± 0.026

NA = Not Available

CONCLUSION

From the results obtained in this study, it can be concluded that semi-carbonised fibre based brake pad samples exhibited higher thermal conductivity with an average value of 0.625 W/m. K than all the other samples investigated.

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