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Production of Brake Pad Material for Industrial Application

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ABSTRACT

Brake pads is widely applied in industries on heavy equipment such as cement rotary kilns, ball mills and turbines to enables precise positioning for maintenance activities and increases the safety of equipment as it cannot move once the brake is engaged. Brakes are used on inching systems to prevent rotation of the drive train after power is removed from the system. This research work focuses on development of brake pad material from carbonized doum palm shell, talc and blend of vulcanized rubber (VR) and phenolic resin (PR) were as binder. The best PR and VR blend's where determine from wear rate and compressive strength. the blend S2 with PR/VR 70/30 exhibits the highest compression strength and low wear rate were chosen as the optimal blend for the binder. The production parameters such as moulding temperature, moulding pressure, curing time and curing temperature were optimized using Box-Behnken design in response surface methodology (RSM). Moulding pressure of 150 MPa, moulding temperature of 120 ^oC, curing time of 113.9 min at 200 ^oC were the optimized values obtained for the production of the brake pad material. Five different blend compositions for the brake pad material were produced using carbonized doum palm shell, Talc and PR/VR blend as binder. The properties of the composite produced were analyzed. The wear resistance of 0.000126 g/s was obtained as the lowest at composite blend 3, compressive strength of 45.08 MPa, the thermal stability found good and suitable for industrial application. Oil and water absorption were found to be within acceptable limits 0.45% to 0.72% and 0.26% to 0.56% by weight and density of the material for all the blends is between 1.57 to 3.53 g/cm^3 . All the values obtained are within range for optimal performance of brake pad materials for industrial application especially the cement kiln whose standard minimum values for thermal stability, coefficient of friction, wear rate, compressive strength, water and oil absorption and density are 500^{o}C, 0.3, 0.0001g/s, 42 MPa, 1% and 5% and 2.5g/cm^3.

Key words: Friction material, Brake pad, industrial application, cement kiln, breaking system

INTRODUCTION

Brake pads are disc components of steel plates backed by friction materials bound to the surface. They bound unto the surface facing the brake disc and are placed in wheel assembly to continuously clamp and hold wheels to slow down or completely stop their motion (Sathyamoorthy *et al*, 2022, Kurma *et al*, 2016 and Matějka *et al*, 2013). Brake pads are known to be used in automobile industries in cars. However, their wide application is found in different industries. It is use on heavy equipment such as cement rotary kilns, ball mills and turbines to enables precise positioning for maintenance activities, facilitates tasks like liner replacement, inspections, or any requirement to align ball mills, kilns and other heavy-duty equipment, and increases the safety of equipment as it cannot move once the brake is engaged. According to Cahala and Uherek (2013), brakes are used on inching systems to prevent rotation of the drive train after power is removed from the system. They also prevent backdriving of the system if the kiln or mill while inching is stopped in an unbalanced position. A third reason for systems without a clutch connection is to protect the drive train in case the main drive is started while the inching drive train is still connected. Figure 1 showed a schematic diagram for the kiln auxiliary drive showing the breaking device.

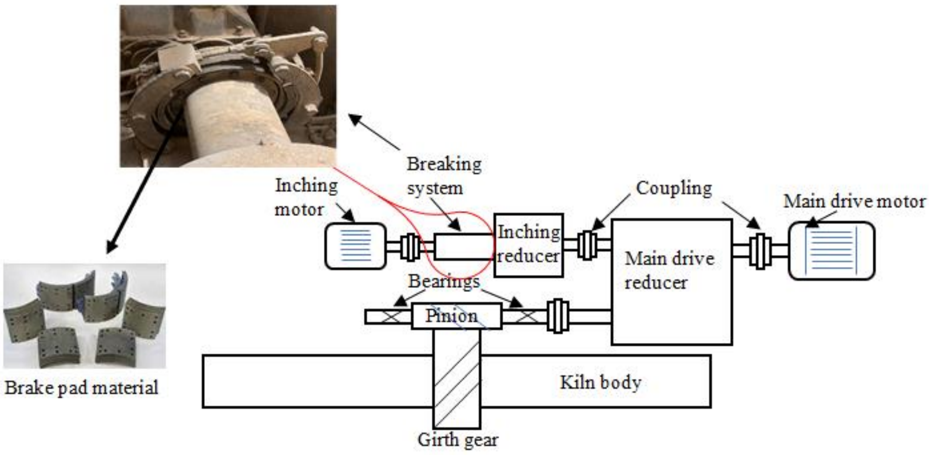

Figure 1: Schematic diagram for the kiln auxiliary drive showing the breaking device.

Brake linings for industrial and automobile applications are made from asbestos, metals, and ceramics blends for years. Asbestos, a constituent in brake lining pads, imparts desired high friction properties that automobiles require to function correctly as motion stoppers. However, the asbestos constituent of the brake pad material released gases and particles hazardous to human health as they gradually wear off from the brake pad. Most worn particles from drum brakes are retained within enclosed drums and are inhaled by mechanics when they open up the wheels for maintenance repair. Also for maintenance worker while working on industrial brake pad material. The asbestos particles may gradually poison the human system and cause other health hazards like asbestosis, mesothelioma, lung ailments and other ailments. (Rao, and Gudla, 2022 and Shinde *et al,* 2017).

Fono–Tamo and Koya (2013) developed automobile brake pad materials using standard factory procedures from palm kernel shells. The mechanical properties of the material developed were studied. The results showed that the developed pad has an average hardness of 32.34, average shear strength of 40.95 MPa and the product's friction coefficient of 0.43. This result agreed with the work of Nagesh *et al.* (2014), in which the coefficients of friction of palm kernel shells on metal surfaces are in the range of 0.37– 0.52. All the values of the responses, though not as excellent as asbestos–based brake pads whose coefficient of friction falls within 0.37– 0.41 as recommended by SAE, were reported to be good and can be applied as friction material, therefore making palm kernel shell a good substitute for asbestos and suitable for brake friction pads production.

Ibhadode and Dagwa (2008) also studied the feasibility of using agro–waste material, palm kernel shell (PKS), to replace asbestos in brake pad production. The material was used along with other constituents. Taguchi optimisation technique was adopted to achieve the optimal formulation and manufacturing variables. The value of experimental parameters selected includes moulding pressure (16.74 – 27.90 MPa), moulding temperature (150 – 170 ^{o}C), curing time (6 – 10 minutes) and heat treatment time (1– 3 hours). The composition used during their study includes 56 % reinforcement, 24 % binder, 14 % abrasives and 6 % friction modifier. The brake pads produced were tested on a test rig and a car (Toyota Carina II) to examine their effectiveness and wear properties. The test results conducted on the produced brake pad samples indicate that the surface hardness falls within 64 –89 Rockwell scale B while the coefficient of friction falls within 0.35 – 0.44 and wear values within 0.017– 0.170. The results compared well with asbestos–based brake pads and performed satisfactorily.

Ikpambese *et al.* (2014) also developed asbestos–free automobile brake pads from palm kernel fibres and epoxy resin as a binder. The fibres (PKFs) were soaked in a caustic soda solution (sodium hydroxide) for 24 hours to remove the remnant of red oil in the fibre. The fibres were washed with water to remove the caustic soda and dried under the sun for one week. The binder used during the study varied formulations during production. The composite's physical, morphological and mechanical properties were investigated to examine the effect of composition on the friction material. The results obtained from the study indicated that the coefficient of friction, temperature, wear rate, stopping time and noise level of the pads increases with increasing speed. The results also show that moisture content, porosity, surface roughness, hardness, specific gravity, water and oil absorption rate remained stable with increasing speed. From the microstructure analysis, it was observed that worm surfaces wear where the asperities ploughed were characterized by abrasion, thereby exposing the fibers' white region

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and increasing the composite material's smoothness. The report showed that the brake pad sample, which had a composition of 10 % palm wastes, 40 % epoxy resin, 15 % calcium carbonate, 6 % Al_2O_3, and 29 % graphite, had optimum properties. Therefore, palm kernel fibers can be used effectively as a suitable replacement for asbestos in friction pad production. These echoing issues necessitate the development of composite that is asbestos-free and eco-friendly and simultaneously meets the friction properties of the asbestos brake pad material for industrial application.

Depending on the area of application and properties of the material of the brake pad, the configuration and usage, wear rates will vary considerably. The properties that determine material wear involve trade-offs between performance and longevity. The friction coefficient for most standard pads will be in the region of 0.280-0.55 when used with cast iron discs. Racing pads with high iron content designed for use with cast iron brake discs reach 0.55 to 0.60 which gives a very significant increase in braking power and high temperature performance. High iron content racing pads wear down discs very quickly and usually when the pads are worn out so are the discs. Different brake design applications require different kinds of friction materials; several considerations are weighed in the development of brake pads; the coefficient of friction must remain constant over a wide range of temperatures. The brake pads must not wear out rapidly nor should they wear the disc rotor, should withstand high temperatures without fading and they should be able to do all these with little or no noise. Materials that make up the brake pad include; friction modifiers, abrasives, binders, fillers, and curing agents (Mohamad *at al.;* 2018, Nagesh, *et al.;* 2014, Rongping *et al.* 2010). Friction modifiers such as graphite and cashew nuts shells alter the friction coefficient. Powdered metals such as lead, zinc, brass and aluminum increase the material's resistance to heat fade (abrasives). Binders are the glues that hold the friction materials together. Phenolic resin is the most common binder in current use due to its favourable properties. Fillers are added to friction materials in small quantities to accomplish specific purposes such as rubber chips to reduce brake noise. The brake pad material is bonded to a stamped steel backing plate using a high temperature adhesive to which heat and pressure are applied to cure the assembly as presented by Zhezhen *et al.;* 2012. Friction lining must meet the following requirements.

(a) Maintain a sufficiently high friction coefficient with the brake disc.

(b) Shouldn't decompose or break down at high temperatures, compromising the friction coefficient with brake disc.

(c) Exhibit a stable and consistent friction coefficient with the brake disc.

(d) Frictional additives determine the frictional properties of the brake pads and comprise a mixture of abrasives and lubricants.

(e) Fillers, which reduce the cost and improve the manufacturability of brake pads.

(f) A binder, which holds components of a brake pad together.

(g) Reinforcing fibers/material, which provides mechanical strength

MATERIAL AND METHOD

The materials used for the production of the brake pad lining are shown in Table 1 below

Table 1: Material required for brake pad fabrication

S/No	Material	Function
1.	Phenolic Resin (INR118).	Binder
2.	Carbonized Doum palm Shell	Abrasive material

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3.	Talc	Filler and Lubricant
4.	Vulcanized Rubber	Reinforcing material

Method

(a) Processing doum palm shell to carbonized particles

The doum palm shells used in this research were obtained from the local market in Ashaka Gombe State, Nigeria; The edible part and the seed inside the nut were removed. The shell obtained was washed, dried and burnt to char in a vacuum oven. The doum palm char obtained was then crushed into smaller particles using a high-speed blender and sieved to obtain an average particle size of 75 µm. Figure 2 describe the conversion process of the doum palm fruit to carbonized doum palm shell.

Figure 2: Carbonized doum palm shell preparation

Blending of phenolic resin (PR) with vulcanized rubber (VR)

Phenolic resin and vulcanized rubber were blended according to the formulation in Table 2. Vulcanized rubber was processed in a two-roll mill at a temperature of 65 °C until a band formation of the rubber on the front roll was achieved. Phenolic resin was added to the rubber on the roll and rotated at a rate of 500 rpm. The blending continues until a homogenous blend is achieved. The product was sheeted out, labelled, and wrapped in polyethene film. The PR and VR blend's wear rate and compressive strength were determined to ascertain the suitable blend for the brake pad formulation. The compressive strength and wear rate tests were conducted to obtain the suitable blend for brake pad production.

Table 2: Table Showing Formulation of PR/VR Blend

Sample (Blend)	Phenolic Resin (PR) (wt %)	Vulcanized Rubber (VR) (wt %)
S_1	80	20
S_2	70	30
S_3	60	40
S_4	50	50
S_5	40	60

Optimization of the production parameters for the brake pad composite material

For better performance of the brake bad material, the production parameters such as mounding temperature, moulding pressure, curing time and curing temperature are optimized using Box-Behnken design in Response Surface methodology (RSM). Table 3 present the factors considered and the response are shown below the table.

Table 3: Factors considered in the optimization process.

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Factors description	Coded factors	Factors values		
		Low	**Middle**	**High**
Moulding pressure	X_1	15	20	25
Moulding Temperature	X_2	5	27.5	50
Curing Temperature	X_4	150	175	200
Curing time (min)	X_5	5	7.5	10

The response for the design are coefficient of friction, wear rate and thermal stability. These are used to optimized the operating conditions for excellent performance of the friction materials.

Preparation and production of the composite brake pad

The optimized production parameters were used in the production process for the brake pad composite. Five samples of the brake pad material were produced according to the formulation in table 4 using carbonized doum palm shell, Talc and PR/VR at 70/30 blend as binder.

Table 4: Composite formulation design

Sample Blend	PR/VR (Binder)	Carbonized doum palm shell (Reinforcing Material)	Talc (filler and lubricant)
B_1	5	85	10
B_2	10	75	15
B_3	15	65	20
B_4	20	55	25
B_5	25	45	30

The binder, carbonized doum palm shell particles and talc were blended according to the formulations in Table 4. in a two-roll mill at a temperature of 120°C until homogeneity is achieved. The blend is then poured into a steel mould and pressed using a compression moulding machine at 15 MPa, 200ºC for 114 minutes. The brake pad material produced is displayed in figure 3.

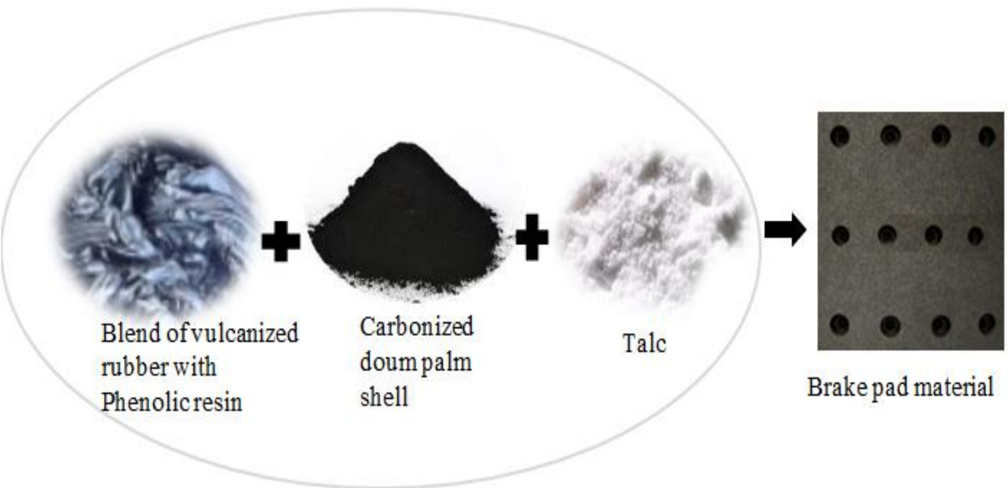

Figure 3: Composite brake pad material

Property test and analysis of the brake pad material

The brake pad composite properties were examined. The following properties of interest were measured following the procedure below:

(i) Thermal stability

Thermal stability of the sample was measured in terms of global mass loss using a thermogravimetric analyser (model TGA Q50). The tests were performed in an inert atmosphere over the temperature range from 25 °C to 1000 ° C at a heating rate of 10 °C/min.

(ii) Wear rate and coefficient of friction

The wear rate for the sample was measured with Tribometer at loads varying from 25 to 40 N in 5 N intervals with sliding speed and distance of 2 m/s and of 2 m, respectively, using a tungsten carbide ball. Frictional force at the sliding interface was measured using a strain gauge while the wear rate was determined by weighing the specimen before and after each test. The formula used to convert the weight loss into wear rate is expressed as Equation 1:

$$Wear\ rate = \frac{\Delta W}{s} \quad \ldots (1)$$

where ΔW is the weight difference of the sample before and after the test in mg, S is total sliding distance (m) and F is the applied load (N).

The coefficient of friction was determined using equation 2

$$\text{Coefficient of friction } \mu = \frac{F}{W} \quad \ldots (2)$$

Were F is the total force, N is the normal reaction and μ is the coefficient of friction.

(iii) Water and Oil absorption test

The water and oil absorption test are conducted according to SEA 20/50 and ASTM D570-98 standards for the purpose of evaluating the porosity of the brake pads depending on the amount of oil and water they absorb.

$$Water\ absorption\ (\%) = \frac{W_n - W_d}{W_d} \quad \ldots (3)$$

(iv) Compressive strength

The compression test is quite similar to the tension test. There are several loading fixtures and specimen configurations used to determine compressive strength. ISO 26867 standard describes the test method of compressive strength of polymer matrix composite using fixture. By this test elastic moduli and Poisson's ratios of composite material can be determined and the stress-strain curve in compression can be plotted

(v) Density

The density of a material is mass per unit volume. It is based on the ISO 26867 standard. The procedure for performing the density test contains obtaining the weight of the specimen in the air (a) and the weight of the specimen in the water (b). The density is calculated by getting the weight of air and water. Whereas the density of air is negligible and the density of water is 1 g/cm3 . The density of composite material at 23°C was calculated as follows.

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$$\rho = \frac{a}{a+w-b} \times 100 \quad \ldots (4)$$

$\rho = density$ (g/cm^3), a= weight of the specimen in air, b= apparent weight of fully immersed specimen and partially immersed water. W= apparent weight of partially immersed water alone, density if distilled water at 23°C (g/cm^3).

RESULTS AND DISCUSSION

This part of the paper explains in detail the interpretation of the result obtained from the experiment conducted above.

(a)Phenolic resin (PR) with vulcanized rubber (VR) Blends

The best blend for PR/VR binders was determined from the result of the wear rate, and compressive strength for good brake pad material. From figure 4. S2, representing 70 % PR to 30 % VR blend, recorded the lowest wear rate, this is because there is good bonding at this blend which can give better performance.

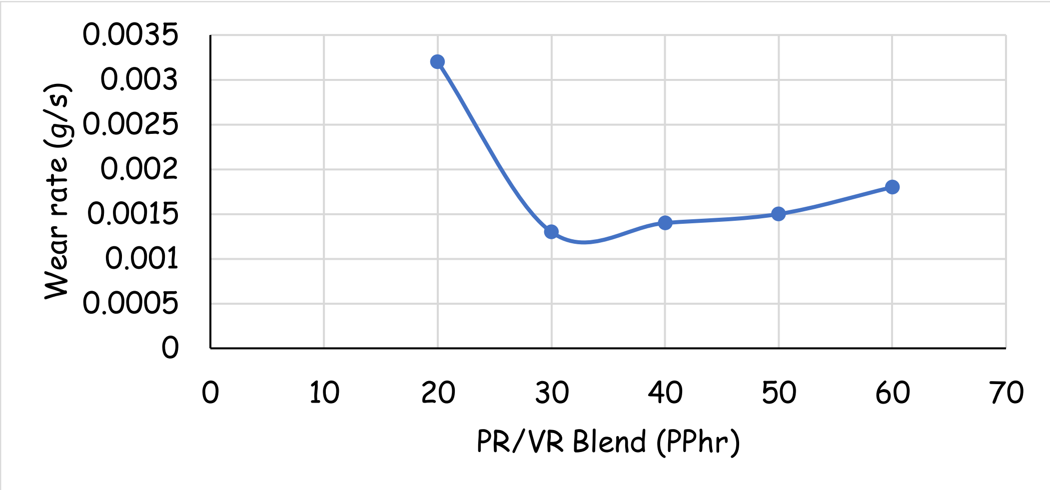

Figure 4: Wear rate result for VR-PR Blends

The compressive strength also reveals that the PR/VR blend at S_2 gives the best compressive strength at 25 MPa as shown in figure 5. Brake material with high compressive strength implies good performance with low wear resistance, good thermal stability and excellent material bonding. Therefore, the suitable blend for the binder with 70% PR and 30 %VR is selected as the suitable blend for the production of brake bad material.

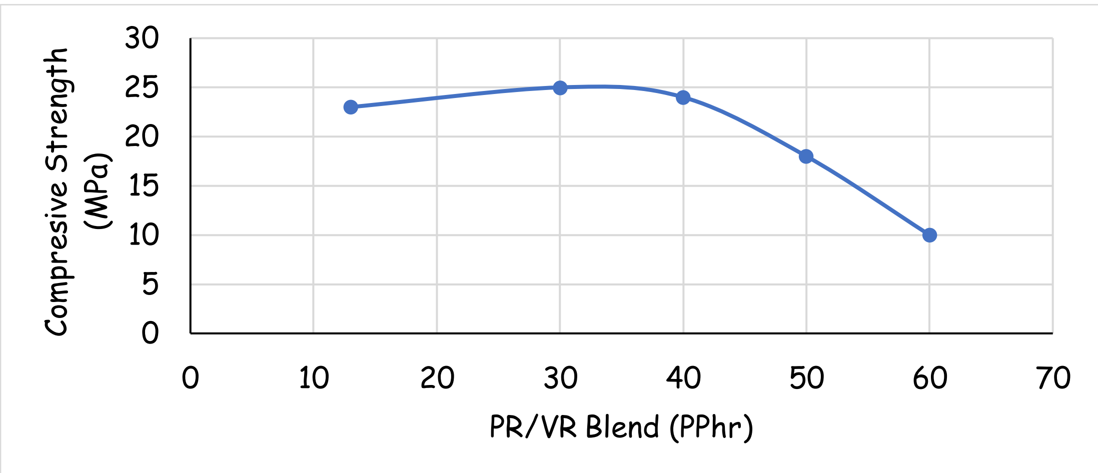

Figure 5: Compressive strength Test

(b) Optimization of the production parameters for the brake pad composite material

The optimization of the operating parameters was achieved using RSM in box- Behnken method. For the four factors consider 27 runs with 3 center points was obtained. The P-values was found to be less than 0.01 which implies that there is very strong evidence of significant effect on the responses. The R-squire predicted and R-square adjusted shows an excellent fit because for all the responses with values above 99 %. Following the fit table using the P-values, the regression equations for the responses are presented in equation 5 - 7.

Response Surface Regression equation for Coefficient of Friction versus Moulding Preasure (MPa), Moulding Temperature (^{o}C), Curing time (min), Curing temperature (^{o}C) was determine as

$$\text{Coefficient of Friction} = 0.278 + 0.00378\,X_1 + 0.004042\,X_2 + 0.002917X_3 - 0.004333\,X_4 - 0.000017\,X_1X_4 - 0.000012\,X_2X_4 - 0.000008\,X_3X_4 \quad \ldots (5)$$

Response Surface Regression equation for Wear Rate versus Moulding Preasure (Mpa), Moulding Temperature (oC), Curing time (min), Curing temperature (oC) is

$$\text{Wear Rate} = 1.158 + 0.00244\,X_1 + 0.00562\,X_2 - 0.02428\,X_3 + 0.00554\,X_4 - 0.000033X_1X_3 - 0.000033X_2X_3 - 0.000033X_3X_4 \quad \ldots (6)$$

And for Thermal Stability versus Moulding Preasure (Mpa), Moulding Temperature (oC), Curing time (min), Curing temperature (^{o}C) is

$$\text{Thermal Stability} = 38 - 22.96\,X_1 + 2.33\,X_2 + 2.32\,X_3 + 3.23\,X_4 + 1.0222\,X_1^2 - 0.1000\,X_1\,X_2 - 0.1000X_1\,X_3 - 0.1280\,X_1\,X_4 + 0.01117X_3X_4 \quad \ldots (7)$$

The equations above were use to determine the optimized values for the responses which contributes to the high quality performance of the brake pad material. The results were summarized in table 6

Table 5: Optimized values factors and the responses

Moulding Preasure (MPa)	Moulding Temperature (^{o}C)	Curing time (min)	Curing temperature (^{o}C)	Thermal Stability (Fit)	Wear Rate (Fit)	Coefficient of Friction (Fit)	Composite Desirability
15	120	113.939	200	824.508	0.732086	0.311414	0.905928

Table 5 showed there is good desirability between the factors and the responses. The composite desirability of 0.9.5928 indicates an excellent balance of material properties and is often considered optimal for brake pad materials production process parameters. The graph in figure 6 gives the summary of the production parameters that are used in the brake pad material production. The brake pad material is produced under the following conditions. Moulding pressure of 150 MPa, moulding temperature of 120^{o}C, curing time of 114 minutes at 200^{o}C with desirability of 0.9059 which is excellent balance in properties.

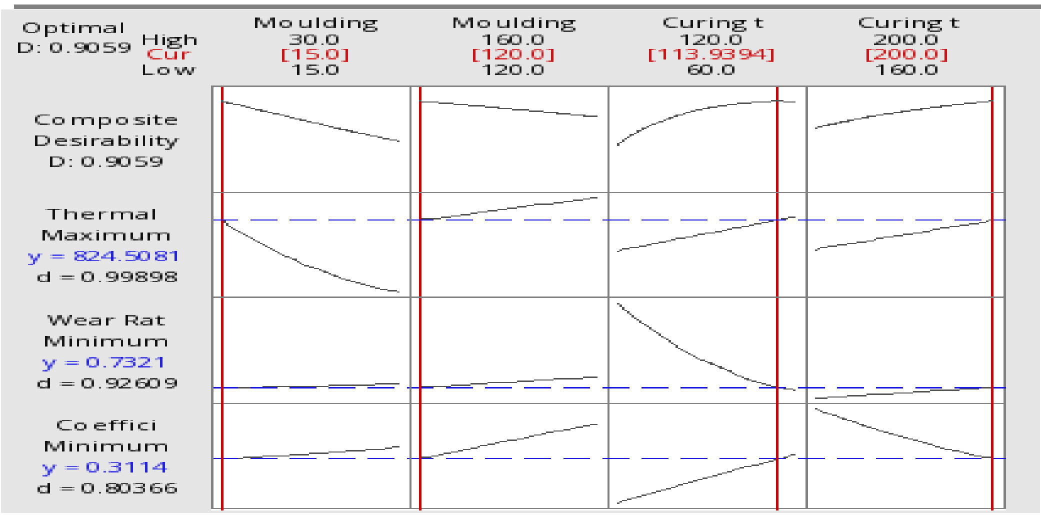

Figure 6. optimized values for the production parameters

Figure 6: Optimized values for the composite brake production parameters production parameters

(a) Thermal stability

The thermogravimetric (TG) curves in Figure 7 described the thermal behaviour and stability of the commercial brake pad material from cement kiln as well as the developed composite brake pads. Both TG profiles are characterised by step-wise degradation. An initial oxidation resulted in about a 6 % mass loss below 100°C. This mass loss can be associated with the formation of volatiles during firing. Continued heating above 200°C led to the oxidation of carbon. However, the developed composite brake pad showed a slightly better stability to degradation in an oxidising environment compared to the commercial pad. The residual mass of the commercial composite was 56 % compared to the developed composite brake pad, 58 %, after heating to 1000°C. The maximal degradation occurred at 200°C. Although TG curves have shown the better thermal stability of the developed composite than those of commercial grade. This showed that the brake pad material produced has a competitive thermal stability with the commercial brake pad material use for industrial application. Similar result was achieved by Agunsoye *et al.;* 2018.

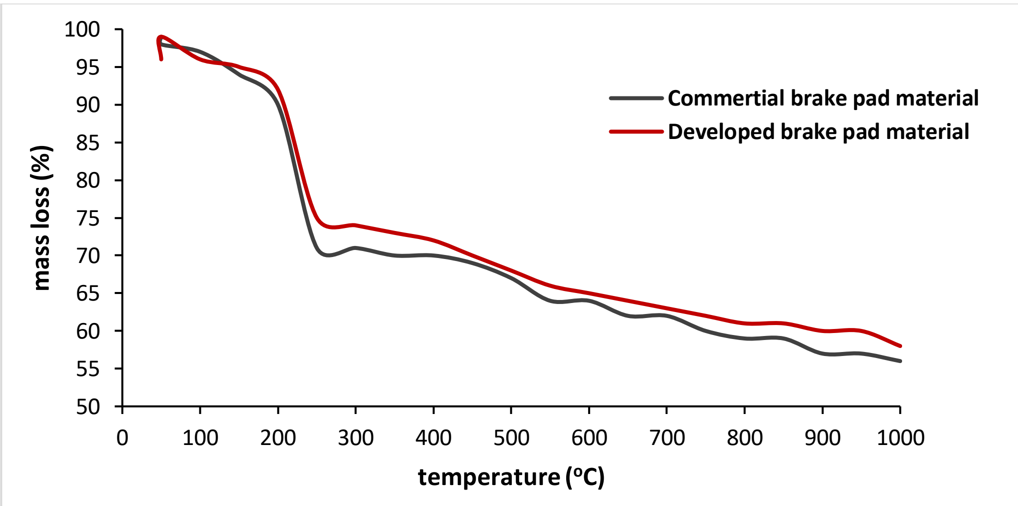

Figure 7: Thermogravimetric analysis of the commercial brake pad and the developed composite brake pad as percent mass loss.

(b) Wear rate and coefficient of friction

From figure 8, the wear rate for the material developed is within the standard range (0.0003 – 0.001g/s) for general industrial application. Wear rate increases with increase in composition of the blinder and talc (which comprises the filter and lubricant) with decrease in the composition of the reinforcing material (carbonized doum pall shell). The wear rate for all the blends is very good with the best wear resistance found to be 0.000126 g/s at blend with 15 wt. of the binder, 65wt of the carbonized doum palm shell and 20 wt. of the talc. These values prove that there is good bonding of the material for better performance of the brake pad. Yawas *et al.;* (2016) reported similar phenomenon.

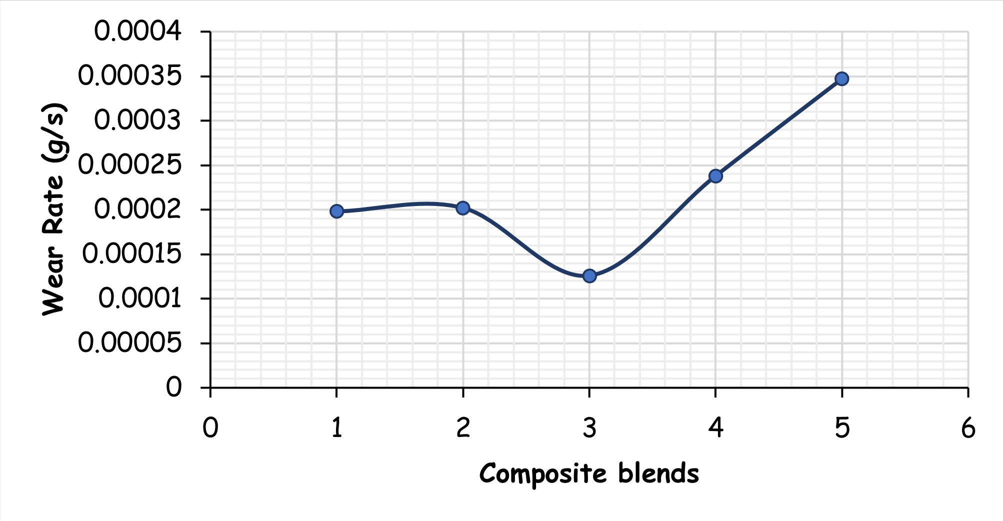

Figure 8: Wear rate verses composite blends

From figure 9, the composite coefficient of friction decreases with increasing composition of the blinder and talc (which comprises the filter and lubricant) with decrease in the composition of the reinforcing material (carbonized doum palm shell). This is because of the increasing content of talc which have the lubrication property of the material. The range coefficient of friction for industrial brake pad material according to ISO 26867 is 0.25-0.55. This means the coefficient of friction for the brake material meets the requirement for coefficient of friction for good performance of the brake pad. The decrease in wear rate of the periwinkle based brake pad composites may also be attributed to higher load bearing capacity of hard material and better interfacial bond between the particle and the resin reducing the possibility of particle pull out which may result in higher wear.

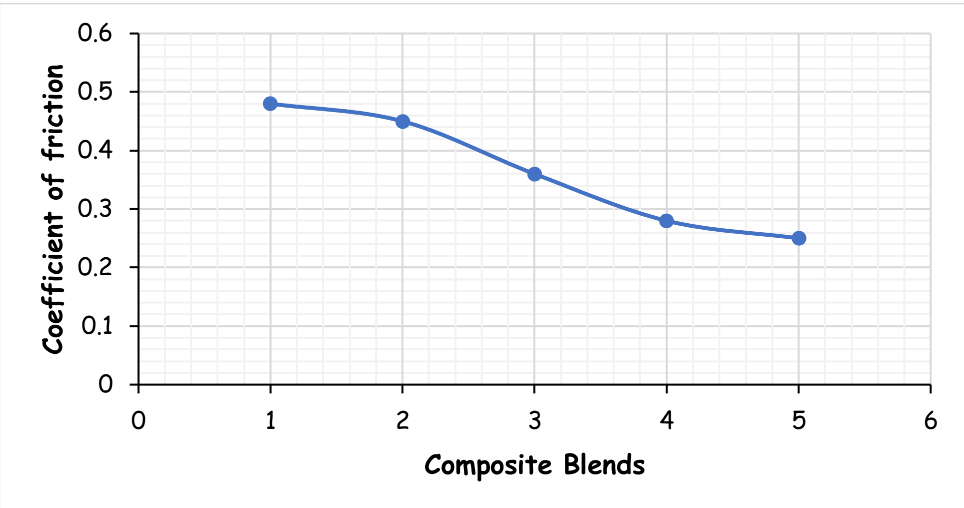

Figure 9: Coefficient of friction verses composite blends

(iii) Water and Oil absorption test

According to ISO 26867, the maximum Water absorption for industrial machinery brake pad materials such as the kiln and ball mill is between 1% to 3% by weight and oil absorption is 5% to 10% by weight. The water absorption for the material developed is between 0.26% to 0.56% by weight and oil absorption is 0.45% to 0.72%

by weight. This values showed that the brake material is well compacted with less pores in the material that prevent oil and water absorption property. This is good for the material properties and the brake bad performance.

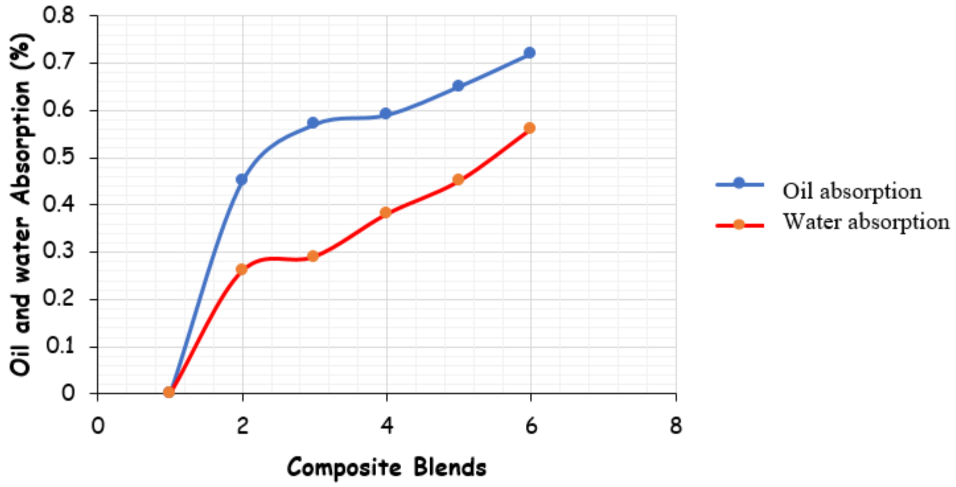

Figure 10: Water and oil absorption verses composite blends

(iv) Compressive strength

From figure 11, the composite compressive strength increases with increasing composition of the blinder and talc (which comprises the filter and lubricant) with decrease in the composition of the reinforcing material (carbonized doum pall shell). Best wear resistance is found to be 45.08 MPa at blend with 15 wt of the blends, 65wt of the carbonized doum palm shell and 20 wt. of the talc. This may be attributed due to good bonding of the brake pad material. A similar trend was also observed by (Aigbodion et al., 2010).

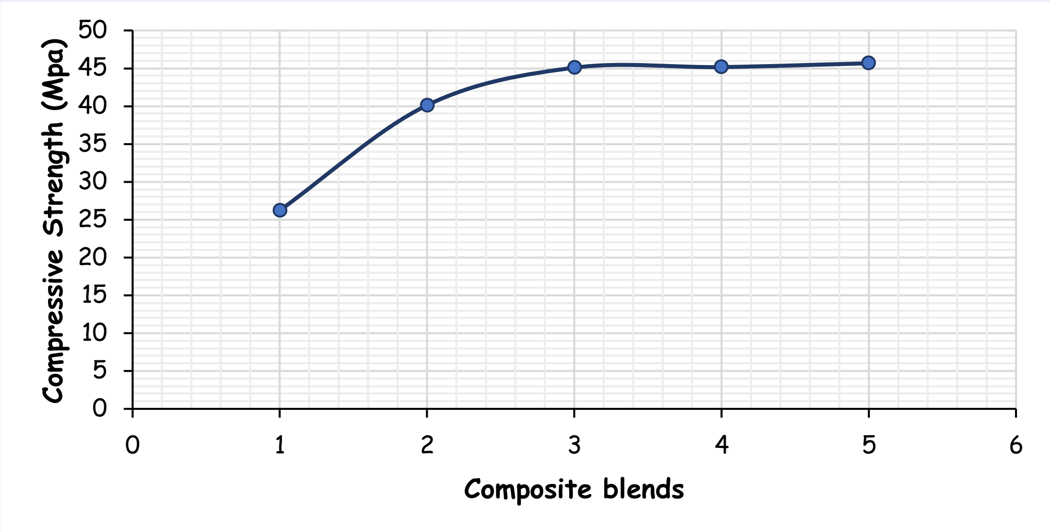

Figure 11: Compressive strength verses composite blends

(iv) Density of the composite

The composite density increases with increasing composition of the blinder and talc (which comprises the filter and lubricant) with decrease in the composition of the reinforcing material (carbonized doum palm shell). The increase in density is a result of closer packing the blends creating more homogeneity in the entire phase of the composite body. The levels of density obtained from (figure 12) are within the recommended values for brake pad application in industries. According to ISO 26867, the density of the frictional material for industrial machinery such as kilns, mills, turbines is between 2.8 g/cm³ to 3.8 g/cm³. The density of the material developed is between 1.57 to 3.53 g/cm^3 which is within recommended values of industrial brake pad material. The result is in agreement with the earlier work of Aigbodion *et al.* (2010).

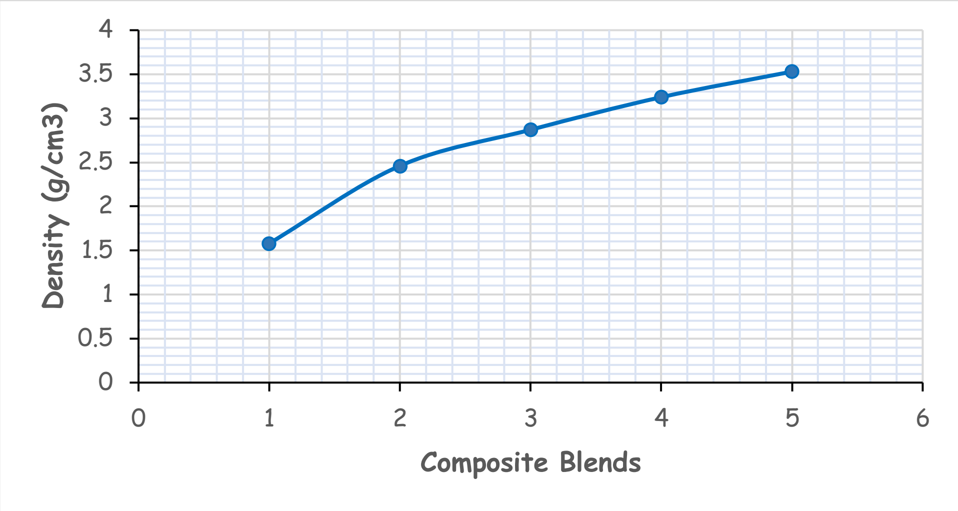

Figure 12: Density verses composite blends

CONCLUSION

The brake material produced from the carbonized doum palm shell, Talc and PR/VR blend as binder under the following production conditions, Moulding pressure of 150 MPa, moulding temperature of 120 ^oC, curing time of 113.9 min at 200 ^oC proved to be suitable for industrial application. This is because the properties of interest analyzed were found to be within acceptable range values for good performance of brake pad materials especially the cement kiln whose standard minimum values for coefficient of friction, wear rate, compressive strength, water and oil absorption and density are 0.3, 0.0001g/s, 42 MPa, 1% and 5% and 2.5g/cm^3.

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