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ASBESTOS FREE BRAKE PAD DEVELOPMENT USING COAL ASH AND PALM KERNEL SHELL AS FILLER MATERIAL

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ABSTRACT

The investigation of coal ash and palm Kernel shell for brake pad production is presented as follows, no change after 30mins of exposure to temperature of 240^{0}C, 73.53%, water absorption and specific gravity of 0.756. The disc brake friction lining with the geometrical specification of Peugeot 504 model was produced using coal ash and palm Kernel shell as base materials, polyester resin as binder materials, fiber mesh as reinforcement, brass flex as abrasives and rubber dust from burnt tire as filler. The commercial brake pad gotten from the market was used as a control. Nine groups of sample were produced containing different percentage composition the materials. The samples were subjected to hardness, wear, specific gravity and oil/water absorption tests. Result showed that hardness, thermal resistance and specific gravity increases with increase in coal ash content while wear rate reduces with increase of coal ash. Taguchi method of design of experiment was used to determine the optimum design mix and optimum design parameter. Wear rate and hardness were used as response with molding temperature curing time and heat treatment time as control factors. Results showed that the optimum setting for wear rate is 175^{o}C molding temperature, 8mins curing time and 3hrs heat treatment time (Sample 5). For hardness the optimum settings is 175^{o}C molding temperature, 6mins curing time and 3hrs heat treatment time. Analysis of variance (ANOVA) was used to confirm the experiment that the most significant factor for wear rate is heat treatment time while the most significant factor for hardness is the molding temperature as depicted in their signal to noise ratio using minitab 2017 soft ware.

Keywords: Coal ash, Palm Kernel Shell, Brake Pad, Filler, Temperature, Gravity

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1.0 BACKGROUND OF STUDY

Brake pad lining are consumable surfaces in brake systems such as drum brakes and disc drums used in transport vehicle. The discovery and development of brake lining materials can be trace back to 1988 (Rao and Babji, 2015). The idea of braking system was conceived to aid slowing down of vehicle or to stop the vehicle completely (Rao *et al, 2015*). When brake is applied the brake shoe is forced outwards and pressed against the drum. In the process of applying brake, friction occurs between the rotating disc and the pad; this makes the vehicle to stop by converting kinetic energy of the vehicle into heat energy. In other words the brake pads should quickly absorb heat, should also withstand high temperature and should not wear. When the brake is heated up by coming in contact with either a drum or rotor, it immediately starts to transfer little amount of friction material to the disc or pad (the reason a brake disc is dull grey).

From the foregoing, asbestos has been used as base material in the manufacture of brake lining materials for close to 100 years. It is still being used by some manufacturers who do not possess the necessary technology or will to change to other materials. Though asbestos has been referred to as a "God given" material for inclusion in friction linings due to its good physical and chemical properties that remain stable over the temperature range experienced by friction materials it has been reported that asbestos has serious health risks (Elakhame, Alhassan, and Samuel, 2014). Diseases associated with it include asbestosis, Mesothelioma, lung cancer and other cancers. Efforts have been geared to replace asbestos fibers in friction linings. This is exemplified by the work of (Athreya and Venkatesh, 2012), used metal fibers for inclusion in brake pads to overcome environmental pollution. They developed semi-metallic pad material using chatter–machined short metal fibers because it exhibited excellent properties in view of brake characteristics and resistance to wear. As a result of these efforts, asbestos-free organic, semi - metallic and metallic friction lining materials are now increasingly being utilized. The brake pad contained about 60% by weight of steel fibers with 60µm in diameter and 3mm long (Deepika, Bhaskar, and Ramana, 2013).

Researchers have been carried out in the area of development of asbestos-free brake pads. The use of coconut shell, palm kernel shell (PKS) has been developed for asbestos free brake pads materials. Researches globally today are focusing on ways of using either industrial or agricultural wastes as a source of raw materials in the industry. These wastes utilization will not only be economically advantageous, but may also result to foreign exchange earnings and environmental control. There is evolution of new materials and constituents currently used in automotive brake friction material after the phasing-out of asbestos, which had gained widespread acknowledgments as a carcinogen, although the introduction of the asbestos ban in some countries only came about in 1989. All forms of asbestos are carcinogenic. This ban was overruled in 1991 due to widespread complaints of the difficulty of finding asbestos replacements; existing uses of asbestos are still permitted, while new applications and uses (of asbestos) are banned. (Adeyemi, Nuhu, and Boye, 2016) revealed in their work that palm kernel shells (PKS) can be used to make brake pad and friction material as it showed good potentials based on results obtained from evaluation. PKS is cheap to obtain and available in large quantity. It has the characteristics of Influencing adhesion and dispersion of polymer composite fabrication. (Egeonu, Oluah, and Okolo, 2015) produced coconut shells based brake pad. The formulation included ground coconut shells (filler), epoxy resin (binder –matrix), iron chips (reinforcement), methyl ethyl ketone peroxide (catalyst), cobalt nephthanate (accelerator), iron and silica (abrasives), and brass (friction modifier). Sieve of 710µm aperture was used to sieve the pulverized filler. It was concluded that higher percentage of ground coconut powder gave lower breaking strength, hardness, compressive strength, and impact, and vice versa, thus high percentage of ground coconut powder induces brittleness. This supported the analysis that the tensile -impact strength of treated and untreated palm kernel nut shells polymer composite decreases with increase in its filler content (Vijay, Kumar, Satish, Thiyagarajan and Subramaniam, 2011). (Elakhame *et al.*, 2014) developed brake pads from Periwinkle shells. In the work, periwinkle shell (asbestos-free) brake pad material was characterized and its morphology and properties were determined. Researchers (Egeonu et al., 2015; Ibhadode and Dagwa, 2008; Olabisi, 2016) recently showed that it could be used to make brake pad and friction material as it showed good potentials. This work would improve on the existing PKS based brake pad by intermixing it with coal ash. PKS is cheap to obtain and available in large quantity. It has the characteristics of Influencing adhesion and dispersion of polymer composite fabrication. Physical and chemical characteristics of palm kernel shell was determined by (Adeyemi, Ademoh, and Okwu, 2016).

2.0 EXPERIMENTAL PROCEDURES

2.1 MATERIALS AND EQUIPMENT

The materials and equipment used during the course of this work are: Polyester resin, coal ash, palm Kernel shell, burnt rubber dust, fiber mesh, brass flex, sieve, weight balance,

2.2 METHODOLOGY

The base raw materials, coal ash and palm Kernel shell, were collected and cleaned thoroughly to remove impurities. There were crushed and ground to a fine powder, and sieved using 125µm sieve. The weight of palm kernel shell powder and coal ash powder filler materials, matrix (polyester) was varied while that of the abrasives and reinforcement was kept constant. For each formulation quantities expressed in percentage weight presented in Table 2.1 for fillers, abrasives and reinforcement were approximately measured into mixing vessel and thoroughly mixed for 15 to 20 minutes to obtain homogenous mixture. The desired amounts of polyester resin as shown in Tables 2.1 was poured into a separate container and required quantity of hardener was added to form the matrix and thoroughly stirred for about 5 minutes to obtain uniform mixture. Thereafter, the matrix mixture was poured onto the powdered friction material mixture and stirred further to obtain a paste-like homogenous mixture. The formed paste was poured into mold cavities that already had powdered talc applied for ease of component removal, the mixture was thereafter pressed with a hydraulic pressing machine at 100kN force for 2 minutes at room temperature and allowed to cure for 90 to 130 minutes and thereafter hardened by putting them under controlled temperature of 150°C for 3hours in an oven to ensure a complete curing of the resin. After the trial formulations, a fairly good composition was arrived at, which was used for determining the manufacturing parameters: molding temperature, curing time and heat treatment time. This friction lining formulation also served as a starting point for the determination of the optimum friction lining formulation. Nine brake pads based on this formulation were made using nine different sets of manufacturing parameters derived by the Taguchi method.

2.4 CASE STUDY-FORMULATION OF BRAKE PAD

Brake pad will be formulated to fine-tune at least two product attributes which will be measured as responses from a designed experiment such as;

- Hardness
- Wear rate

With the following choosing mixture constraints as shown Table 2.1 below

2.5 MIXTURE OPTIMIZATION

Experimental design and optimization are tools that are used to systematically examine different types of problems that may arise in production. It is obvious that if experiments are performed randomly the result obtained will also be random. Therefore, it is a necessity to plan the experiments in such a way that the interesting information will be obtained. In this research, experimental design and optimization are presented to give useful tools in the real experimental situation, as well as the necessary theoretical background. To determine the manufacturing conditions for the brake pad manufacture, the effects of three factors were studied: molding temperature, curing time and post curing heat treatment. Three levels of each factor were chosen to run the L9. Taguchi orthogonal array as earlier reported (Ibhadode and Dagwa, 2008). Table 2.3 shows the factor levels for the manufacturing parameters obtained by creating equal interval between the manufacturing parameters that are commonly used in brake pad manufacture. Table 2.3 shows the experimental design layout using the Taguchiorthogonal array L9. After the selection of the arrays, the variables were assigned to the columns of the orthogonal arrays. The actual experiments were carried out as shown in Table 2.2. Table 3.1 shows the results characteristic of the experiments conducted toward identifying the optimum level setting for the manufacturing parameters within the experimental region. Nine specimens of the brake pad were made. The relative importance of the factors was evaluated in terms of their percentage contributions using analysis of variance. From Table 2.3, using the analysis of variance and the averaged values of the signal-to-noise ratios for the manufacturing parameters at different levels [low(-), medium(0), and high(+)] for each of the performance response (surface hardness and wear) the optimum settings for the parameters were determined as presented in Table 2.3. Hence, this is the synergistic effect of S/N ratios for the properties measured that were obtained by using the quality that is, the smaller-the-better. The experimental condition having the maximum S/N ratio is considered as the optimal condition as the variability characteristics is inversely proportional to the S/N ratio, that is, reduced variance is achieved at optimal setting.

Table 2.1: Brake pad constrained mixtures

Brake pad mixture	Low(g)	High(g)
Coal ash	35	45
Polyester resin	20	22
Palm Kernel shell	15	25
Rubber mesh	7	7
Fiber mesh	7	7
Brass flex	6	6

Table 2.2: Actual composition of the nine brake pad samples

No of runs	Binders	Coal ash	PSK	Rubber mesh	Fiber mesh	Brass flex
1	20	35	25	7	7	6
2	21	37	22	7	7	6
3	20	39	21	7	7	6
4	22	40	18	7	7	6
5	21	42	17	7	7	6
6	21.5	42.5	16	7	7	6
7	22	43	15	7	7	6
8	21	44	15	7	7	6
9	20	45	15	7	7	6

Table 2.3: Factor levels for the manufacturing parameters

FACTORS	LOW LEVEL	MEDIUM LEVEL	HIGH LEVEL
MOLDING TEMPERATURE(MP)	150	175	200

^{0}C			
CURING TIME (Ct) minute	6	8	10
HEAT TREATMENT TIME (Ht), hour	1	2	3

2.6 Finishing Process

After molding, finishing operations were done on the brake pads, this includes the surface of the produced brake pads were leveled to acquire a uniform thickness of 15mm as well as a uniform surface finish, this was done by milling machine to eat away excess materials and produce final product.

Table 2.4: Applicable Taguchi standard orthogonal array L9

Experimental Number	Parameter 1: A	Parameter B: 2	Parameter C: 3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

2.7 Evaluation of Developed Brake Pad

The following parameters will be evaluated on the produced brake pad they are:

2.7.1. Wear Rate:

When considering wear rate, a common thinking is that performance pads have faster wear rate compared to none performance brake pads, this neither true nor false from literature but the wear rate can vary due to variations in temperature, contact pressure and speed as shall be seen later in this work. The wear results obtained in compliance with society of automotive engineer SAE J661 wear test standard. In the test, each sample was pressed against the rotating disk of inertial dynamometer running at different speed by the application of braking pressure. Thereafter the thickness were measured and weighed before and after the test to obtain the wear rate using equation 1

$$\text{Wear rate} = W2\text{-}W1/S \quad = \Delta w/2\pi DNt \quad - \qquad (1)$$

Where W_1= weight before the test.
W_2= weight after the test.
S = the sliding distance.
D = the disc diameter.
N = radial speed (rpm).
t = time taken to expose the specimen to wear.

2.7.2 Hardness Test:

To determine the resistance of brake lining material used to indentation, hardness test was carried out on the samples. The hardness scale based on indentation hardness of the material. The Rockwell test determines the hardness by measuring the depth of penetration made by a preload. The equipment hardness mode was set to Rockwell hardness mode HR, and the impact device was loaded and impacted on two points at random. The result obtained is recorded and tabulated for each brake samples with the aim of determining the hardness of the produced brake pad, each specimen is clamped down on the floor while the striking arm of the mobile tester is released and allowed to strike the surface of the produced brake pad and the commercial brake pad respectively at three different positions and the average values of the results of S1, S2, S3, S4, S5, S6, S7, S8 and S9 are recorded and tabulated. The test was carried out at the Enugu office of standards organization of Nigeria.

2.7.3 Shear Strength

A digital shear strength testing machine with ASTM standard D412-68 was used to subject a brake pad specimen dimension 20mm by 20mm by 10mm by applying a tensile shear load on the specimen until the specimen fails by developing a crack. The maximum load of failures was determined and used to calculate the ultimate tensile strength using equation 2 as follows:

Ultimate tensile strength (UTS) =

$$\frac{\text{Average maximum load to crack formation}}{\text{Shear area}} \quad - \qquad (2)$$

Shear area = length*width

2.7.4 Water and oil Absorptions:

The composite samples were dried in an oven to constant mass and immersed in distilled water at room temperature. The same thing was done with lubricating oil, brake fluid and saline water. The water/oil absorption was determined by weighing the samples (W_a). The samples were immersed in water at room temperature for 24 hours. The sample was then removed, wiped with a tissue paper and weighed (W_b).

Then percentage of water absorption (PWA) was determined as follows.

$$PWA = Wa\text{-}Wb/Wa \quad (3)$$

Where Wa and Wb are original dry weight and wet weight after exposure respectively. Where weight of commercial brake pad used is 259.01grams, weight when soaked in water is 260.11grams, gain in weight is 1.10grams and it percentage of water absorption is 0.425%.

2.7.5 Thermal resistance:

The nine samples were exposed to heat at temperature ranging from 150°C, 200°C, 250°C, and 300°C. This is to determine at what temperature blisters/crack could occur at the various samples. Furthermore, I went further to establish the length of crack of each of the samples that had crack.

2.7.6 Specific Gravity

Specific gravity is the ratio of the density of a substance to the density of a reference substance equivalently; it is the ratio of the mass of a substance to the mass of a reference substance for the same given volume.

3.0 RESULTS AND DISCUSSION

3.1 COAL ASH AND PALM KERNEL SHELL POWDER CHARACTERISATION

From the elemental composition of PKS and coal ash powder in table 4.1 above shows that Coal ash and palm Kernel shell are suitable for use as a brake pad material due to its large content of environmentally friendly minerals such as graphite (C), Fe, Si, Al, Ca, etc that are also seen as frictional modifies in a purely or semi metallic brake pad manufacture.

Table 3.1 COAL ASH AND PALM KERNEL SHELL POWDER CHARACTERIZATION

S/N	Element	Coal ash (%)	PSK (%)
1	Si		22.3
2	Ca	15.62	20.9
3	Fe		8.3
4	Zn	2.4	
5	Mg		0.4
6	S	0.07	12.8
7	Al		10.6
8	C	52.72	12.55
9	H	5.92	
10	N	0.68	0.4
11	Cu	4.56	
12	K	17.35	11

3.2.1 Wear rate

Table 3.2 below shows the wear resistance response of the various samples after undergoing the wear resistance test. The results so obtained were also represented in the bar chart below. The graphic representation shown in fig 3.1 below illustrates the wear behavior of the different brake pad material composition and that of the control. The wear rate of the control which is $0.02gm^{-1}$

Tables 3.2 wear rate response for the nine samples

S/N	TIME(Minutes)	WEAR(g)	WEAR RATE (gm-1)
SAMPLE 1	10	0.740	0.0740
SAMPLE 2	10	0.160	0.0160
SAMPLE 3	10	0.107	0.0107
SAMPLE 4	10	0.104	0.0104
SAMPLE 5	10	0.100	0.0100
SAMPLE 6	10	0.110	0.0110
SAMPLE 7	10	0.103	0.0103
SAMPLE 8	10	0.108	0.0108
SAMPLE 9	10	0.400	0.0400

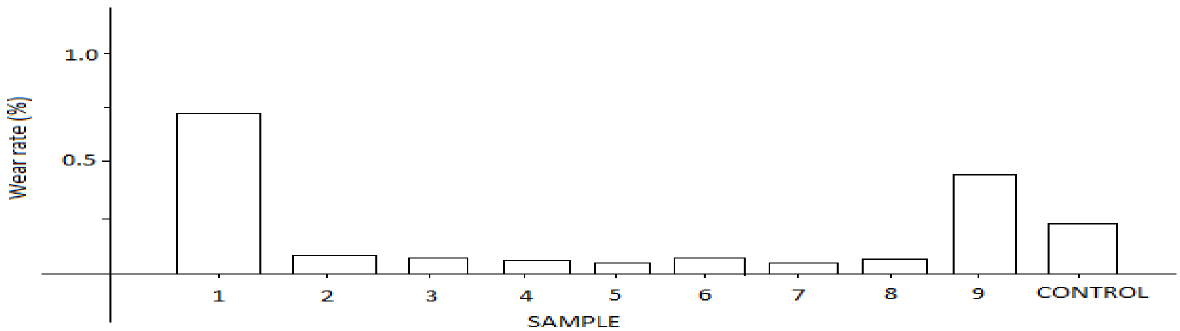

Figure 3.1 bar chart representation of the wear rate of the samples and the control

3.2.2 HARDNESS

Table 3.2 shows average maximum load to cracking of the produced brake pad. The maximum load to crack the produced brake pad ranged between 374N to 395N. Sample 7 with Rockwell hardness of 404 and mixture compositions of binder 22g, coal ash 43g, PKS 15g, rubber mesh 7g, fiber mesh 6g, brass flex 6g, gave a higher hardness of the samples.. Generally, the average hardness for the entire laboratory specimen was 395 while commercial pad had 400. This results suggest that the laboratory brake pad was only slightly less harder than commercial brake pad hence the laboratory brake pad specimen would not have any adverse effect on the brake disk. Therefore the specimen has an equal comparative advantage as that of the conventional brake pad.

Table 3.3 Average maximum load to cracking of produced brake pad

S/N	POINT 1(N)	POINT 2 (N)	MEAN VALUE (N)
SAMPLE 1	347	401	374
SAMPLE 2	371	389	379
SAMPLE 3	398	365	382
SAMPLE 4	400	390	395
SAMPLE 5	403	391	397
SAMPLE 6	393	397	394
SAMPLE 7	407	401	404
SAMPLE 8	349	407	378
SAMPLE 9	381	365	373

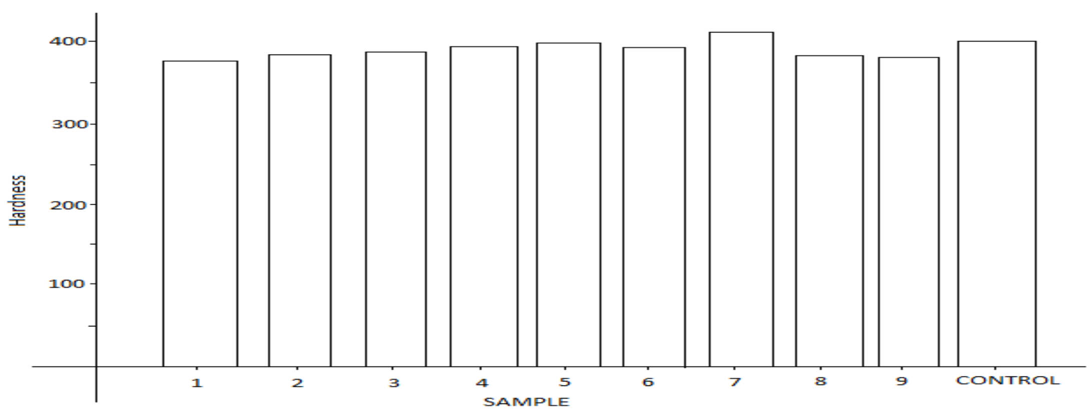

Fig 3.2 bar chart of the surface hardness of the samples and the control

3.2.3 RESISTANCE TO DIFFERENT MEDIAS

Table 3.3 below also shows the percentage wear response of the samples and the control, which is the standards, set by standards organization of Nigeria when exposed to different media. The standard set by the organization is that the wear for the brake pad samples should not exceed 0.2% for water and saline water and 0.3% for lubricating oil and brake fluid. For the test conducted for water, saline water and lubricating oil, all the samples met with the requirement. For the test conducted on the produced brake pad for wear in brake fluid all the samples slightly went above the level set.

Table 3.4 Percentage wear response of the samples to different media

S/N	WATER (%)	SALINE SOLUTION (%)	BRAKE FLUID (%)	LUBRICA-TION OIL (%)
SAMPLE 1	0.180	0.190	0.400	0.170
SAMPLE 2	0.123	0.120	0.390	0.160
SAMPLE 3	0.120	0.135	0.350	0.140
SAMPLE 4	0.120	0.200	0.392	0.190
SAMPLE 5	0.110	0.190	0.400	0.170
SAMPLE 6	0.115	0.180	0.380	0.200
SAMPLE 7	0.120	0.190	0.420	0.165
SAMPLE 8	0.120	0.200	0.410	0.190
SAMPLE 9	0.200	0.180	0.440	0.210
CONTROL	0.200	0.200	0.300	0.300

3.2.4 THERMAL RESISTANCE

Table 3.4 below shows the response of the nine samples and the control which is the standard set by standards organization of Nigeria (SON). Based on the standard set by SON blisters are not to be seen on the samples at ranging from 0°C to temperature 300°C. The result of the samples and the control when exposed to different degree of temperature are shown below.

Table 3.5 Response of the samples when subjected to temperature

S/N	150°C	200°C	250°C	300°C
SAMPLE 1	NO	YES	YES	YES
SAMPLE 2	NO	NO	NO	YES
SAMPLE 3	NO	NO	NO	NO
SAMPLE 4	NO	NO	NO	NO
SAMPLE 5	NO	NO	NO	NO
SAMPLE 6	NO	NO	NO	NO
SAMPLE 7	NO	NO	NO	NO
SAMPLE 8	NO	NO	NO	NO
SAMPLE 9	NO	NO	NO	NO
CONTROL	NO	NO	NO	NO

The control indicated that crack is not to be seen in the brake pad when exposed to temperature of up to 300°C. Sample 1 and sample 2 fail the test. But the other samples passed the test.

3.3 MIXTURE OPTIMIZATION

3.3.1 Analysis of Signal to Noise ratio

Tables 3.7 and 3.10 shows the computations for the quality characteristics (Wear rate and Hardness) with their respective signal-to-noise ratios which are targeted at reducing the variations due to uncontrollable parameters. The signal-to-noise ratios employed for the Wear rate and Hardness are THE LOWER THE BETTER and THE LARGER THE BETTER. They are expressed mathematically as:

LOWER THE BETTER

$$\frac{S}{N} = -10log_{10}y^2 \quad - \quad - \quad - \quad (3.1)$$

LARGER THE BETTER

$$\frac{S}{N} = -10log_{10}\frac{1}{n}\sum\frac{1}{y^2}(2) \quad - \quad (3.2)$$

The evaluation of the signal-to-noise ratios and mean responses for the wear rate and hardness are shown graphically in Figures 3.1-3.4 they indicate the factors that are statistically significant in the orthogonal array. Figure 3.1 indicates that wear rate under the S/N ratio of LOWER THE BETTER is best at the following settings: molding temperature of 175°C, cure time of 8 minutes and heat treatment time of 3 hours. Figure 3.2 clearly shows that the hardness under the S/N ratio of LARGER THE BETTER of the brake pad is best at the following settings: molding temperature of 175°C, cure time of 6 minutes and heat treatment time of 3 hours. The range (Delta) is the difference between the high and low response. A high delta value signifies the strength of the parameter on the response factor while a low delta value signifies the least effect on the response factor. Therefore, Tables 3.8 and 3.12 shows that the most significant factors responsible for wear rate for the brake pad investigated are ranked as follows: Heat treatment > Molding Temperature > Curing time while for the hardness as shown in Tables 3.11 and 3.12, the most significant factors are: Molding Temperature> Heat treatment> curing time.

Table 3.6 Experimental Outlay showing factors and levels

S/N	Parameters	Unit	Levels	levels	Levels
1	A:Molding temp	°C	150	175	200
2	B: Curing time	Minute	6	8	10
3	C:Heat treatment time	Hour	1	2	3

Table 3.8 Response Table for Signal to Noise Ratio Smaller is better for Wear rate

Level	A: Molding temperature	B:Curing Time	C:Heat Treatment time
1	13.84	14.01	13.71
2	19.61	19.61	15.70
3	15.68	15.51	19.72
Delta	5.77	5.60	6.01
Rank	2	3	1

Table 3.7 Experimental design matrix for Wear rate for the Brake pads developed

Experimental Number	A:Molding temperature	B:Curing time	C:Heat treatment	Wear rate(%)	S/N Ratio	Mean
1	1	1	1	0.740	2.6154	0.740
2	1	2	2	0.106	19.4939	0.106
3	1	3	3	0.107	19.4123	0.107
4	2	1	2	0.104	19.6593	0.104
5	2	2	3	0.100	20.0000	0.100
6	2	3	1	0.110	19.1721	0.110
7	3	1	3	0.103	19.7433	0.103
8	3	2	1	0.108	19.3315	0,108
9	3	3	2	0.400	7.9584	0.400

Table 3.9 Response Table for Means for the wear rate

Level	A:Moulding Temperature	B: Curing Time	C:HeatTreatment time
1	0.3177	0.3157	0.3193
2	0.1047	0.1047	0.2033
3	0.2037	0.2057	0.1033
Delta	0.2130	0.2110	0.2160
Rank	2	3	1

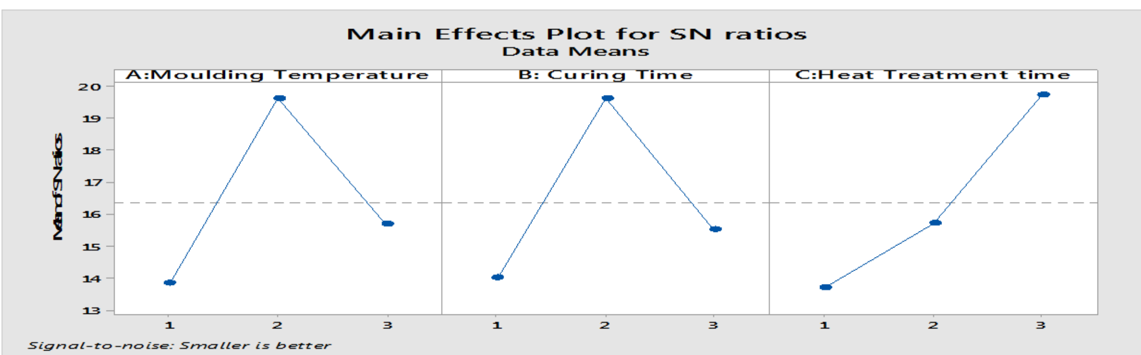

Figure 3.1 Main Effects plots for Signal-to-noise ratio of Wear rate

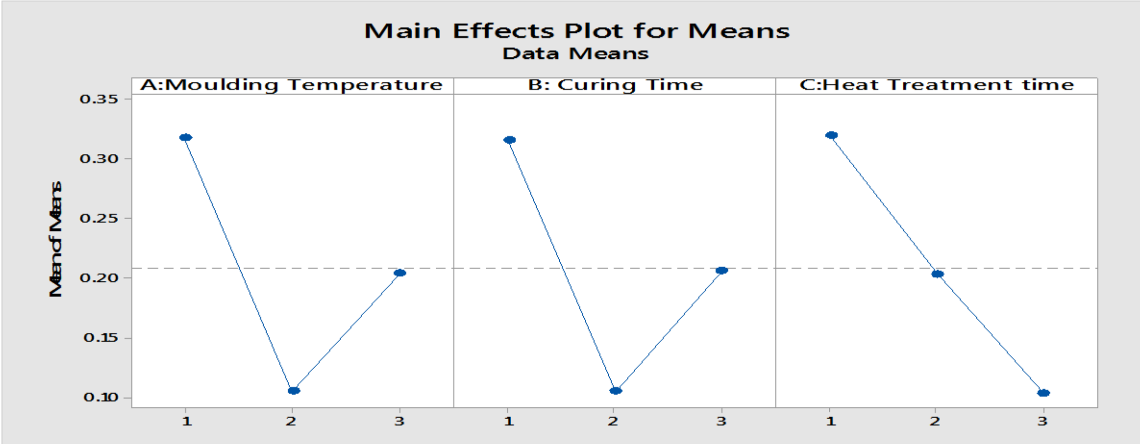

Figure 3.2 Main Effects plots for mean of means of Wear rate

Table 3.10 Experimental design matrix for Hardness for the Brake pads developed

Experiment number	A:Molding Temperature	B:Curing Time	C: Heat Treatment time	Hardness	S/N Ratio	Means
1	1	1	1	374	51.4574	374
2	1	2	2	379	51.5728	379
3	1	3	3	382	51.6413	382
4	2	1	2	395	51.9319	395
5	2	2	3	397	51.9758	397
6	2	3	1	394	51.9099	394
7	3	1	3	404	52.1276	404
8	3	2	1	378	51.5498	378
9	3	3	2	373	51.4342	373

Table 3.11 Response for Signal to Noise Ratios Larger is better for Hardness of the brake pad

Level	A:Molding Temperature	B:CuringTime	C:Heat Treatment time
1	51.56	51.84	51.64
2	51.94	51.70	51.65
3	51.70	51.66	51.91
Delta	0.38	0.18	0.28
Rank	1	3	2

Table 3.12 Response Table for Means for the Hardness

Level	A:Moulding Temperature	B:Curing Time	C:Heat Treatment time
1	378.3	391.0	382.0
2	395.3	384.7	382.3
3	385.0	383.0	394.3
Delta	17.0	8.0	12.3
Rank	1	3	2

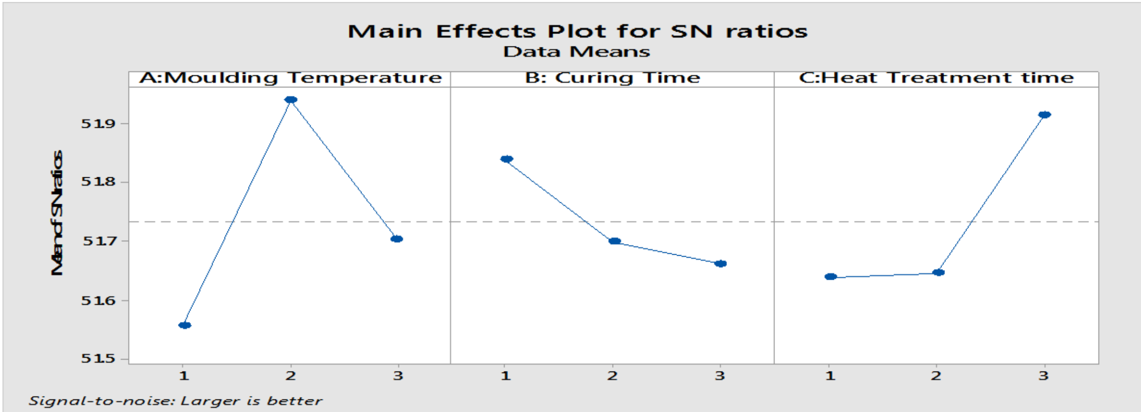

Figure 3.3 Main Effects plots for Signal-to-noise ratio of Hardness

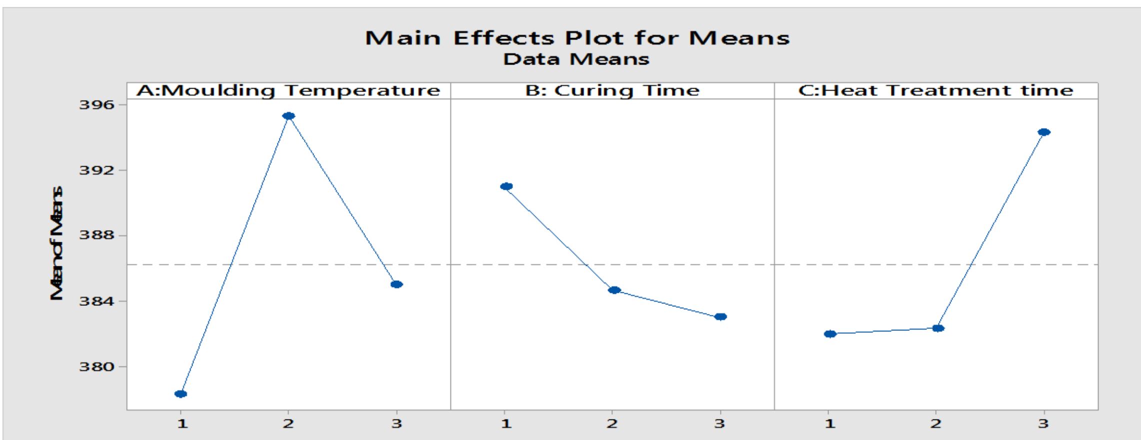

Figure 3.4 Main Effects plots for mean of means of Hardness

3.4 Analysis of Variance (ANOVA)

Analysis of Variance (ANOVA) is conducted to examine the factors that significantly affect the responses (Wear rates and Hardness). The percentage contribution, P reports the significance level. The Fisher test (F-Test) is used to determine statistically, the parameters that have significant effect on the quality characteristics. The lower the percentage value (P value), the more significant is the factor. Tables 3.13-3.15 shows the one-way ANOVA results for wear rate response. The most significant factor for the wear rate is heat treatment as depicted in Table 3.15. Tables 3.16- 3.18 shows the one-way ANOVA result for hardness response. The most significant factor for hardness is molding temperature as shown in Table 3.16. The result obtained from the ANOVA is in agreement with the analysis of the signal-to-noise ratios obtained in Tables 3.8-3.9 and 3.11 -3.12.

Table 3.13 One-way ANOVA results for wear rate using the factor molding temperature

Factor	DOF	Adj SS	Adj MS	F-value	P-value	Status
A:MouldingTemperature	2	0.06817	0.03408	0.63	0.565	Insignificant
Error	6	0.32543	0.05424			
Total	8	0.39360				

S=0.232892; RSq=17.32%; RSq (adj)=0%;RSq (Pred)=0.0%

Table 3.14 One-way ANOVA results for wear rate using the factor curing time

Factor	DOF	Adj SS	Adj MS	F-value	P-value	Status
B: Curing time	2	0.6682	0.03341	0.61	0.572	Insignificant
Error	6	0.32678	0.05446			
Total	8	0.39360				

S=0.233372; RSq=16.98%; RSq (adj)=0%;RSq (Pred)=0.0%

Table 3.15 One-way ANOVA results for wear rate using the factor Heat treatment

Factor	DOF	Adj SS	Adj MS	F-value	P-value	Status
C:Heat treatment	2	0.07011	0.03506	0.65	0.555	Significant
Error	6	0.32349	0.05391			
Total	8	0.39360				

S=0.232195; RSq=17.81%; RSq (adj)=0%;RSq (Pred)=0.0%

Table 3.16 One-way ANOVA results for Hardness using the factor molding temperature

Factor	DOF	Adj SS	Adj MS	F-value	p-value	Status
A:Molding Temperature	2	440.2	220.11	2.23	0.188	Significant
Error	6	591.3	98.56			
Total	8	1031.6				

S=9.92752; RSq=42.68%; RSq (adj)=23.57%;RSq (Pred)=0.0%

Table 3.17 One-way ANOVA results for Hardness using the factor curing time

Factor	DOF	Adj SS	Adj MS	F-value	P-value	Status
B: Curing Time	2	106.9	53.44	0.35	0.720	Insignificant
Error	6	924.7	154.11			
Total	8	1031.6				

S=12.414; RSq=10.36%; RSq (adj)=0%;RSq (Pred)=0.0%

Table 3.18 One-way ANOVA results for Hardness using the factor heat treatment

Factor	DOF	Adj SS	Adj MS	F-value	P-value	Status
C: Heat treatment	2	296.2	148.1	1.21	0.362	Insignificant
Error	6	735.3	122.6			
Total	8	1031.6				

S=11.070; RSq=28.72%; RSq (adj)=4.95%;RSq (Pred)=0.0%

Table 3.19 Optimum settings of Control factors and expected optimum values for responses

Response	Control factor	Optimum Settings
Wear Rate:	A: Molding Temperature	175
	B: Curing Time	8
	C: Heat treatment	3
Hardness	A: Molding Temperature	175
	B: Curing Time	6
	C: Heat treatment	3

4.0

CONCLUSION AND RECOMMENDATION

4.1 Conclusion

The thermo-physical properties of coal ash and palm Kernel shell that made them suitable for brake pad production were established. This test was the thermal resistance test, water absorption test and specific gravity. Furthermore, an asbestos free brake pad was produced using coal gotten from Enugu state, palm Kernel shell and other materials gotten locally. The samples of brake pad produced were tested for oil and water absorption, thermal resistance, hardness test, resistance to wear and specific gravity. The results so obtained from the samples produces were compared to the conventional brake pad and the standard set by the standards organizations of Nigeria (SON). These results are in agreement with those of asbestos friction materials produced. It is therefore deducible that this material can be used on peogout 504 model. Finally, this work can be regarded as the initials ground work needed for subsequent improvements and optimization, Though more work is still required, the objectives which were set out at the beginning of the work have to a large extent been achieved.

Reference

Adeyemi, I. ., Ademoh, N. ., and Okwu, M. . (2016). Development and Assessment of Composite Brake Pad Using Pulverized Cocoa Beans Shells Filler. *International Journal of Materials Science and Applications*, *5* (2): 66 - 73

Adeyemi, O., Nuhu, A., and Boye, T. (2016). Development of asbestos - free automotive brake pad using ternary agro-waste fillers. *Journal of Multidisciplinary Engineering Science and Technology*, *3*(7).

Athreya, S., and Venkatesh, Y. D. (2012). Application Of Taguchi Method For Optimization Of Process Parameters In Improving The Surface Roughness Of Lathe Facing Operation. *International Refereed Journal of Engineering and Science*, *1*(3), 13–19.

Deepika, K., Khaskar, R. C., and Ramana, R. D. (2013). Fabrication and performance evaluation of composite material for wear resistance application. *International Journal of Engineering Science and Innovative Technology*, 2 (6): 66-70

Egeonu, D., and Njoku, C. O. P. O. H. (2015). Production of eco-friendly brake pad using raw materials sourced locally in Nsukka. *Journal of Energy Technologies and Policy*, 5 (11): 47-54.

Elakhame, Z. U., Alhassan, O. A., and Samule, A. E. (2014). Development and production of brake pads from palm kernel composites. *International Journal of Scientific and Engineering Research,* 5, 735-744

Ibhadode, a. O. a., and Dagwa, I. M. (2008). Development of asbestos-free friction lining material from palm kernel shell. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, *30*(2), 166–173.

Olabisi, A. I., Adam, A. N., and Okechukwu, O. M. (2016). Development and assessment of composite brake pad using pulverized cocoa beans shells filler. *International Journal of Materials Science and Applications,* 5(2), 66-78.

Rao, R. U., and Babji, G. (2015). A review paper on alternative materials for asbestos brake pads and its characterization. *International Research Journal of Engineering and Technology*, 2(2), 556-562

Vijay, R., Kumar, S. R., Satish, V., and Thiyagarajan, V., Subramaniam, L. (2011). Development and testing of asbestos free brake pad material. *International Journal of Manufacturing Science and Engineering, International Science Press,* 2(2), 57-63