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PRODUCTION AND TESTING OF BRAKE PAD COMPOSITES MADE FROM CASHEW NUT SHELLS AND PLANT GUM BINDER

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Abstract
Asbestos, Formaldehyde, phenolic and epoxy resins have been used for so long as automobile brake pads materials because of their good physical and chemical properties. However, due to the health hazard associated especially with handling, several alternative materials are being increasingly considered. This paper presents a new asbestos free brake pad composites developed from agro waste material based of cashew nut shells, Nigerian plant gum along with other ingredients such as steel dust, graphite and silicon carbide. While the cashew nut shells replaced the asbestos for carcinogenic concerns, the equally toxic and commonly used epoxy resin binder is replaced with a plant gum binder known as Nigerian Gum Arabic. The experiment in this study was based on Taguchi Design of Experiment (DOE) and $L_{27}3^5$ orthogonal array where twenty- seven (27) brake pad composites were produced following the standard procedures of compression moulding. The cashew nut shells were particled into 100μm sieve size. The optimal hardness, compressive strength, wear rate and Coefficient of friction of the composites were 76.66 BHN, 17.197N/mm^2,1.16 and 0.5632 respectively.

Keywords: Composites, Cashew Nut Shells, Plant Gum, Brake Pads

1. INTRODUCTION

Brake pads are components of disc brakes used in automobiles. Brake pads have steel backing plates bonded on the surface facing the brake discwith friction materials and are placed in wheel assembly to continuously clamp and hold wheels to slow down or completely stop a moving automobiles (Aigbodion and Agunsoye, 2010).It controls the speed by converting the kinetic energy to thermal energy by friction and dissipating the heat produced to the surroundings. Brake Pad composites contain binders, structural materials, fillers and frictional additives. Friction materials containing metal powders are called semi-metallic friction materials, while those with asbestos are called asbestos friction materials, while those that do not contain asbestos are called asbestos-free friction materials.

According to Idris, Aigbodion, Abubakar and Nwoye (2015) brake pads generally consist of asbestos in the matrix along with several other ingredients. The use of asbestos is being avoided because of its carcinogenic and harmful nature. More than thirty three (33) countries like USA, UK, Colombia, Japan, China and other countries have banned the use of asbestos as a friction material because of its carcinogenic concerns on the workers and users .Asbestos has long been known to cause lung and other cancerous diseases

(Bala, Okoli and Abolarin,2016). Consequently, numerous researches have been on to discover human friendly material replacements for asbestos portions in engineering components. Asbestos constituents in brake lining pad composites impart desired high friction property that automotive pads require to function properly as motion stoppers. Brake pads are important components of braking system for all categories of vehicles equipped with brake discs.

The asbestos constituent has been found to release gases hazardous to human health upon use of brake pads. Brake pads used automobile brakes are of two types. Brake shoes are located inside a drum (for drum brake type) so that on application of brakes, the shoe is forced outward and pressed against the drum. Disc brakes operate in similar way except that drum brakes are enclosed while disc brakes are exposed to environment (Bono and Dekyrger, 2010). In 1930s, Ferodo changed to thermosetting resins and produced molded instead of knitted linings. Molded linings were made by combining fiber with resin and polymerizing resin under elevated pressure and temperature (Deepika, Reddy, Ramana and Reddy, 2013).It was reported that the additive effects of different non-asbestos materials on friction lining sensitized and increased the use of asbestos-free organic, semi-metallic and metallic friction lining materials(Blau ,2001).

Deepika *et al.*,(2013), in their work on fabrication and performance evaluation of a composite material for wear resistance application, made use of an agro-waste (palm kernel shells -PKS) as filler material with sulphur, cashew nut shell liquid, calcium carbonate, brass chips, quartz, iron ore, ceramics, and carbon black.

Coconut shells based brake pad was produced by Bashar, Peter and Joseph,(2012).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).

Yawas,Aku and Amaren,(2013)produced brake pads from Periwinkle shells. In their work, periwinkle shell (asbestos-free) brake pad material was characterized, and its morphology and properties were determined. The formulation included periwinkle shell powder, phenolic resin (phenol formaldehyde), engine oil (SEA 20/50), and water.

Aderiye (2014) in his research work carried out geological studies on kaolin clay group within the sedimentary mineral material zone of Ise-Orun-Emure local government areas of Ekiti State, Nigeria. Clay major characteristic properties were examined, beneficiated and processed for automotive friction lining material. It was discovered that kaolin clay group can be used because of its good heat resistance for friction lining material in automotive industry, for refractoriness, in electronic products, technical works and ceramic manufacturing industries. Thermal property of kaolin samples was investigated between 1000 to 1400^oC temperatures in order to ascertain their suitability for producing automobile brake pads. In the research work, kaolin clay was explored, exploited and employed specifically for ceramic disk brake pads.

Idris *et al*., (2013) in their research work investigated and produced brake pads using banana peels to replace asbestos with phenolic resin (phenol formaldehyde) as binder. The resin was varied from 5 to 30 %wt in an interval of 5 %wt. Study was carried out on physical, mechanical, wear and morphological properties of brake pad. Results showed that compressive strength, hardness and specific gravity of the samples were increased with increased %wt of resin addition. Egg Shells (EG) based eco-friendly (biodegradable) brake pad was developed and evaluated by Edokpia, Aigbodion, Obiorah, and Atuanya,(2014).In their work, Gum Arabic (GA) was used as the binder. Both additives were investigated as possible replacement for asbestos and formaldehyde resin which are carcinogenic in nature and non-biodegradable. The brake pad formulation was produced by varying the GA from 3 to 18 %wt Tests carried out on samples included wear rate, thickness swelling in water and SAE oil, thermal resistance, specific gravity, compressive strength, hardness values and microstructure. Results showed that formulations containing 15 to 18 wt% of GA produced fair bonding. The sample with 18 %wt of GA in ES particles gave the best properties.

Therefore, this paper presents a research work which proffer green alternative materials of cashew nut shells and Nigerian gum Arabic to replace asbestos based materials and epoxy resin/phenolic binders respectively used in brake pads production.

2. METHODOLOGY

The research which was experimentally based involved the following materials, equipment, and methods.

3. MATERIALS AND EQUIPMENT

For this study, the materials are locally sourced, and the equipment and workshop/Laboratory were accessed at the Federal Institute of industrial Research, Oshodi, (FIIRO) in Lagos State.

3.1 Materials for Formulation and Production of the Brake Pad samples

The materials for the formulation and production of the brake pad composites include: Cashew Nut Shell (CNS) as the Reinforcement/Filler and based Material, Nigerian Gum Arabic grade 1 as the Binder, Silicon Carbide (SC) for the thermal stability, Graphite (G) as the Friction Modifier and Steel Dust (SD) as the abrasive material. They are shown in Plates 1, 2, 3 and 4. The Preliminary Samples Preparation is shown in Plate 5

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Plate 1: Cashew Nut Shells, Gum Arabic and Ground Powders Plate 2: Silicon Carbide Plate 3: Graphite

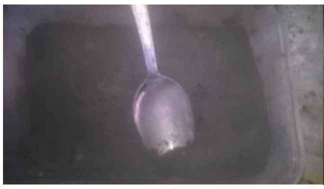


Plate 4: Steel Dust Plate 5: Preliminary Samples Preparation

Equipment

The main equipment used in the course of this work included:-Ball Milling Machine (Model 87002, Limogos-France, A50...43), Hammer Crushing and Milling Machine(Model 1,000T, Poissnce:1.5KV,No 13634),Hydraulic Press (Model Piooeh-type,100T-Capacity,Serial No 38280),Vibro Electric Oven (Model Memmert, Western Germany),Tensometer (M500-25KN,Gunt Hamburg Hardness tester and WP300),Europer bench grinder (MD-250F,750W,380V-50Hz,29500rpm) Testometric Universal Testing Machine (TUF-C 1,000KN),Ø(50-27)mm by 65mm Mould Digital Weighing Machine. Other equipment used were BS 410 standard sieve sizes of aperture 100 µm, 150 µm, and 300 µm (Endecotts Ltd, London) and Homogenizer/Mixer(Model 89..2 Rid Scale & Co Ltd, Middleborough, England),Steel Spatula, Stirrer, Bowls, Optical Electron Microscope(OEM), micrometer screw gauge and desiccators.

Methods

The experimental development of the green agro-allied brake pad involved the Design of Experiment, Main Production of the Composites and characterization of the various compositions for Brinell Hardness, Compressive Strength, Wear Rate and Coefficient of Friction.

Design of Experiment-Minitab Approach

The experiment in this study was based on Taguchi Design of Experiment (DOE) and $L_{27}3^5$ orthogonal array with twenty seven (27) different formulations of Cashew Nut Shells(CNS),Nigerian Gum Arabic(NGA) and Silicon Carbide(SC) varied while the other constituents such as the Graphite(G) and Steel Dust(SD) were fixed as shown in Table 1

.

Table 1: Factor Levels for Composition Parameters

		Percentage Composition (%)		
S/No	Factor/Composition	Level 1	Level 2	Level 3
1	Cashew Nut Shell	35	45	55
2	Steel Dust	15	15	15
3	Graphite	5	5	5
4	Silicon Carbide	20	15	10
5	Nigerian Gum Arabic	25	20	15

Since Ikpambese, Gundu and Tuleu,(2014) suggested176grams by weight, 150grams adopted in the designed experiment so as to accommodate the shortfalls and excesses in weights generated from the Taguchi approach and hence the Factor Level for the composition Parameters in grams as shown in Table 2.

Table 2: Factor Levels for Composition Parameters in Grams

		Percentage Composition (Grams)		
S/No	Factor/Composition	Level 1	Level 2	Level 3
1	Cashew Nutshell	52.5	67.5	82.5
2	Steel Dust	22.5	22.5	22.5
3	Graphite	7.5	7.5	7.5
4	Silicon Carbide	30	22.5	15
5	Nigerian Gum Arabic	37.3	20	22.5

The $L_{27}3^5$ orthogonal array experimental Design Matrix of the Formulations obtained from Minitab 17 is shown in Tables 3 and 4 which also show the evaluated properties such as Hardness, Compressive Strength, Wear Rate and Coefficient of Friction.

Development of the Composites

The compression moulding as adopted by Fono-Tamo and Koya, (2013), Bashar *et al.*, (2012), and Yewas *et al.*, (2013) was used in this study to produce the composites. The powdered Cashew Nut Shells was sieved into grade of 100 µm and the component materials (Cashew Nut Shells Powder, Gum Arabic Powder, the Steel Dust, Silicon Carbide and Graphite) are weighed in the Digital weighing Machine accordingly with respect to corresponding formulations. The mixtures are thoroughly ensured with the help of Homogenizer or Mixer of Model 89.2 Rid Scale & Co Ltd, Middleborough, England).The mixing of the composition was done for 20 to 30 minutes to achieve almost homogeneous mixture inside the mixer before pouring into the mould kept in a hot plate press at temperature of 150^0C and 100,000N/cm^2 pressure for two (2) minutes. They were then be subjected to cold pressing and hot pressing before being allowed to cool at room temperature. After removing from hot press, the composites were removed from the mould and properly cleaned. It was then heat treated at a temperature of 120^oC for 8 hours in the hot air oven. These procedures were repeated for all the twenty-seven (27) formulations to produce the respective composites. The produced samples are shown in Plate 6.

Characterization of the Composites

All the twenty-seven (27) formulated composite samples were tested, evaluated and characterized for Brinell hardness, Compressive Strength, Wear Rate and Coefficient of friction.

Brinell hardness Test

The Brinell Hardeness for all the samples was done using the Brinell hardness testing machine model BS240 Tensometer (M500-25KN, Gunt Hamburg Hardness Tester and WP300). The hardened steel ball of diameter *D* was used to indent the test specimen. The ASTM 785 specification was adopted with a steel ball of D = 10 mm diameter steel ball used and stable 3000 kgf load, P was applied. The Brinell Hardness value was obtained from the equation (Lawal, Bala and Alegbede, 2017).

$$BHN = \frac{2P}{\pi D\left(D-\sqrt{D^2-d^2}\right)} \quad \text{-------1}$$

Where P = applied load, D = diameter of hardened steel ball, d = diameter of indentation.

Compressive Strength

The ASTM D 3039-79(2000) specification was adopted to determine compressive strength of all the samples using the Testometric Universal Testing Machine (TUF-C 1,000KN).The composites were all subjected to compressive force, loaded continuously until failure occurred. The load at which failure occurred were recorded and copied out from the testing machine.

Wear Rate

The wear rates for the samples were measured using pin on disc machine by sliding it over a cast iron surface at a load of 10N, sliding speed of 2,950 rev/min and sliding distance of 2000m. The initial weight of the samples was measured the digital weighing machine with an accuracy of 0.01g. The Wear Rate is calculated from equation 2.

$$Wear\ rate = \frac{\Delta W}{S} \text{ ---------2}$$

Where ΔW = weight difference of the sample before and after the test (mg), S = is the total sliding distance (m)(Lawal *et al*, 2017).

Coefficient of Friction (COF)

The Coefficient of Friction of the samples were determined by MS 474: PART 10, 2003 standard procedures with horizontal plane Norwood Instrument Ltd apparatus (Model 12558) loaded with composite Mass M(Afolabi *et al*, 2015).Weight hander and a cord were then attached to the sample and the weight on the hanger was gradually increased until there is a slide by the brake sample at constant velocity. This load at which this slide occurred was recorded as M_f and the Coefficient of friction is determined from equation 3. The procedures were repeated for all the formulated composites.

$$COF = \mathrm{Mf/M} \text{ ----------------------------3}$$

4. RESULTS AND DISCUSSION

The produced composites are shown in Plate 6 while the microstructure of the first formulation is shown in Plate 7.From the microstructure, it was clear there is strong bonding and cohesiveness of the various constituents of the composites

Plate 6: Produced Composites

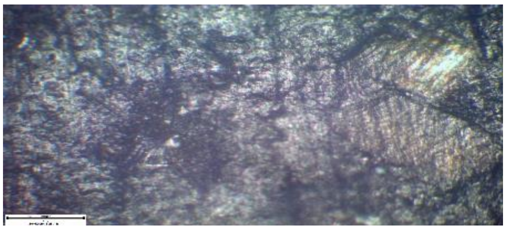

Plate 7: Microstructure of a Composite

Table 3: The Characterization of the Composites

S/No	CNS (g)	SD (g)	G (g)	SC (g)	NGA (g)	Hardness (BHN)	Compressive Strength (N/mm^2)	Wear Rate (mg/m)	Coefficient of Friction
1	52.5	22.5	7.5	30	37.5	22.27	6.035	1.16	0.4456
2	52.5	22.5	7.5	30	30	47.49	11.580	3.08	0.4358
3	52.5	22.5	7.5	30	22.5	31.83	7.568	9.24	0.4554
4	52.5	22.5	7.5	22.5	37.5	31.83	9.519	11.56	0.4554
5	52.5	22.5	7.5	22.5	30	47.49	9.009	10.02	0.5240
6	52.5	22.5	7.5	22.5	22.5	47.49	11.038	3.85	0.4260
7	52.5	22.5	7.5	15	37.5	31.83	10.579	7.32	0.4260
8	52.5	22.5	7.5	15	30	31.83	15.558	3.47	0.4162
9	52.5	22.5	7.5	15	22.5	22.27	17.197	5.39	0.4554
10	67.5	22.5	7.5	15	37.5	31.83	7.410	4.62	0.4652
11	67.5	22.5	7.5	15	30	76.66	13.869	10.02	0.3672
12	67.5	22.5	7.5	15	22.5	47.49	7.512	11.18	0.4162
13	67.5	22.5	7.5	30	37.5	76.66	10.867	8.09	0.4750
14	67.5	22.5	7.5	30	30	76.66	11.012	5.78	0.5632

Table 4: The Characterization of the Composites

S/No	CNS (g)	SD (g)	G (g)	SC (g)	NGA (g)	Hardness (BHN)	Compressive Strength (N/mm^2)	Wear Rate (mg/m)	Coefficient of Friction
15	67.5	22.5	7.5	30	22.5	47.49	9.723	7.71	0.4750
16	67.5	22.5	7.5	22.5	37.5	22.26	8.244	8.86	0.4456
17	67.5	22.5	7.5	22.5	30	47.49	6.298	1.16	0.5044
18	67.5	22.5	7.5	22.5	22.5	31.83	9.107	3.85	0.4946
19	82.5	22.5	7.5	22.5	37.5	22.26	5.736	3.85	0.4554
20	82.5	22.5	7.5	22.5	30	47.49	4.809	2.31	0.4358
21	82.5	22.5	7.5	22.5	22.5	31.83	6.712	5.39	0.4162
22	82.5	22.5	7.5	15	37.5	47.49	5.844	7.32	0.3966
23	82.5	22.5	7.5	15	30	47.49	3.654	1.93	0.3966
24	82.5	22.5	7.5	15	22.5	22.26	6.398	1.93	0.3770
25	82.5	22.5	7.5	30	37.5	31.83	8.532	12.33	0.5142
26	82.5	22.5	7.5	30	30	31.83	8.219	17.73	0.3770
27	82.5	22.5	7.5	30	22.5	22.26	4.552	4.24	0.5534

It can be seen from the Tables above that the various formulations experimentally designed via Taguchi experimental method has widen the possibility of getting the optimal responses for the characterization of the composites. It is clear from the tables that most of the responses compare closely with the commercial brake pads and other research outputs with the Wear Rate and coefficient of friction appearing to be far better than the asbestos based ones.From the reports of Ademoh and Olabisi,(2015) and Idris *et al*.,(2015), the Brinell hardness, Compressive Strength, Wear Rate and Coefficient of friction of asbestos brake pads are 101 BHN, 110N/mm^2, 3.80mg/m and 0.3-0.4 respectively.

5. CONCLUSION

From the microstructure analysis and the characterization of the various formulations, it can be concluded that the cashew nut shells and Nigerian Gum Arabic along other ingredients can be used for the production asbestos free composites for automobile brake pads. The most promising values for the hardness, compressive strength, wear rate and Coefficient of friction of the composites are 76.66 BHN, 17.197N/mm^2,1.16 and 0.5632 respectively.

RECOMMENDATIONS

Since cashew nut shells and Nigerian Gum Arabic with other ingredients show promising prospect in brake bad production, it is recommended that:

1. That Signal-to-Noise ratios and Contour plots be used optimize formulations for hardness, compressive strength, wear rate and Coefficient of friction respectively.
2. Grey Relational Analysis (GRA) should be used to optimize for a single optimal formulation of composition for the responses and characterization

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