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Optimization of Compositions for Wear Rate of Cashew Nut Shells Based Automobile Brake Pads Composites

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ABSTRACT

This paper presents an alternative composite formulation for the production of automobile brake pads that is free from the carcinogenic concerns associated with the commercial ones due its asbestos composites. Cashew Nut Shells(CNS) and Nigerian Gum Arabic(NGA) binder are agro waste material respectively used as the frictional or base or reinforcement material instead of asbestos often used and the organic binder replacing the equally toxic epoxy or phenolic binder often used. Other functional additives included in the mix are the Steel Dust (SD), Silicon Carbide (SC) and Graphite (G). $L_{27}3^5$ orthogonal arrays of twenty seven (27) formulations designed for via Taguchi method and the composites were produced using compression moulding and particles sieve size was 100µm.The wear rate properties of most of the composites compare favourably with 3.80gm/m of the commercial brake pads and other research outputs while Signal to Noise ratio and Main Effect Plots were used to optimize the compositions for optimal composition. The optimal compositions in grams of Cashew Nut Shells (CNS), Steel Dust (SD), Graphite (G) Silicon Carbide (SC) and Nigerian Gum Arabic (NGA) were 82.5, 22.5, 7.5, 22.5 and 30 respectively.

Keywords: Compositions, Composites, Cashew Nut Shells, Wear Rate, Optimize

1. INTRODUCTION

The automobile brake pads consists of composites made from frictional or reinforcement materials and other additives that are placed in wheel assembly to continuously clamp and hold wheels to slow down or control or stop completely a moving automobiles (Aigbodion and Agunsoye, 2010).Production of these automobile materials dated back to 117 years ago are usually made with blends of asbestos, metals and ceramics. The asbestos constituent has been found to release gases hazardous to human health upon use of brake pads. Asbestos in any domestic components like water pipelines etc. have long been known to cause or aggravate diseases like asbestosis, mesothelioma, lung and other cancers (Idris *et al*,(2015). The efforts of researchers in recent times have thrust a research direction of replacing the asbestos and inorganic resins with agro based materials that are non-injurious to human health and does not corrode any parts of the brake pads assembly. 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.

Bashar *et al*,(2012) was reported to have used coconut shells to produce another asbestos free brake pads. 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) in their efforts produced brake pads from Periwinkle shells. In these works, periwinkle shell (asbestos-free) brake pad materials 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°C 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 a 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, they used Gum Arabic (GA) as 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, Edokpia, *et al.* (2014). The sample with 18 wt% of GA in ES particles gave the best properties.

According to Idris *et al* (2013) 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 weakness that cause cancer risk for workers and users . Asbestos have long been known to cause lung and other cancerous diseases (Bala et al, 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 *et a*l., 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).

Therefore, in efforts to the avoid or reduce the health hazard with asbestos based brake pad materials, this study present an alternative materials to replace asbestos materials used in brake pads production and aims to develop brake pad composites of cashew nut shells bonded with another agro material known as gum Arabic along other additives like steal dust, graphite and silicon carbide and the formulation optimized for wear rate. To find a no- toxic replacement for the inorganic resins such as epoxy, phenolic and formaldehydes, acacia species exudates known as Gum Arabic was reported by Ademoh and Abdullahi, 2010 to provide natural resin that contains arabin which is a semi solidified sticky fluid oozing from incision made on bark of acacia trees. Nigeria produces different grades of exudates and is ranked as the second largest world producer after Sudan with average production of 20,000 tons in 2005.

2 METHODOLOGY

This study was experimentally designed and carried out with the following materials and methods.

2.1 MAETRIALS

The main materials used this study were locally sourced while the equipment/ workshop/Laboratory were accessed at the Federal Institute of industrial Research, Oshodi, (FIIRO) in Lagos State. The basic materials for the formulation and production of the composites were (1) Cashew Nut Shell (CNS) (2) Nigerian Gum Arabic grade 1, (3) Silicon Carbide (SC), Graphite (G) and Steel Dust (SD). The main materials selected and the respective roles for their selection is shown in Table 1.

Table 1: Materials Selected and their Roles

S/No	Materials	Role	Reason(s) for Material Choice
1	Cashew Nut Shell	Base/Filler Material	Cheaply available as Agro-allied material, rarely used and chosen to investigate it usage to replace asbestos,improve resilience in the binder system and reduces brake noise (Spurr,1972).
2	Nigerian Gum Arabic	Binder	Good bindery properties, chosen for the production of brake pad as binder and to increase the chances of substantially green agro-allied (plant) based brake pad
3.	Silicon Carbide	Abrasiveness and Thermal Conductivity	Easy and cheap to obtain. It increases friction and also helps in controlling the build-up of friction film. That is, it effectively controls the thermal conductivity of the brake pad during usage
4	Steel Dust	Reinforcement and Abrasiveness	It is a reinforcement that influences adhesion and dispersion of polymer composite fabrication (Hoeganaes, 1990), it also has abrasive functions.
5.	Graphite	Friction Producer/Modifier	Cheap and widely used and it is non-hazardous for improving wet friction

The equipment that were used include (1) Ball Milling Machine (2) Hammer Crushing and Milling Machine,(3) Hydraulic Press Model Piooeh-type,100T-Capacity,Serial No 38280 (4)Vibro Electric Oven (5) Europer Bench Grinder of MD-250F,750W,380V-50Hz, R 29500rpm (6) Ø(50-27)mm by 65mm Mould (7) Digital Weighing Machine. Other equipment used were BS 410 standard sieve sizes of aperture 100µm, micrometer screw gauge Stirrer, Bowls, Optical Electron Microscope(OEM), Steel Spatula, and desiccators.

2.2 Methods

The first step is the $L_{27}3^5$ orthogonal array Design of Experiment (DOE) via Taguchi with twenty seven (27) different formulations of Cashew Nut Shells, Silicon Carbide, Nigerian Gum Arabic, Graphite and Steel Dust. The Cashew Nut Shells, Silicon Carbide and Nigerian Gum Arabic compositions were varied while the other constituents such as Graphite and Steel Dust were kept constant and three (3) level $L_{27}3^5$ orthogonal array Experimental Matrix for the Composition formulation that was originated and utilized is shown in Table 2.

Table 2: Three (3) level $L_{27}3^5$ orthogonal array Experimental Matrix for the Compositions

Trial No	Cashew Nut Shells CNS (Grams)	Steel Dust SD (Grams)	Graphite G(Grams)	Silicon Carbide SC (Grams)	Nigerian Gum Arabic (Grams)
1	52.5	22.5	7.5	30	37.5
2	52.5	22.5	7.5	30	30
3	52.5	22.5	7.5	30	22.5
4	52.5	22.5	7.5	22.5	37.5
5	52.5	22.5	7.5	22.5	30
6	52.5	22.5	7.5	22.5	22.5
7	52.5	22.5	7.5	15	37.5
8	52.5	22.5	7.5	15	30
9	52.5	22.5	7.5	15	22.5
10	67.5	22.5	7.5	15	37.5
11	67.5	22.5	7.5	15	30
12	67.5	22.5	7.5	15	22.5
13	67.5	22.5	7.5	30	37.5
14	67.5	22.5	7.5	30	30
15	67.5	22.5	7.5	30	22.5
16	67.5	22.5	7.5	22.5	37.5
17	67.5	22.5	7.5	22.5	30
18	67.5	22.5	7.5	22.5	22.5
19	82.5	22.5	7.5	22.5	37.5
20	82.5	22.5	7.5	22.5	30
21	82.5	22.5	7.5	22.5	22.5

22	82.5	22.5	7.5	15	37.5
23	82.5	22.5	7.5	15	30
24	82.5	22.5	7.5	15	22.5
25	82.5	22.5	7.5	30	37.5
26	82.5	22.5	7.5	30	30
27	82.5	22.5	7.5	30	22.5

2.2.1 Development Of The Composites

The second step is preparation of the constituent materials into 100μm sieve size and formulated into twenty seven (27) different compositions as originated from table 2.

The powder metallurgy method also known as the Compression moulding method as successfully adopted and reported by Yewas *et al*, (2013), Koya and Fono (2013) and Bashar *et al*, (2012) were used development of the brake pad composites. The powdered Cashew Nut Shells was sieved into grades of 100 μm and the component materials of Cashew Nut Shells Powder, Gum Arabic Powder, the Steel Dust, Silicon Carbide and Graphite were weighed in the Digital weighing Machine correspondingly with formulations designed via Taguchi. 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°C 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 being oven dried is shown in Figure 2.1 and Europer Bench Grinder for determining the wear rate is shown in Figure 2.2.

Figure 1: Composites being Oven Dried

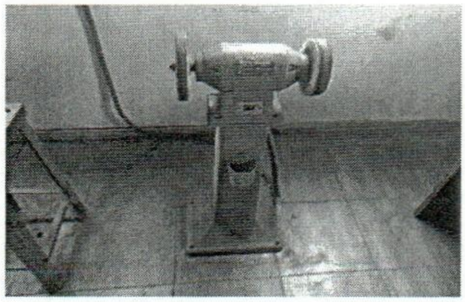

Figure 2.2: Europer Bench Grinder

2.2.2 Wear Rate Characterization Of Twenty Seven Composites Produced

The twenty seven (27) formulated and produce composite samples were tested for rear Rate

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 were measured the digital weighing machine with an accuracy of

0.01g. The Wear Rate is calculated from equation 1.

$$Wear\ rate = \frac{\Delta W}{S} \qquad 1$$

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

2.2.3 Signal-To-Noise (S/N) Ratio

The small is better Signal-to-Noise ratio quality characteristics as given in equation 2 was used for the optimization of the wear rate (Tribological property).

Smaller-the better: $S/N = -10Log1/n(\sum_{i=1}^{n} yi^2)$ 2

Where n = number of factor level combination responses.

y = Responses of given factor level combination.

3 RESULTS AND DISCUSION

The wear rate obtained using equation 2.1 for the twenty seven (27) different composites produced and the corresponding Signal to Noise Ratio from equation 2.2 is presented in Table 3.

Table 3: Wear Rate Properties of the Composites

CNS (grams)	SD (grams)	G (grams)	SC (grams)	NGA (grams)	Wear Rate (mg/m)	SMALLER THE BETTER S/N Ratio for Wear Rate
52.5	22.5	7.5	30	37.5	1.16	-1.2892
52.5	22.5	7.5	30	30	3.08	-9.7710
52.5	22.5	7.5	30	22.5	9.24	-19.3134
52.5	22.5	7.5	22.5	37.5	11.56	-21.2592
52.5	22.5	7.5	22.5	30	10.02	-20.0174
52.5	22.5	7.5	22.5	22.5	3.85	-11.7092
52.5	22.5	7.5	15	37.5	7.32	-17.2902
52.5	22.5	7.5	15	30	3.47	-10.8066
52.5	22.5	7.5	15	22.5	5.39	-14.6318
67.5	22.5	7.5	15	37.5	4.62	-13.2928
67.5	22.5	7.5	15	30	10.02	-20.0174
67.5	22.5	7.5	15	22.5	11.18	-20.9688
67.5	22.5	7.5	30	37.5	8.09	-18.1590
67.5	22.5	7.5	30	30	5.78	-15.2386

67.5	22.5	7.5	30	22.5	7.71	-17.7411
67.5	22.5	7.5	22.5	37.5	8.86	-18.9487
67.5	22.5	7.5	22.5	30	1.16	-1.2892
67.5	22.5	7.5	22.5	22.5	3.85	-11.7092
82.5	22.5	7.5	22.5	37.5	3.85	-11.7092
82.5	22.5	7.5	22.5	30	2.31	-7.2722
82.5	22.5	7.5	22.5	22.5	5.39	-14.6318
82.5	22.5	7.5	15	37.5	7.32	-17.2902
82.5	22.5	7.5	15	30	1.93	-5.7111
82.5	22.5	7.5	15	22.5	1.93	-5.7111
82.5	22.5	7.5	30	37.5	12.33	-21.8193
82.5	22.5	7.5	30	30	17.73	-24.9742
82.5	22.5	7.5	30	22.5	4.24	-12.5473

From table 3 the various formulations experimentally designed via Taguchi experimental method was seen to have clearly increased the chances of optimizing the response which in this study is the wear rate. It is clear from the table that the wear rate of most of the composites compare favourably with 3.80gm/m of the commercial brake pads and other research outputs reported by Ademoh *et al* (2015) Ikpambese *et al*, (2014), and Idris *et al* (2015).

3.1 Main Effect Plots

The Signal-to-Noise ratios in table 3 was used to plot main effects plots. These plots determine the optimum composition formulations of the input parameters for the wear rate response.

The main effects plots for the wear rate is shown in figure 3.1

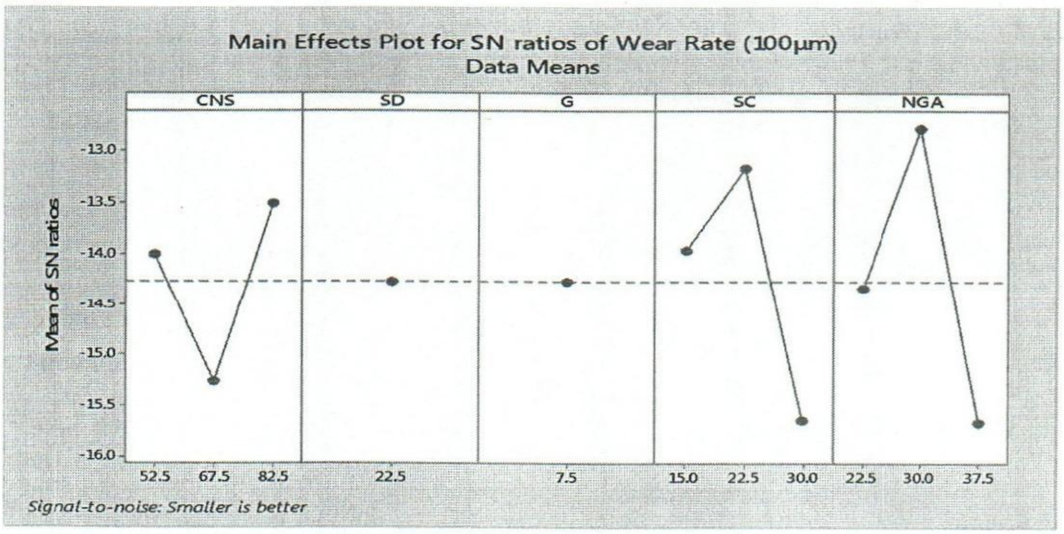

Figure 3.1: Main Effects Plot for S/N ratio of Wear Rate

From Figure 3.1, it is observed that for optimal Wear rate, the optimal compositions (in grams) of Cashew Nut Shells(CNS), Steel Dust(SD),Graphite(G),Silicon Carbide(SC) and Nigerian Gum Arabic(NGA) are 82.5,22.5, 7.5,22.5 and 30 respectively.

4 CONCLUSION

From the wear rate characterization of the various formulations, the following conclusion is drawn.

The cashew nut shells and Nigerian Gum Arabic along other ingredients can be used for the production asbestos free, non-hazardous and agro waste based composites for automobile brake pads.
To obtain best and optimal wear rate properties that can compare favorably with the commercial brake pads with wear rate of 3.80gm/m, the optimal mass in grams of Cashew Nut Shells(CNS), Steel Dust(SD),Graphite(G),Silicon Carbide(SC) and Nigerian Gum Arabic(NGA) are 82.5,22.5, 7.5,22.5 and 30 respectively.

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