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Production of Asbestos-free Brake Pad Using Groundnut Shell as Filler Material

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Abstract

The development and evaluation of brake pads using groundnut shell (GS) particles as substitute material for asbestos were carried out in this study. This was with a view to harnessing the properties of GS, which is largely deposited as waste, and in replacing asbestos which is carcinogenic in nature despite its good tribological and mechanical properties. Two sets of composite material were developed using varying particle sizes of GS as filler material, with phenolic resin as binder with percentage compositions of 45% and 50% respectively. Results obtained indicate that the compressive strength and density increase as the sieve size of the filler material decreases, while water and oil absorption rates increase with an increase in sieve size of GS particle. This study also indicates that the cost of producing brake pad can be reduced by 19.14 percent if GS is use as filler material in producing brake pad. The results when compared with those of asbestos and industrial waste showed that GS particle can be used as an effective replacement for asbestos in producing automobile brake pad. Unlike asbestos, GS-based brake pads are environmental friendly, biodegradable and cost effective.

Keywords: ***Brake pad, Groundnut shell, Asbestos, Mechanical and tribological properties***

1.0 Introduction

A brake is a mechanical device that inhibits movement by absorbing energy from a moving system. Brake pads are steel backing plates with friction material bound to the surface with rivet or high temperature adhesives (Adegbola et al., 2017). The major constituents that make-up brake pads are divided into four broad groups, namely frictional additives, binders, filler materials and reinforcing fibres (Pradep et al., 2011; Abutu et al., 2017). This classification is based on their performance apart from controlling wear and friction. Frictional additives are compounds added to lining materials, primarily aimed at modifying the frictional coefficients and wear rates. Frictional additives control the build-up of frictional films and remove oxides, as well as maintaining the cleanliness of mating surfaces. According to Chan and Stachowiak (2004) frictional additives are divided into two main categories, lubricants which decrease the wear rate and abrasives which increase the frictional coefficient while decreasing the wear rate of the counter face material. Binders function primarily in maintaining the structural integrity of the brake pad under mechanical and thermal stresses. Binders hold other constituents of the brake pad together, thereby reducing the rate of constituent shear. Fillers are used in brake pad production primarily to improve the manufacturability of the pad as well as reduce the cost of production. Fillers could also be referred to as any material used in large proportions in producing brake pad. Reinforcing fibers enhance the mechanical strength of the brake lining material. Historically, leather from animal skin and hard wood from trees were first used as brake pad materials prior to the discovery of asbestos as friction materials (Darlington et al., 2015). However, the poor temperature, high wear rate and poor stability were some of the reasons why these materials lost favour as friction lining material. According to Nicholson (1995), the development of frictional materials dates back to late 1890, when Herbert Frood invented the first brake lining. These lining materials were cotton-based materials impregnated with bitumen solution. These textile materials were used as brake for wagon wheels as well as early automobiles. These materials were observed to have a major limitation as the cotton tends to char easily when load is applied. It was also observed that cotton-based materials had very low coefficients of friction and specific heat capacity, making it imperative to replace cotton with other materials that can withstand high temperature and load. Asbestos are naturally occurring minerals like chrysotile and amphiboles, which occur in serpentine rocks in the form of fine, silky, flexible fibrous crystals (Pia et al., 2017). Asbestos was introduced as a constituent in brake pad production due to its resistance to heat at elevated temperature, low wear rate and its high friction stability (Elakhame et al., 2017). The high awareness that asbestos is a carcinogenic material in 1983 lead to its ban as a filler material in many developed countries like Iceland, United States, and Australia (Ken & Philip, 2016). Although the use of asbestos for producing brake pad has not been banned all over the world, the ban in these countries resulted to an urgent need for researchers to find substitute materials. The World Health Organization (WHO) in 2010 estimated that over 107,000 people die each year from asbestos-related lung cancer, mesothelioma, and asbestosis resulting from occupational exposures. Growing concerns for safer environments coupled with increasing cost of asbestos have led to the need to develop brake pads which are environmental friendly, biodegradable and of reasonable cost. The present study focuses primarily on the development and evaluation of asbestos-free brake pads using GS particle as filler material. This work also compares the cost of producing GS-based brake pad with that of conventional brake pad. GS has the potential to substitute asbestos owing to its high content of alumina and silica. These elements are known to function as reinforcing materials (Kenneth et al., 2018). The use of GS also has the potential of reducing the current cost of producing brake pad, as well as generating foreign exchange for a developing country like Nigeria. Development of innovative friction materials via utilization of GS would also be part of the solutions to reducing the environmental pollution occasioned by indiscriminate disposal of this agricultural waste in the country. Groundnut (Arachis Hypogaea) is a major crop grown in arid and semi-arid zones of Nigeria, being grown mainly for its nut, oil and vegetable residue. Its shell is then discarded after the nut has been collected. The shell occupies 20 – 24 percent of the total harvest, the ratio vary by variety (Mahmoud et al., 2012). GS contributes significantly to the solid waste in the country, hence the need to develop a system that would convert these excess wastes to useful products. In 2011, Nigeria was the third largest producer of groundnut after China (16,114,231 tons) and India (6,933,000 tons) producing 2,962,760 tons of groundnuts (Kenneth et al., 2018). The benefits associated with the use of waste materials in producing brake pads cannot be overemphasized. Various researches have been carried out to replace asbestos materials with organic, inorganic or industrial waste materials. Aigbodion et al., (2010) formulated asbestos-free brake lining using baggase as filler materials. Their findings indicated that the compressive strength, hardness, and density of the brake lining produced decreases with an increase in sieve size of baggase, while the flame resistance, wear rate, water and oil absorption rate increase as the particle size increase.

2.0 Materials and Methods

The conversion of waste materials to useful products is important to improving the economy of any country, this study replaces asbestos which are carcinogenic with GS particles.

2.1 Materials

The materials used in carrying out this study include groundnut shell, phenolic resin, Calcium carbonate, compound rubber, Calcium hydroxide, graphite, engine oil (SAE 20W/50) and water. Plate 2.1 shows the various materials used in producing the brake pad. These materials were selected based on their availability and literature review from similar research. The equipment's used in carrying out this research include metallic mould, compression moulding machine, two roll mill machine, oven dryer, tribometer, differential scanning calorimeter, sensitive electronic weighing machine and set of sieves.

Plate 2.1: Constituents of Produced Brake Pad

2.2 Experimental Procedure

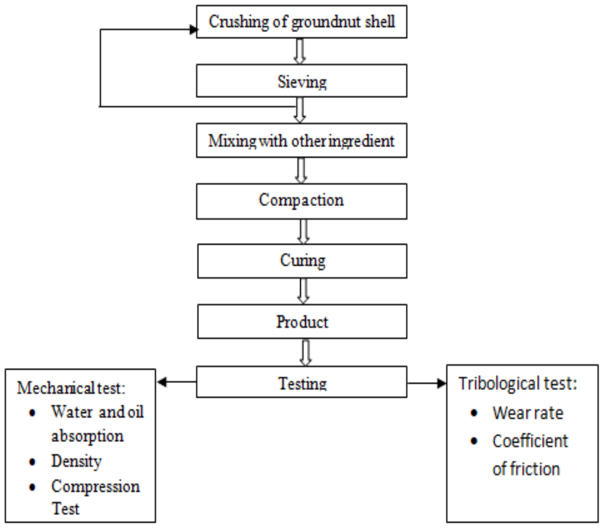

Figure 2.1: Process Flow Chart for Groundnut Shell Brake Pad Production

Figure 2.1: Shows a flow chart for the production of GS-based asbestos-free brake pad.

2.3 Material Preparation

The GS was sourced from a groundnut mill in Zaria, Nigeria. The GS was washed with water to remove sand particles and then poured in a solution of Sodium hydroxide and water with a composition ratio of 1:15 to remove impurities like lignin and pectin. The GS was then resin in distilled water to dilute Sodium hydroxide on the shell, and then subsequently dried under the sun until it was observed that almost all the moisture present in the shell had dried up.The shell was poured into a grinding machine (Thomas-Willy laboratory mill, model 4, Philadelphia) to reduce its size. The shell was then sieved in a 150 and 350 micrometer sieve. The shell particles were then mixed with other ingredient in a two roll mixing mill (Model XK-160, USA).

2.4 Casting of Composites

Two sets of rectangular mould (40×40×5mm) made of mild steel were used in casting the composite. For easy removal of the brake lining an aluminium foil was placed over the mould cavity and engine oil (SAE 20W/40) used to grease the surface of the foil, and the composite was put to fill the cavity of the mould. The mould was put into a compression moulding machine at varying moulding temperatures and time at a pressure of 25bar. The formulations of the two samples are tabulated in Table 2.1

Table 2.1 Formulation of brake Pad

S/N	Ingredients	Composition 1(% Weight)	Composition 2 (% Weight)
1	Phenolic resin	45	50
2	Groundnut shell	30	25
3	Compound rubber	10	10
4	Calcium Carbonate	5	5
5	Calcium Hydroxide	5	5
6	Graphite	5	5

Composition 1 was used in producing sample 1, 2, 3 and 4, while composition 2 was used to produce sample 5, 6, 7 and 8.

2.5 Test Procedure

Various tests were carried out on the developed sample to determine the mechanical and tribological properties of the samples.

2.5.1 Coefficient of Friction and Wear Test

Wear is the gradual removal of material from the sides of two solid surfaces in contact. Wear test was performed on the samples using the ASTM D 2583 standard. A ball-on-disc tribometer was used for the experiment to measure the wear rate and coefficient of friction. The sample used for the test was shaped to a 10mm diameter. The ball was held against the counter face of the rotating disc with a wear track radius of 5mm. Test for wear rate for the specimen were conducted under a normal load of 5N and a sliding velocity time in seconds. The test was carried out at 250C and a humidity of 55%. The setup was used to determine the coefficient of friction and wear rate of the composite friction lining. The formula for determining wear is thus:

$$Wear\ loss\ (g) = W_1 - W_2 \qquad \ldots\ldots\ldots\ldots.2.1$$

$$\%\ Wear\ loss = \frac{W_1 - W_2}{W_1} \times 100 \qquad \ldots\ldots\ldots\ldots2.2$$

Where:

W_1 = initial weight
W_2 = final weight

The coefficient of friction is calculated thus:

$$\mu = \frac{f}{N} \qquad \ldots\ldots\ldots\ldots\ldots2.3$$

Where:

μ = Coefficient of friction

f = load applied
N = Normal

2.5.2 Compression Test

The aim of this test is to determine the behavior of a material while it undergoes compressive load. This test was carried out according to ASTM D6641 standard for testing of polymer matrix composites using a universal testing machine (Model: 3369 Instron, Illinois). The test was carried out at room temperature. The specimen was shaped to a rectangular form (30mm × 10mm × 8mm). The specimen was properly gripped to the machine, and then load was applied on the specimen, and strain was recorded at intervals. The formula for determining the compressive strength of the materials is thus:

$$c = \frac{L}{A} \qquad \ldots\ldots\ldots2.4$$

Where:

C = Compressive strength of the material
L = Load applied at compression
A = Cross sectional area

2.5.3 Water and Oil Absorption Rate Test

The aim of the test is to determine the amount of water and oil absorbed under specified conditions. The water and oil absorbent property were conducted on the produced brake pad samples according to ASTM D570 standard. The samples were dried in desiccators for 30 minutes and then placed on a tray to cool at atmospheric temperature. Immediately upon cooling to room temperature the specimens were weighed, the initial weight of the sample before immersion (W_1) and the final weight of the sample after immersion (W_2) for 24 hours were measured. The water and oil absorption ($\imath$) was calculated using the relationship:

$$\imath = \frac{W_2 - W_1}{W_1} \qquad \ldots\ldots\ldots\ldots.2.5$$

2.5.4 Density Test

Density test was used to determine the weight per volume of the pad produced. This test was carried out based on Archimede's principle which is used to determine the volume of irregular materials by measuring the mass in air (m) to the volume (V) of liquid displaced. The samples were immersed in 100mL cylinder filled with distilled water at room temperature. The volume of water before immersion and after immersion of the samples was read, and their difference in volume calculated. This can be expressed as:

$$\rho = \frac{m}{V} \qquad \ldots..2.6$$

3.0 Results and Discussion

3.1 Coefficient of Friction

The results of the test for coefficient of friction for GS- based brake pad composite are indicated in Figure 3.1

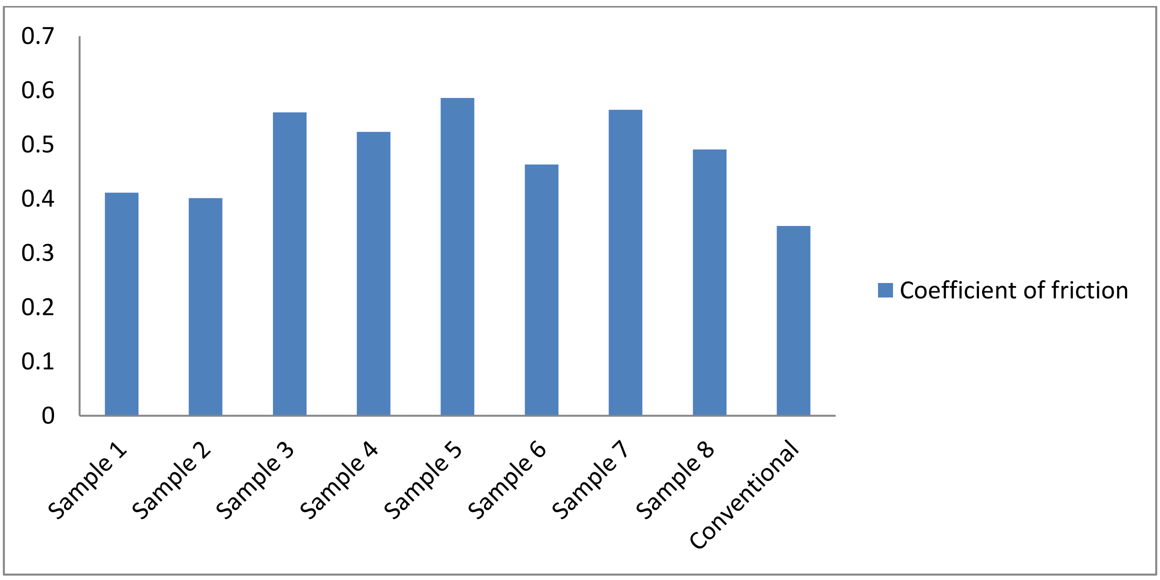

Figure 3.1: Comparative Analysis of Coefficient of Friction for Various Samples.

The average values of the dynamic friction coefficient obtained from the test are shown in Figure 3.1. It is observed that the coefficient of friction for GS-based brake pads ranges from 0.401 to 0.586 which is higher than that of conventional brake pad with coefficient of friction of 0.35 to 0.42 (Nuhu & Adeyemi 2015). The high coefficient of friction of GS based brake pad could be as a result of alumina and silica which are components of GS. This would result in a better grip between the brake pad and the brake disc then conventional brake pad. Although, faster wear rate was observed as the load applied to the GS-based brake pad was increased above 5N.

3.2 Compression Test Results

The results of the compression test for GS- based brake pad composites are indicated in Table 3.1

Table 3.1: Compression Test Result

S/N	Moulding Temperature (°C)	Moulding Time (min)	Curing Time (min)	Particle Size (μm)	Compressive Stress (MPa)	Strain at Break (mm/mm)	Modulus (MPa)	Load at Break (N)
	(A)	(B)	(C)	(D)				
1	110	10	30	150	(-) 8.98	0.018	433.261	336.313
2	110	10	30	350	(-) 8.77	0.017	420.871	321.788
3	110	20	60	150	(-) 9.46	0.025	576.966	377.734
4	110	20	60	350	(-) 8.99	0.020	508.321	352.113
5	130	20	60	150	(-) 9.68	0.027	589.869	386.182
6	130	20	60	350	(-) 9.38	0.025	578.240	368.436
7	130	10	30	150	(-) 9.04	0.021	512.344	361.110
8	130	10	30	350	(-) 9.01	0.019	442.818	340.821

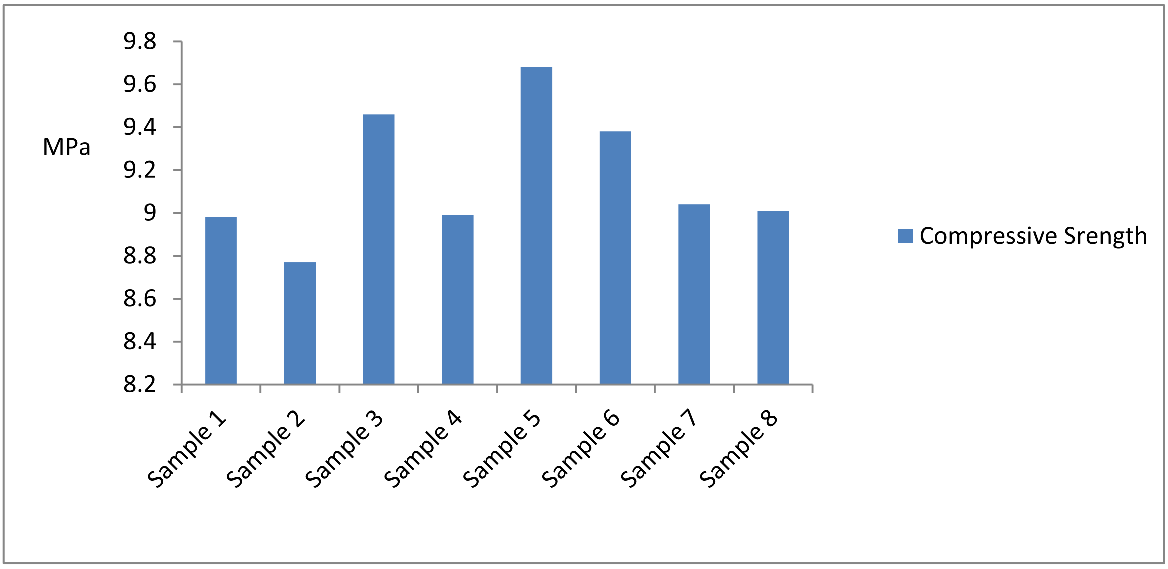

Figure 3.2: Comparative Analysis of the Compressive Strength for Various Samples.

It was observed that the universal testing machine used could not compress the composite further beyond the reported values. The compressive stress and load had a negative value indicating that the specimen require more compressive load to be applied. It is observed from Figure 3.2 that an increase in the binder (phenolic resin) resulted to an increase in the compressive strength of the specimen and verse visa.

3.3 Oil and Water Absorption Rate

The percentage oil and water absorption rate for GS-based brake pad composite are indicated in Table 3.2a and 3.2b

Table 3.2a: Oil Absorption Rate for Groundnut Shell Based Brake Pad Composite

S/N	Moulding Temperature (°C)	Moulding Time (min)	Curing Time (min)	Particle Size (μm)	Weight before immersion (g)	Weight after immersion (g)	Oil absorption rate (%)
	(A)	(B)	(C)	(D)			
1	110	10	30	150	76.97	77.51	0.702
2	110	10	30	350	62.33	63.04	1.139
3	110	20	60	150	68.45	68.99	0.789
4	110	20	60	350	64.21	64.91	1.090
5	130	20	60	150	83.84	84.11	0.322
6	130	20	60	350	78.86	79.70	1.065
7	130	10	30	150	70.41	70.98	0.810
8	130	10	30	350	80.05	80.88	1.037

Table 3.2b: Water Absorption Rate for Groundnut Shell Based Brake Pad Composite

S/N	Moulding Temperature (^oC) (A)	Moulding Time (min) (B)	Curing Time (min) (C)	Particle Size (μm) (D)	Weight before immersion (g)	Weight after immersion (g)	Water absorption rate (%)
1	110	10	30	150	76.37	77.81	1.886
2	110	10	30	350	61.33	62.66	2.169
3	110	20	60	150	68.14	68.99	1.247
4	110	20	60	350	64.75	66.11	2.100
5	130	20	60	150	83.22	83.97	0.901
6	130	20	60	350	78.23	79.32	1.393
7	130	10	30	150	68.88	70.08	1.742
8	130	10	30	350	79.45	81.01	1.963

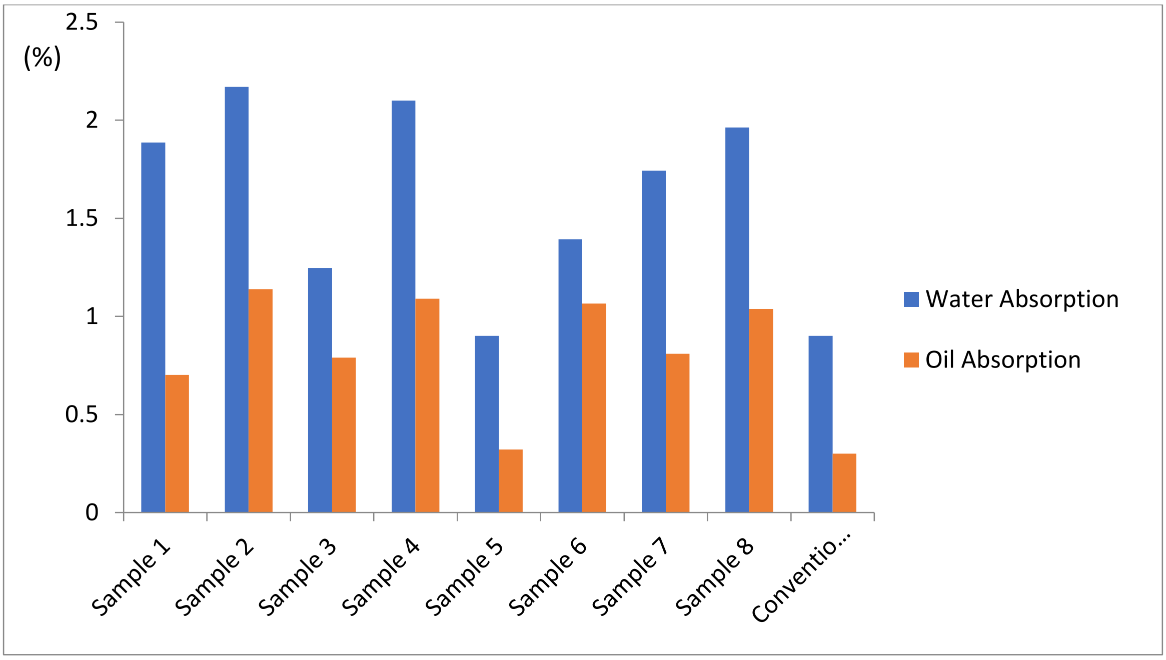

Figure 3.3: Comparative Analysis of Water and Oil Absorption Rate for various Samples.

From Figure 3.3 the water and oil absorbent property of the samples were observed to be directly proportional to the filler size in the formulations. The decreased in water and oil absorption rate may be due to the increased interfacial bonding between binder and filler particle that caused decreased porosity (Edokpia et al., 2014). The result compared favorably with that of conventional model with water and oil absorption rates of 0.9% and 0.3% respectively (Aigbodion et al., 2010)

3.4 Density Test

The results of the density test for GS-based brake pad composites are indicated in Table 3.3

Table 3.3: Density Test Result

S/N	Moulding Temperature (^oC) (A)	Moulding Time (min) (B)	Curing Time (min) (C)	Particle Size (μm) (D)	Weight in air (g)	Volume of water displaced (cm^3)	Density (g/cm^3)
1	110	10	30	150	11.69	12.32	0.949
2	110	10	30	350	12.11	12.99	0.932
3	110	20	60	150	13.99	14.25	0.982
4	110	20	60	350	11.61	13.22	0.878
5	130	20	60	150	14.00	16.16	0.866
6	130	20	60	350	13.66	14.81	0.922
7	130	10	30	150	13.81	14.62	0.945
8	130	10	30	350	13.71	14.01	0.978

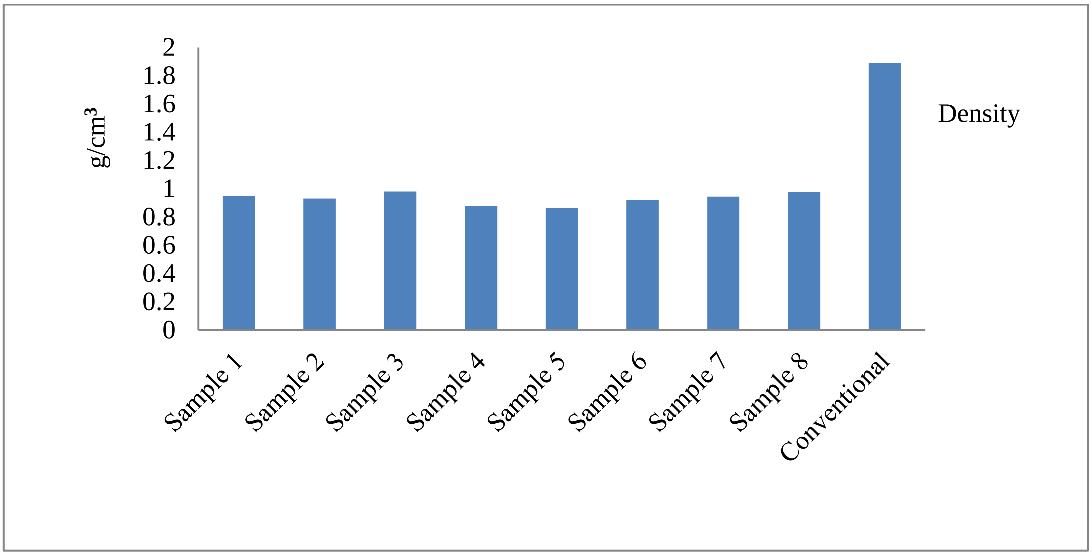

Figure 3.4: Density Test Analysis for Various Samples

The design and manufacture of automotive brake pads take into consideration the light weight of the pad produced. The density of the sample is plotted against the compositions of the specimens as presented in Figure 3.4 where density varied irregularly with decreasing filler content. It was also observed that the density of the pad sample increase as the sieve size of GS decreases. The decrease in density could be attributed to increased packing of the filler particles as observed by Edokpia et al. (2014). The density of specimens was less than that of commercial brake pad, which has a density of 1.890g/cm3.

3.5 Cost Analysis

The cost of any produced item is essential to every manufacturing organization. This section evaluates the cost of the produced item (brake pad), and compares the cost with that of existing commercial brake pads sold in Nigeria. In carrying out the cost analysis, the assumption is that the cost of machinery and labour is the same for producing brake pads of any composition. The bill of engineering and cost estimation for the GS-based brake pad is tabulated in Table 3.4

Table 3.4: The Bill of Engineering Measurements and Evaluations for the Groundnut Shell-Based Brake Pad Material

S/N	Material	Quantity (g)	Rate (₦)	Amount (₦)
1	Groundnut Shell	60	1.5	90
2	Phenolic resin	90	90	8,100
3	Compound Rubber	20	5	100
4	Limestone	10	10	100
5	Graphite	10	5	50
6	Calcium Hydroxide	10	5	50
7	Equipments			760
8	Labour			1,100
	Total			10,350

Cost Analysis

From the analysis of the cost of producing GS-based lining in Table 3.4, it is observed that the cost of producing eight sets of brake linings is Ten Thousand Three Hundred and Fifty Naira (₦10,350). Therefore, the cost of producing a set of brake lining is One Thousand Two Hundred and Ninety Three Naira Seventy Five Kobo (₦1,293.75) only. A Honda Accord brake pad model which was used for comparison cost One Thousand Six Hundred Naira (₦1,600) from market survey. This indicates a price decrease of 19.14 percent in the cost of producing the pad. This price decrease could be related to the introduction of GS as filler material in the brake pad formulation.

Conclusion

Based on the mechanical and tribological properties obtained from evaluating GS-based brake pad, the performance of GS based brake pad compares optimally to that of the conventional model and others developed brake pad using agricultural and industrial waste. Therefore, GS particles can be used as a replacement for asbestos in producing brake pad. It was observed that the water and oil absorption rate for GS-based pad is close to that of the conventional brake pad with a percentage deviation of 0.001 and 0.022 for water and oil absorption rates, respectively. The density of GS based brake pad was better than that of conventional brake pads as all eight samples had a low mass to volume ratio. Finally, the research shows that GS has the potential to reduce the current cost of producing brake pads by about 19.14 percent.

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