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Design and Production of a Brake Pad Using Coconut Shell as Base Material

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ABSTRACT

Automotive brake friction materials are an important part in brake and clutch devices. Friction materials used for brake pad/linings are obtainable from the simple formulation containing some elements to complex composites with as much as 20 or more elements. This research presents the use of an organic-based (mainly agro-based) formulation as base materials for the production of automobile brake pad/lining and for other industrial applications with a view to replacing the use of asbestos whose dust is carcinogenic. The research involves the preparation of experimental materials by addition in percentage weight of graphite, coconut shell powder, zinc barite, carbon black resin, oxide, friction dust, and brass powder as 2.1,2.5,1.3,1.4,0.2,0.7, 0.5, and 0.6 wt. % respectively in that order. Test samples were produced by steel molding method and machined to the standard size for the purpose of determining quality bonding, hardness value and swell-growth. The result obtained show a standard homogenous bonded experimental brake pad/lining having a Brinell hardness value (BHN) of about 32.3 and swell growth of 0.625%.

Keywords: *Brinell-hardness, Coconut shell, Formulation, Homogenous, Indentation, Swell-growth.*

1.0 INTRODUCTION

In every sphere of modern activities materials are used in one form or the other. Many of our modern technologies require materials with unusual combination of properties that cannot be met by the conventional metal alloys, such as ceramics and polymeric materials (Courtney, 1997). This is especially true for materials that are needed for automotive applications.

The brake pad, one of the components of braking systems is designed for high friction with brake pad material embedded in the disc in the process of bedding while wearing evenly. They need a stable friction at different temperatures, loads, environments, and stages of wear. Furthermore, seizure, excessive wear rates, and macroscopic fracture must be avoided, (Eriksson, 2000).

Brake pads convert the kinetic energy of the car to thermal energy by friction. Two brake pads are contained in the brake caliper with their friction surfaces facing the rotor. When the brakes are hydraulically applied, the caliper clamps or squeezes the two pads together into the spinning rotor to slow/stop the vehicle. When a brake pad is heated by contact with a rotor, it transfers small amounts of friction material to the disc, turning it dull gray. The brake pad and the disc (both now with friction material), then stick to each other, providing the friction that stops the vehicle.

Currently the major base material for the manufacture of brake pad/lining material is asbestos fiber (Shigley and Miscwe, 2001), they are used by industry, mainly in construction and friction materials. Although, in the 1920s, asbestos fiber was chosen as a friction material for use in all kinds of vehicles but due to its harmful effects on human health, non asbestos organic (NAO) material have become main stream nowadays (Lomash, et al, 2004, Stachowiak, 2004, Gurunnath and Bijwe, 2007, Granguly and George, 2007, Ibhadode and Daqwa, Mutlu, 2009).

Many of our modern technologies require materials with unusual combination of properties that cannot be met by the conventional metal alloys, such as ceramics and polymeric materials. This is especially true for materials that are needed for automobile applications. Nowadays, the objective of the automotive industries is to manufacture automotive component having the following qualities: low fuel consumption; convenience; safety; environmentally- friendly qualities; and maximum effecienciency (Farsani, and Shokuhfar, 2011).

Researchers all over the world today are focusing on ways of utilizing, either industrial or agricultural wastes as source of raw materials for the industry. These wastes utilization would not only be economical, but may also result to foreign exchange earnings and environmental pollution control (Bienia, et al, 2003), (Aigbodion, et al, 2010). Coconut shell is such an agricultural waste and is available in very large quantities throughout the tropical countries of the world. The coconut particles also have remarkable interest in the automotive industry owing to its hard-wearing quality and high hardness (not fragile like glass fiber),good acoustic resistance, moth-proof,not toxic, resistance to microbial fungi degradation, and not easily combustible(Singh and Bhaskar,2013). Currently the major base material for the manufacture of brake pad/lining systems in automobiles is asbestos. According to (Elakhame et al, 2014), asbestos has some few engineering properties that make it suitable for inclusion in brake linings. Some of these include its good sound absorption, resistance to heat, fire and affordability

In spite of its good properties asbestos is being withdrawn from all those applications where there is possibility of man consuming or inhaling its dust, because of its cacogenic nature (Lomash, et al, 2004). The use of asbestos has been suppressed afterwards, because of health implication (*Roubic et al, 2008*). Consequently, researchers have struggled to come up with efficient alternatives. Barites, mica, cashew dust, fly ash, ceramic fibre, are some of the materials that have been considered for use as fillers (Chan and Stachoneiak, 2004; Hee and Fillip, 2005; Mohanty and Chugh, 2007).

These observations and similar reasons stimulated interest in considering the use of coconut shell, coconut fibre and other agro-base residue as friction material in brake pad/lining. Hence the present work is focused on the use of alternative materials fornon carcinogenic brake pad/linings for automobiles and other industrial applications.

2.0 EXPERIMENTAL PROCEDURES.

2.1 Materials and Equipment.

A 20kg quantity of coconut shell experimental material for this work was obtained from local market in Kaduna central area. The material was cleaned to remove impurities and other contaminants. The shells were ground to powder in a conventional mill (*see photo2.0*) and was graded using a set of BS 410 standard sieves (Endecotts Ltd., London). The fractions retained on the 100m were used in the formulation (Gurunath and Bijwe, 2007).

Experimental materials for formulation in brake pad/lining can be selected from the following materials or agro-waste (residue): coconut shell/fiber (CS/CSF); palm kernel (PK), mild steel iron filings (MSIF), a binder, (Phenol resin powder) combined with other additives as shown in photo 2.0 (a, b, c,& d) and figure 1.

Photo 2.0 (a)

Photo 2.0 (b)

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Photo 2.0 (c)

Photo 2.0 (d)

The experimental material used in this research is coconut shell and any of the combination in the formulation. The coconut shell was ground to form coconut shell powder in a conventional mill. The grounded powder was graded using a set of BS 40 standard sieves placed in descending order of fines and shaken for 15 minutes which is the recommended period for complete classification (Endecotts Ltd, London).The fraction that was retained on the 100m sieve were used for the formulation (Gurunath and Bijwe,2007).

Equipment used in this research include Brinell Hardness Tester, Chapy Impact testing machine, Electrical resistance furnace,(Oven), Metallurgical Microscope, Mild steel mould, Hydraulic press, Beaker, Sieves, Venire caliper, etc.

2.2 Specimen Preparation.

The production of the specimen brake pad consists of series of unit operations including mixing, cold and hot pressing, cooling, post-curing, and finishing. The ingredient for the formulations are, coconut shell powder,(CNS),Brass, Graphite, Barite, Carbon black, Friction dust, Zinc oxide and Resin were blended for 15 minutes in a mixer until an homogenous component was formed shown in (Figure1, Photo 2.0 (a,b, c, & d).

A mould was prepared to the shape and curvature of a brake pad from a metal strip (made of a cope and drag). The coconut shell was crushed, processed in powdered form and mixed in a ratio 3: 1 after which a binder (synthetic resin solution) is measured and poured into the mixture. Following an effective mixing, the paste was rolled and lined in the mould to a length of 26cm along the curvature of the mould, cope, and then the drag was used to cover and pressure application. The mould was placed in an oven at a temperature of 100˚C and left for 35minutes for effective curing.

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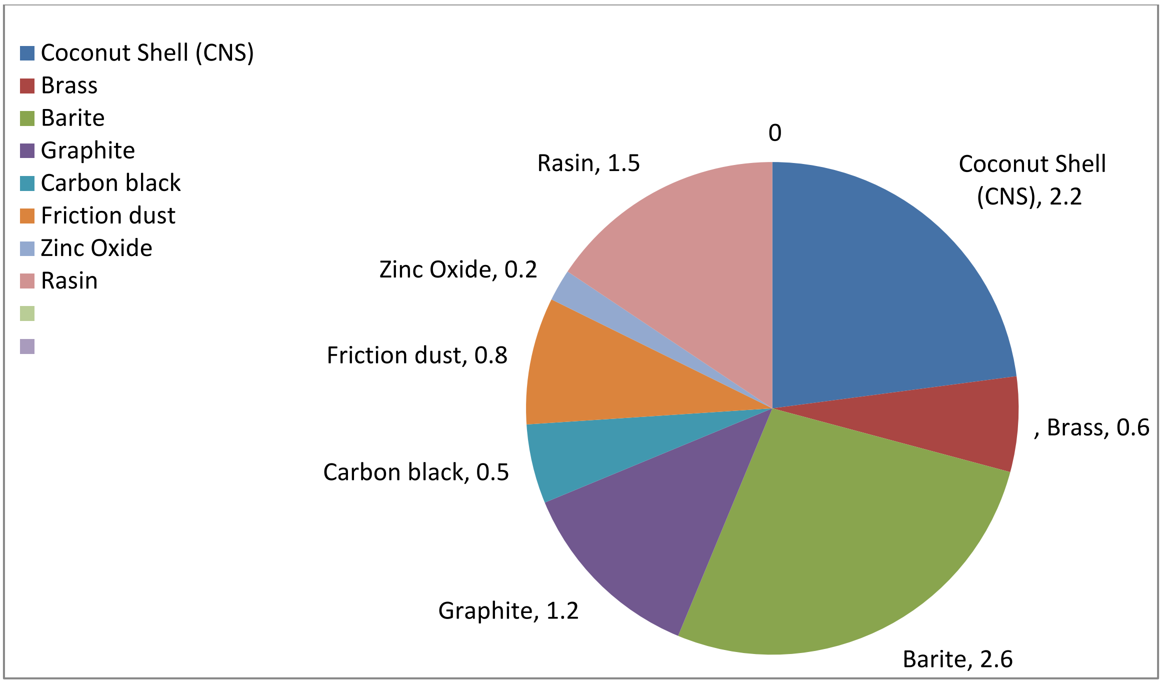

Figure 1: Consistent Ingredient used in the brake pad formulation.

2.3 Swell Growth Analysis

This performance standard specifies a universal method of measuring the dimensional change of friction materials to determine the effects of temperature. The test applies to both, disc and drum type linings commonly used in hydraulic and air brake systems for automotive or commercial vehicle applications. This standard describes two main test procedures. Method A, where the friction material is in contact with a heated surface to simulate the heat input to the pad that occurs during actual usage. Method B uses an oven to heat the freestanding material and is an approximate procedure requiring less instrumentation. Method A is recommended for disc brake pad assemblies, noise insulators, or flat coupons; while Method B is recommended for curved drum brake linings.

Dimensional stability of the friction composite when subjected to changes in temperature and humidity was quantified by measuring its percentage swell growth (*Chen et al 2006*), Adewuyi, (2008). The thickness of the sample before being introduced into an oven T_{bo} was measured with a venire caliper with an accuracy of $\pm$0.001mm. The temperature in the oven was stabilized at 250^0c and the sample, on a Steel tray, was kept inside the oven for one hour. The thickness of the sample after being withdrawn from the oven and allowed to cool at room temperature for 20minutes Tc, was noted. The percentage of Swell Sp, was computed as:

$$SP = \frac{(Tc - Tbo)X100\%}{T_{bo}} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (1)$$

Where,

Sp= Percentage of swell

T_{bo} = Thickness of sample before being introduced into an oven

T_c=Thickness of sample after being withdrawn from an oven

3.0 RESULTS AND DISCUSSIONS

The elemental composition of the C.N.S. particles is shown in table below. The result reveals that C.N.S. contains semi-metals and non-metals, this suggest the need to enrich the Coconut Shell (CNS) – based lining with metallic elements to improve the thermal conductivity.

The Coconut Shell (CNS) particle exhibited a bulk density of 560 $\pm$ 17.4kg/m^3 and a relative density of 1.26 $\pm$ 0.07. In comparison, the corresponding values for asbestos are 350kg/m^3 and 2.5. The higher bulk density of CNS particles implies that the particles are closely packed, which reduces the possibility of air infiltration, which may initiate cracks in the manufactured product. The lower specific gravity shows that the CNS based brake pad will be lighter than the asbestos brake pad. Consequently, CNS particles are more suitable as filler material than asbestos on the account of the overall weight of the brake pad.

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The observed thermal conductivity and specific heat capacity were 6.825w/mk and 1.98kj/kgk and the corresponding values of asbestos are 0.15w/mk and 1.59kj/kgk. Because high thermal conductivity is undesirable in brake pad, this suggests the need to improve C.N.S. particles for brake pad applications. Barite has been known for brake pad applications. (Chan and Stachowiak, 2004) and, an increase in its fraction in the formulation would inhabit conductivity of friction element on the braking fluid.

3.1 Thermal Gravimetric Analysis

The change in weight of the friction composites with increasing heating temperature was used to evaluate the thermal integrity of the brake pads. The size of test specimen was 20 x 20mm. each sample was kept in a mild Steel Crucible and heated in an electric furnace from 50 – 600^0c. The change in the sample's weight was monitored. At each observation when the set temperature was attained, a check time of 20minutes was allowed for even heat distribution into the sample. The weight losses at each observation were plotted against the temperature.

3.2 Tensile Test

The tensile test on the samples were conducted on tinus-Olsen tensile machine at stain of 2x10-3s-1 and the value od load agaist extension was recoerded and used to obtain a graph of he relationship.

Table1. TENSIL STRENGTH

Wt%	TS (N/mm^2
0	140.1
2	156.0
4	179.3
7	188.4
11	198.6
13	192.4

3.3 Impact Energy Test

The impact test was conducted using Avery Denison test machine and the precision of the machine was o-2 joules. The results were obtained as follows:

Table 2. IMPACT ENERGY

Wt %	(J)
0	14.02
2	14.00
4	13.77
7	13.00
11	12.11
13	12.00

3.4 Wear Test

A pin-on-disc test apparatus was used to investigate the dry sliding wear characteristics of the composites as per ASTM G99 standards. The test were conducted by varying applied load from 10N to 30N at a speed of 2.0m/s. Results obtained as thus

Table 3. WEAR

Wt%	10N	20N	30N
0	3.0	3.2	3.9
2	3.0	3.1	3.8
4	2.7	2.9	3.1
7	2.2	2.4	2.8
11	1.8	1.9	2.0
13	1.7	1.88	1.99

From table 1 – 3 it can be seen that as weight of coconut shell material increases, tensile strength, increases while wear rate and impact energy decreases.

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3.5 Bonding Effect

The bonding effect of coconut shell was from 24kg/cm3 to 26.5kg/cm3. The conventional brake pad made from asbestos material produced has bonding effect of 32kg/cm3. The disparity in these results is attributed to the choice of resin and compacting pressure used. Phenolic resin is the best binding agent for brake pad production, it decomposes at a temperature of about 450oC.

3.6 Scratch Hardness

The scratch hardness of the specimen and that of the lbeto product asbestos brake pad ranges from 80 to 85 using the durometer in the measurement of the hardness of the two brake pad material.The scratch hardness value obtained is due to the good strength property exhibited by reinforcing fibre and filler materials that were selected for this work

Table 1.Elemental Composition of C.N.S. Particles (chem. Lab Kaduna Polytech)

ELEMENTS	CONC VALUE	CONC ERROR	UNIT
K	34.3586	± 0.8308	wt. %
Ca	16. 0.318	± 0.5872	wt. %
Ba	2. 5319	± 0.0100	wt. %
V	2593	± 401	Ppm
Cr	6034	± 100	Ppm
Ma	2. 1327	± 0. 0100	wt. %
Fa	29. 2421	± 0. 0100	wt. %
Ni	4. 2829	± 0. 0100	wt. %
Cu	4. 5568	± 0. 0100	wt. %
Zn	2. 3982	± 0. 0100	wt. %
Se	5408	± 100	wt. %
Sr	3205	± 100	wt. %
Br	6328	± 100	wt. %

3.7. Physical characteristics

Images of the performs and finished coconut shell (CNS) based friction composite are shown in photo 3. The C.N.S based brake pad exhibits a bonding strength of 3375N/S compared to 5125N/S for asbestos-based, and a minimum of 2250N/S recommended by Standard Organization. The correspondingBrinell Hardness Number(BHN) for the three sources is 32.3, 44.2 and 27.0, respectively. The values for the C.N.S. sample though lower than for asbestos are within the limit recommended by Standard Organization of Nigeria (SON) (NIS 323, 1997). The C.N.S. brake pad shows a lower Swell and growth rate of 0.62% compared with 0.86% in asbestos based, and the maximum of 2.7% as used by Cheng et al, 2006).

Photo 3.0 (a) Perform of brake pad lining.

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Photo 3.0 (b) Shaping and grinding of the brake pad.

Photo 3.0 (c) Plate of perform and finished CNS-based friction composites.

3.8Physico-Thermal Properties of Pulverized Coconut Shell

Bulk density of the pulverized coconut shell was determined using the Mass/volume relationship (Fasina, 2008, Jain and bal, 1997), a graduated empty plastic container of predetermined tare weight was filled with the sample, by pouring from a constant height, striking off the top level and weighing.

The relative density was determined using a specific gravity jar, to divide the weight of the sample by the weight of water occupying the volume taken up by the sample. The jar containing a known weight of the sample was rapidly filled with water. The observed weight was then deducted from the weight of the jar when filled with water only.

The thermal conductivity of the sample was computed based on fourier law of heat transfer which is given as:

$$\frac{K}{\Delta t} = \frac{\Delta Q \times L}{A \times \Delta T} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where;

K = is the thermal conductivity;

ΔQ= the quantity of heat transmitted during the time

Δt = through a thickness

L = a direction normal to a surface of area

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A = due to a temperature difference

ΔT= under steady conditions and when the heat transfer is only on the – temperature gradient.

Sample of the pulverized material was placed in a cylindrical dish (90m diameter and 12.7mm high) on a hot plate, which had been pre-heated for 3 munites, the hot plate was disconneted from the power source and a thermocouple was used to measure the temperature at the bottom of the pan and also at the surface of the material contained in the pan. Thus, the variables required in the evaluation of equation (i) were determined.

The elemental composition of the coconut shell particle was determined based on the X-Ray flourescence (XRF) analysis.

Samples of the material were formed into pallets in a pelletizer with hydraulic press (Carver Inc.). The pallet were then sealed into the chamber of the X-Ray flouresence XRF (Amptek Inc.) and allowed to run for 1000s at a voltage of 25kv and a current of 50A. the resulting spectrum measured the elemental composition of the material.

The observed properties of coconut shell (CNS) were compared with those of asbestos to determined the variation in brake lining formulaion when replacing asbestos with coconut shell (CNS).

3.9Thermal Integrity

The mass loss of the C.N.S. and asbestos based friction composites are shown. In both materials, the mass losses were comparable but low, up to about 300^0c. Statistical analysis using paired comparison showed no significant difference in weight loss of the two composites over the range of temperature used. Typical automotive brake lining materials are rarely subjected to temperatures higher than 399^oc (Mohanty, 2007), George, 2007) but when such situation arises, it is not maintained for up to 90minutes used in the experiment. Therefore, it is believed that the C.N.S.-based brake pad will not decompose or deform under practical application temperatures and time duration. Comparison of effect of temperature on weight of Absestosanad C.N.S. Base friction composite are shown below.

3.10Comparison of Effect of Temperature on Weight of Asbestos of C.N.S Base Friction Composite

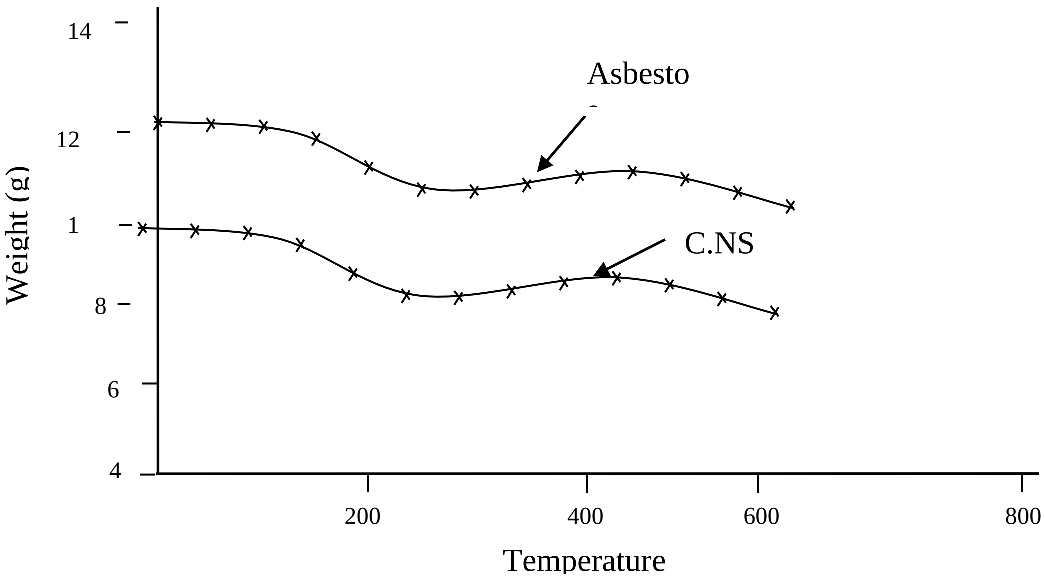

Fig 2: A graph showing comparison of Effect Temperature on Weight of Asbestos of C.N.S. Base Friction Composite.

3.11Wear Characteristics

Average value of wear detected in the C.N.S. and the asbestos based friction composite were noted. Wear rate for C.N.S. is lower than that of asbestos but both show similar trend. Regression analysis shows that the wear describes a third order polynomial relationship with run-in time. Wear rate for the C.N.S. brake pad is 9.17E-5g/min, while for the asbestos, it is 1.11E-5g/min. the Lower wear rate of the C.N.S. material may be due to its high abrasive properties compared to asbestos. This property is desirable in heavy truck brake lining where large braking force are involved (Blau and Jolly, 2008),furthermore, the C.N.S. could be modified for use in other classes of automobile.

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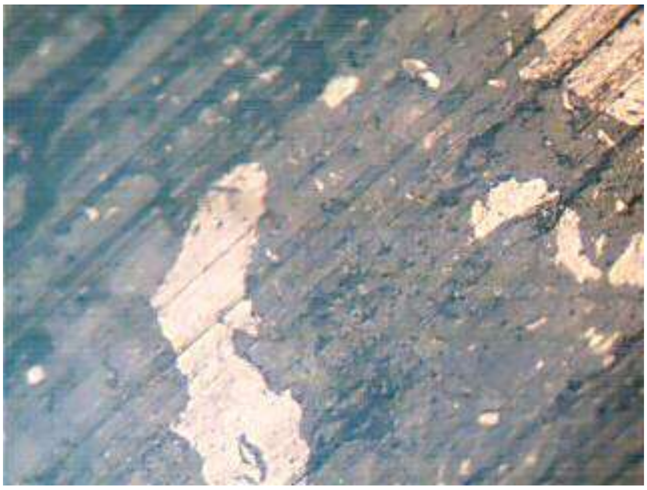
Figure 4.6 (a): CNS-based of unworn worn surface friction

Photo 4.6b **worn out surface** **Photo 4.6c**



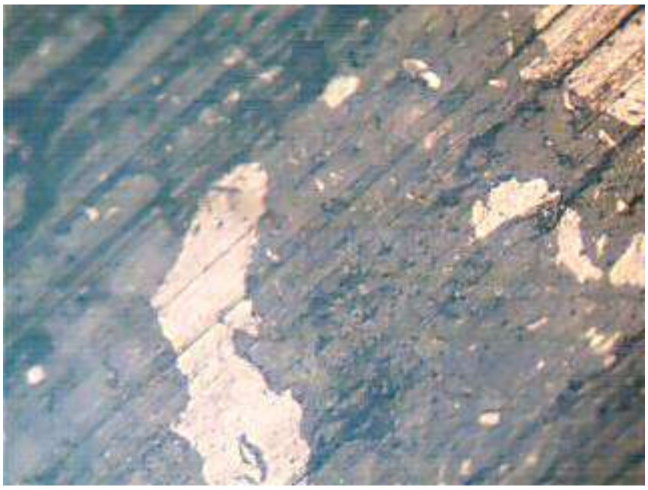


Figure 4.6 SEM Images of Worn out surface

3. 12 Characteristics of Friction Surface

The microstructure of the C.N.S. and asbestos based brake lining before and after wear test is shown in (photo.4.6 (b, c,). It is clear that before wear test takes place; it is easy to identify the various ingredients in the friction element. From photo.4.6 (a), C.N.S. Particles is surrounded by copper dust and other unidentifiable element. photo.4.6 (b, c,).presents asbestos fibers surrounded by many other ingredients too. Once wear takes place, the impact of friction on friction composites has a double character: alternative for phases on friction surfaces and damaging for friction surfaces; voids are generated after wear test on both surface of photos.4.6 (b) and 4.6(c). soft copper particles are plastically deformed and smeared, while this is not the case in C.N.S.-based Friction composites. See photo. 4.6 (a).

Grooves parallel disk rotation appears in both base materials. The interaction between the cast iron disk and the composite material leads to the creation of iron traces on the friction surfaces. This shows that the rotor has higher Vickers hardness than the friction composite; hence the use of C.N.S. like the asbestos does not degrade the surface of the brake disc

4.0 CONCLUSION

Based on the result of the experimental work carried out in the use of alternative materials for braking system of automobiles and other industrial applications, the following conclusions are drawn:

1. Coconut shell (CNS), mild steel iron filings (MSIF), a binder, (Phenol resin powder) combined with other additives were effectively used in the formulation for the manufacture of brake pad/lining of the braking system of automobiles.
2. From the experimental results obtained in this research, tests such as: bonding test, mechanical tests,ie, tensile test, wear test, Scratch hardness,brinell hardness(see 3.7 physical properties) impact test, and thermal analysis shows that coconut shell has a positive effect on the component produced.
3. The result also show that both the tensile strength increases with increase in the amount of coconut shell powder and also an increase in impact strength while wear reduces with increase in coconut powder.

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4. The methods and processes involved in the manufacture of brake pad using coconut shell and other ingredients in the formulation have been followed to produce a standard brake pad comparable to the commercial ones in the market.
5. The health hazard situation involved in the use of asbestos in brake pad formulation is extremely minimized.
6. The growth of cottage industry is a catalyst for industrialization as it forms the bases for accelerated industrial transformation.

RECOMMENDATIONS

The result of various tests carried out shows that the overall performance of the coconut shell (C.N.S.) in brake pad formulation is comparable with asbestos-based linings and is recommended for use in automobile brake pad/lining, since it is within the limits recommended by the Standard Organization of Nigeria (SON).
Further tests of this developed C.N.S based brake pads is being undertaken, therefore more research work in this area is recommended to produce coconut shell based automotive component for new generation vehicles.

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