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Reviews in Automobile Brake Pads Production and Prospects of Agro Base Composites of Cashew Nut Shells and Nigerian Gum Arabic Binder.

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***Abstract*:** The reviews of automobile brake pad production processes, formulations, materials, and properties revealed most works attempt mainly on replacing asbestos found to be carcinogenic with base materials with other ingredients in various formulations and particle sizes. The overview of these trends suggests the need to replace not only the asbestos but also the commonly used epoxy resins or phenolic resins or phenol formaldehyde binders that has been found to corrode outside plates of brake assembly. Therefore, this paper thrust a new research direction of replacing the asbestos and inorganic resins with agro based materials of Cashew Nut Shell and Plant Gum binder respectively to obtain a substantially green based brake pads that are non-injurious to human health and does not corrode any parts of the brake pads assembly. Taguchi design of experimental method was deployed to formulate twenty seven (27) different formulations with the help of Minitab Software approach. The particle size of the compositions was 300µm and the produced composites have favourable properties such as BHN, Compressive Strength, coefficient of friction, wear rate and very high ash content retention suggesting good thermal capacity of the brake pads. The values obtained respectively are 76.66BHN,12.187N/mm2, 0.4848, 1.16mg/m and 97.71%.
Keywords: Brake pad, Composites, Compositions, Cashew Nutshell, Plant Gum binder

1. Introduction

The automobiles brake pad composites are steel plates backed and are the friction materials that grip the disc of the wheel assembly. They are in the assembly to continuously clamp and hold wheels to slow down or completely stop their motion [1]. The function is to regulate the speed of moving automobile as it convert the kinetic energy to thermal energy by friction and sending the heat produced to the surroundings. Most of the automotive brake pads available in the market are either classified as metallic, semi-metallic or non-asbestos organic (NAO) materials [2]. Friction materials include binders, structural materials, fillers and frictional additives. Those containing metal powders are called semi-metallic friction materials while those of asbestos are called asbestos friction materials. Those without asbestos are referred to as asbestos-free non-asbestos friction materials.

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 [3].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 [4].According to Idris et al.,[5] brake pads generally consist of asbestos in the matrix along with several other ingredients. Uses of palm kernel shell, palm kernel fiber and other biomass precursors have been investigated [6].Because of the carcinogenic health challenges asbestos based brake pads posed to workers and users, countries like USA, UK, Colombia, Japan, China and other countries have banned the use of it as friction material [7].The present trend in research for asbestos-free brake pads is to use industrial or agricultural waste (agro-waste) as a raw material source for composite development. Recently, international efforts to address environmental issues and the need to protect the environment has drawn research focus to the use of natural fibers in several applications, including brake pads.The use of asbestos is being avoided because of its health implications such as carcinogenic and harmful nature [7],[8-11]. Asbestos have long been known to cause lung and other cancerous diseases [12].Consequently, numerous trends in researches have been on to discover human friendly material replacements for asbestos portions and that of the binders in engineering components such as automobile brake pad that is intended after this review. There is also the international efforts to use environmentally friendly [13] and non-hazardous natural fibers [14] and biomasses for the various application and replacements especially on brake pad production. The effectiveness and performance of brake pads are absolutely dependent on the frictional material used in the process of its manufacture [15]. In addition, composite materials have evolved that synthetic fiber reinforced composites are obtained from cost-effective and potentially eco-friendly materials for for use in various parts of an automobile.The many advantages of abudance, comfort and cheap cost of natural fibers for industrial use thrusted researchers to study their suitability in producing polymer composites for tribological and other applications [16].Over the years, the production of composite materials worldwide has grown significantly, which means many industries and technology sectors now use the newly formulated polymer composites materials which have successfully replaced traditional composite materials [17].

The investigation of new materials, especially agro-waste, has led to the development of new and low-cost options for the development of brake pads which are commercially viable and environmentally acceptable, including all the properties required. Therefore, Agro-biomass (Agricultural residues, plant and animal wastes products) have now emerged as the trending materials that is used to produce brake pads that are commercially viable and environmentally acceptable [18-22] .It was reported by Cyras et al.,[23] that lignocellulosic fillers of any agricultural products have become choice filler materials for polymers because of its good properties. It has been revealed thta changes in the percentage weight and types of component composition in the formulation may alter the chemical,mechanical and physical properties of the brake pad materials developed[24-27]. Researchers especially the early ones concluded that no simple correlation exist between friction and wear properties of frictional materials with the physical and mechanical properties [28-30].New formulations developed are required to be subjected to several tests to evaluate its friction and wear properties ensure that the brake pad material meets the favourable requirements [28].

2. Properties of alternative Automobile Brake Pad Materials and Composites

The trending issues with researches all over the world today is focused on acheivable ways of utilizing either industrial or agricultural wastes as a source of raw materials in the industry especially the replacemnent of asbestos and inorganic resins in brake pad production.These utilization of wastes will not only be non hazadous and economically profitable, but may increase foreign exchange earnings and environmental control. Researches such as Ibhadode and Dagwa [11]and Deepika et al.[4], have developed and investigated a non–asbestos– friction pad material using an agro –waste material base of palm kernel shell (PKS) as a reinforcement material. Their reason for the selection palm kernel shell was because it exhibited more favourable properties than the other agro–waste they investigated. Researcher like Bashar et al.[31] with other researchers including Aigbodion et al.[1], and Ruzaidi et al.[32] have developed brake pad from that is non–asbestos using shells of coconut, banana peels(bagasse) and ash from palm respectively as material reinforcements.The results obtained in these studies showed the suitability for commercial brake pad alternative. As a result of so many other work carried out,Naemah [34],Lee and Filip [35] and Matějka et al. [36], suggested that comparable materials for brake pads must meet these criteria:

(a) It is safe for use and must be environmentally acceptable.

(b)The materials has to exhibit good wear resistance.

(c) High thermal conductivity and heat capacity, as comfirmed by Lee [3

(d) It should be able to withstand higher contact pressures.

(e)High frictional coefficient of the material.

(f) Frictional stability over range of temperatures and pressures range.

(g)Good environmental resistant from dust, pressure and moisture.

(h) The material should possess excellent frictional force and shear strength.

Two authors named Blau [38] and Bashar et al.,[32] investigated and observed that additives for brake pad and other compostions can alter the end results of the friction material. Therefore, the formulation and control of the composition is of great important in brake production. Blau [38] further stated that friction materials and additives are classified into:

(a) Reinforcement and fillers materials.

(b) Abrasives,

(c) Friction modifiers, and

(d) Binders.

Most of the trending materials are fibers derived from agricultural-waste with economic significance and cultural impact throughout the world [39]. These fibers have great potential as composite materials in brake pad production because of their low cost, availability, high strength, eco-friendly in nature, and sustainability [40, 41]. Fibers obtained from agro-waste have properties with potential for industrial application especially in brake pad production. This have led to a great deal of researches on how to channel them to useful materials while taking human health and environmental safety into consideration. The use of organic waste and residual materials which are best classifies as agricultural materials or biomass in polymer composites represents an eco-friendly and significantly high-value substitutes [42]. According to Jawaid [40],these agricultural wastes are found in many plants such as palm tree, bamboo, corn stalks, sugarcane bagasse, coir (coconut shell), cashew nutshell, pineapple, banana, rice husk, rice straw and plants (stem, leaf, seed, fruit, stem, grass, reed) .It is believed that minutes quantities up till 10 percent of the potentials of these natural fibers are being used and harnessed as alternative raw materials for industrial uses while most common applications are in bio-medical, bio-composites, automotive parts, and others [43]. The most widely tested and importantly used fiber waste produced by agricultural activities are cellulose fibers (CF) with the potentials to enhance materials availability, lightness in weigh, renewability, degradable, low abrasive properties, and low cost [40, 41, 43]. Cellulose fibers (CF) occurs in with other materials such as hemicelluloses, pectin and lignin [21]. Agro-waste is the most abundant form of natural fiber and has been used in many areas of modern industry believed to vary in relation to conditions of growth and harvesting [44].

The need to understand the properties of the fibers for composites necessitated researchers to investigate the chemical compositions, mechanical properties, structure, physical properties and dimension of cells. These properties are believed to vary widely among different species and among same plant [45].

2.1 Chemical Properties

In a report by Kumar et al. [46], agro- biomass consists of hemicellulose, cellulose and lignin and some quantity of protein, pectin, and ash. Cellulose offers stiffness, strength, and structural stability to the fiber and maintain the structure that serves as a determining factor in its mechanical properties. Hemicellulose which is a form of branched polymer that is amorphous in nature. Lignin is a linked formed with hemicellulose in agricultural plant`

cells that has tendency to resist decay in agricultural materials [47]. As reported by Jawaid [48], the composition, properties and structure of agricultural biomass depend on the age of

the plant, conditions of the soil and other environmental factors which include humidity,

stress, and temperature. These polymer characteristics of fibers affect their functionalities and properties [49].Table 1 highlights the chemical properties of some selected agro-materials used as alternative materials for composites.

Table 1. Chemical Properties of selected Agro-materials for Composite [50]

Type of biomass	Composition (%)				
	Cellulose	**Extractive**	**Hemicellulose**	**Lignin**	**Reference**
Sisal	43.85-56.63	2	21.12-24.53	7.21-9.20	[51]
Oil palm	44.20-49.60	4	18.30-33.54	17.30-26.51	[48, 52]
Kapok	65.63-69.87		6.66-10.49	5.46-5.63	[53, 54]
Bamboo	73	3	12	10	[55]
Corn stalks	38.33-40.31	5	25.21-32.22	7.32-21.45	[50, 56]
Banana	60.25-65.21	-	48.20-59.2	5.55-10.35	[57, 58]
Abaca	69.23-70.64	-	21.22-21.97	5.15-5.87	[59]
Sugarcane (Bagasse)	55.60-57.40	10	23.90-24.50	24.35-26.30	[51, 60, 61]
Pineapple	70.55-82.31		18.73-21.90	5.35-12.33	[62]
Flax	69.22-71.65	6	18.31-18.69	3.05-2.56	[51, 59]
Kenaf	37.50-63.00	6.4	15.10-21.40	18.00-24.30	[59, 63, 64]
Jute	69.21-72.35	4	12.55-13.65	12.67-13.21	[51, 59]
Rice straw	28.42-48.33	17	23.22-28.45	12.65-16.72	[56, 65]
Coconut (coir)	36.62-43.21		0.15-0.25	41.23-45.33	[66]

2.2 Physical and Mechanical Properties

Properties both physical and mechanical of brake pad alternative materials could be very important because of their allied nature to the structure of fibers. Biomass fibers are largely natural organic fibers that exhibit high variability in different properties. Yan-hui et al., [67] and Cicala et al., [68] discussed these physical and mechanical properties of composite fiber to have depended highly on the growing conditions, extraction methods, chemical composition and its ratio. These properties are strongly affected by their individual material, with such important role in the selection of such materials for multidisciplinary applications such as brake pad production. The important variables according to Khalil et al. [69] are fiber structure, cell dimension microfibril angle, and defects. John and Thomas [70] in their finding, stated that source, origin, species and maturity of fiber are determined by the size of a single cell. Structural properties such as fiber length, fiber width and cell wall thickness determine of the fiber determine the tensile strength, tear strength, drainage, adhesion and stress distribution of the product derived [71, 72]. In the same vein, the lumen structure has been reported to have significant effects on the bulk density of fibers which is determining factor of the thermal conductivity and acoustic property of the end product [73]. The mechanical properties of natural fibers are affected by many factors such as fiber bundles or ultimate fibers as shown in Table 2 showing the physical and mechanical properties of selected biomass fibers.

Table 2. Mechanical and physical properties of some selected agro based materials

S/No	Types of fiber	Elongation at break (%)	Young's modulus (GPa)	Density gm^{-3}	Tensile strength (MPa)	References
1	Flax	2.70-3.6	50-70	1.27-1.55	500-900	[74] [75]
2	Oil palm	2.13-5.00	2.7-3.2	0.7-1.55	227.5-278.4	[71]
3	Corn stalks	1.90-2.30	4.10-4.50	0.21-0.38	33.40-34.80	[76]
4	Jute	1.69-1.83	20-50	1.3-1.45	300-700	[77] [78] [74]
5	Abaca	09-Nov	38-45	1.42-1.65	879-980	[77]
6	Banana	1.21-3.55	3.00-3.78	0.65-1.36	51.6-55.2	[79] [80] [81]
7	Kapok	1.20-1.75	4.56-5.12	0.68-1.47	80.3-111.5	[82, 83]
8	Rice straw	2.11-2.25	24.67-26.33	0.86-0.87	435-450	[84] [85]
9	Sisal	4.10-4.3	Oct-30	1.45-1.5	300-500	[77] [78] [74]
10	Bagasse	6.20-8.2	15-18	0.31-1.25	257.3-290.5	[62, 86]
11	Kenaf	1.56-1.78	23.1-27.1	0.15-0.55	295-955	[87, 88]
12	Bamboo	4.0–7.0	22.2–54.2	0.6–1.1	360.5–590.3	[89]
13	Pineapple	2.78-3.34	5.51-6.76	1.25-1.60	166-175	[90]
14	Coconut (coir)	27.21-32.32	4.0-6.0	0.67-1.15	173.5-175.0	[90] [91]

An important physical property of composites is the density, while modulus and tensile strength measure the mechanical properties of a single fiber. Development of agro based biomass in the biomaterial and polymer composite manufacturing are very important [92, 93]. From the literatures reviewed, biomass fibers from agro based material are found to have good potential as filler/enhancement material in polymer composites such as brake pad composites.

In various research attempts to replace asbestos with agro-based material in brake pad production for carcinogenic health concern, the need to improve the qualities and properties of emerging brake pad products, many researchers have adopted many material selections, Composition /formulations, processing and various optimization methods. Still on the quests to find suitable agro-allied material composite that could replace asbestos from brake pads, Osarenmwinda and Nwachukwu [94] produce composites from agro waste of sawdust and palm kernel. The particle size of the composite produced was 300 μm with urea formaldehyde binder of 20% of the oven dry weight. The properties evaluated were thickness swelling of 24hr immersion, 24hr immersion in water absorption ,modulus of elasticity, hardness, modulus of rupture, density, yield strength and ultimate tensile strength and internal bond adopting the European Norm (EN) specifications EN 310,317 and 319 [95,96,97].This work was taken further by Lawal *et al*.,[98] on the attempt to use ssawdust particles sieved into three different grades with other inorganic ingredients for the production of the brake pads with good properties.

Most of the materials used are natural fibers from plant, animal or mineral fibers [48].A researcher named Bledzki [99] listed shells, seeds, barks, stems and leaves as natural fiber materials.With these background, a review of some of the trending works would further widen the reseach gap in the quest to improve quality and properties of brake pads as dicussed below:

2.3 Palm Kernel Shells Based Brake LiningQuite a number of researchers have attempted to use either Palm Kernel Shells (PKS) as shown in Figure 1a, fibers (Figure 1b) or slag to replace asbestos as filler or base material/reinforcement materials in the formulation. In the work of Deepika *et al.* [4] on the fabrication and performance evaluation of a composite material for wear resistance application, PKS was used as filler material with sulphur with other brake pad materials such as, calcium carbonate, quartz, iron ore, brass chips, ceramics, cashew nut shell liquid and carbon black. The particle size of the formulation of the pulverized filler was 125µm. The performance of PKS were found to compare closely with asbestos brake linings under different inertial and speed conditions. A developed brake pad materials by Fono–Tamo and Koya[100] for automobile following standard procedures from PKS showed comaprable quality results in properties compared to the comericially produced brake pads.Their results show 40.95Mpa shear strength of and hardness of 32.34Mpa repectively with appreciable coefficient of friction of 0.43. These results were in tandem with the reported findings from the work of Fono–Tamo and Koya [101] which gave frictional coefficients of between 0.37 to 0.52 though (Roubicek *et al.*,[7] suggested friction coefficient range of between 0.30 to 0.70.


Figure 1a: Palm kernel Shell[102]


Figure 1b: Palm kernel fiber [19]

The feasibility of using PKS agro–waste material by Ibhadode and Dagwa, [31] to replace asbestos in brake pad production was also quite favourable.The optimal manufacturing variables and composition formulation was acheived via Taguchi optimization techniques.The moulding temperature,pressure, moulding temperature, curing time and heat treatment time adapted were 150–170oC, 16.74–27.90 Mpa, 6–10 minutes and 1–3 hour respectively. The formulation of the various compostions used in percentage weight of reinforcement, abrasives,binder and friction modifier are respectively 56,14, 24and 6. The produced brake pads were tested and the results were in close agreement with the asbestos based brake pads.The characterization obtained are surface hardness 64 to 89HRB with the frictional coefficient falling between 0.44 to 0.35.The rate of wear was between 0.017 to 0.170 aligning with a report high wear rate at vehicular speeds beyond 80km/hour.The properties tested were satisfactory replacement alternatives.

Also devoloped using palm kernel fibers and other brake pad constituent materials were those efforts of Ikpambese *et al.*,[19].The Palm kernel fibers were prepared and the oil were removed with sodium hydroxide over a period of 24 hours after which it was washed with water and left to dry for a week. The epoxy resin used were varied in the formulations and the properties such as physical, morphological and mechanical were investigated to examine the charecterization and effects of the various composition. They reported that paremeters such as coefficients of friction, temperature, rate of wear,time of stopping and level of noise of the product increased speed increases while surface roughness, specific gravity, porosity, hardness, percentage content of misture, water and oil absorption rate were stable as the speed get higher.The report concluded that the formulation with 40% epoxy–resin along 10% of palm wastes, 15% of calcium carbonate ,6% of Al_2O_3,and 29%

of graphite indicated the satifactory properties and hence palm kernel fibers can be another good replacement of asbestos in brake pad production.

Another investiaged reported work on brake pad production using Palm Kernel Fibers (PKF) was carried out by Achebe et al.[21].The PKS was used to replace asbestor as filler base material with epoxy resin binder in formulation with other ingredients with three sets of formulations made in the study. The standard materials, procedures, and equipment were used to ensure suitable results. The properties of the sample C was characterized and reported that the 40 % PKF compostion has 178 Mpa hardness, compressive strength obtained as 96.2 MPa, the specific gravity 1.8 g/cm^3, abrasion resistance was 1.67, water absorption 1.86% and oil absorption 0.89% .These results were of best performance rating that compares favourably with other studies.The hardness, wear resistance and specific gravity of the composite brake pad were increasing as the filler content increased, while oil and water absorption decreased with an incressing filler content.

Using **palm slag** as base material with phelnolic resin binder along calcium carbonate ($CaCO_3$) and dolomite, Ghazali *et al*.,[103] examined properties which included the hardness, compressive strength and wear behavior of the new composite. The results showed that in the composite formulation used to produce the brake pads, palm slag has great potential to replace existing fillers .Ghazali et al. [104] with the palm slag as filler material reported a higher performance of between 50 °C to 1000 °C in thermal conductivity as compared with other material inputs. Samuel *et al.*,[105] using different particle grades(100 µm, 350 µm, 710 µm and 1mm) of PKS developed an asbestos-free brake pad.The formulation varied PKS compostions from 35 % to 55 % of PKS with 20 % of resin, 10 % of graphite, 15 % of steel, and 20 % of SiC and the processing method used was compression molding.Investigation of all the properties revealed 100 µm samples of Palm Kernel Shells offered better properties.

Efforts by Mgbemena et al. [106] from pulverized PKS as base filler material and metallic fillings as abrasives wth Phenolic and alkyd resis binders. The properties of the newly developed samples of friction lining material were investigated. It was established that the pulverized PKS-based brake friction lining has better thrmal properties with high wear rate of 0.24 µm and high char content as compared to Original Equipment Manufacturer (OEM) brake lining materials which has a wear rate of 0.16 µm. Some researchers in attempt to improve and investigate the properties of the brake pads mixed Palm Kernel related materials with other plant and or animal agro-based materials.Some of these work were done by Mayowa *et al*.,[102] that produced and investgated a developed brake pad from friction materials of PKS and cow bone particles.Different Particle sizes of 120 µm and 100 µm was used with formulation 30% PKS and Cow Bone mix while 60 % of binder(epoxy resin) and 10 % of hardener were used. They reported a decreased density as the particle sizes increases while the higher particle size samples has an increased impact strength than the finer ones. Cow bone composite was also reported to absorbed more water than PKS composite.The thermogravimetric analysis (TGA) observation revealed a percentage weight loss increasing with the temperature from 200° to 500° with increasing sieved size of the sample. In the same vein, Adeyemi [107] produced brake pads composite from mixed Maize Husks (MH), Cocoa Beans Shells (CBS) and Palm Kernel Shells(PKS) using epoxy resin as binder.The physical, mechanical and tribological properties were investigated revealing the abrasion resistance, friction coefficient, and water soak decreasing as the matrix percentage weight formulation is increasing.The compressive strength and tensile strength increased with increasing matrix percentage weight formulation while the density, hardness, thermal conductivity, and oil soak varied inconsistently.The property of the matirx compared well with single fillers as well as the commercial ones.

2.4 Coconut Shells (CS) and Coconut Fiber Based Friction Lining

Bashar *et al.* [32] in their contributions used coconut shells shown in Figure 2 to replace asbestos to produce based brake pads. The formulation consists of other ingredients coconut shells powder as filler, epoxy resin binder, reinforcement of Iron chip, methyl ethyl ketone peroxide as catalyst, cobalt nephthanate as accelerator iron and silica as abrasives and brass as friction modifier.

Figure 2: Coconut Shells (Abutu *et al*., [108])

Figure 3: Coconut Fibers [109]

The percentage weights the coconut shell powder and epoxy resin binder were varied while other igredients such as friction modifier, abrasives, catalyst and accelerator have their percentage weight kept constant as shown in Table 3.

Table 3: Percentage compositions of different samples (Source:Bashar *et al*.,[32]).

S/No	Constituents	Comp 1	Percentage Composition (%) Comp 2	Comp 3	Comp 4	Comp 5
	Matrix	20.00	30.00	40.00	50.00	60.00
1	Reinforcements	10.00	10.00	10.00	10.00	10.00
	Filler	50.00	40.00	30.00	20.0	20.00
2	Catalyst	0.50	0.50	0.50	0.50	0.50
	Accelerator	0.50	0.50	0.50	0.50	0.50
3	Abrasives	10.00	10.00	10.00	10.00	10.0
4	Friction Modifiers	9.00	9.00	9.00	9.00	9.000
	Total	100.00	100.00	100.00	100.00	100.0

The sieve size of 710µm was used to pulverized the filler with the conclusion that the higher the percentage of the ground coconut powder, the lower the breaking strength, compressive strength, hardness and impact thus high percentage of ground coconut powder induces brittleness. The composites which are a cold worked has properties compared with the Honda commercial brake pads of the Enuco model suggesting suitability of the materials selected. Figures 3 and 4 show comparison of some properties of Bashar *et al*. [32] work with the commercial model.

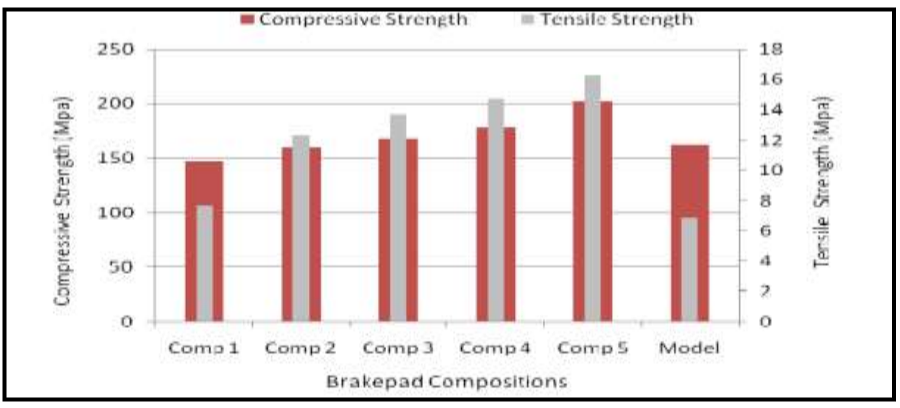

Figure 4: Comparison of compressive and breaking strength for the different compositions and model (Bashar *et al*.,[32])

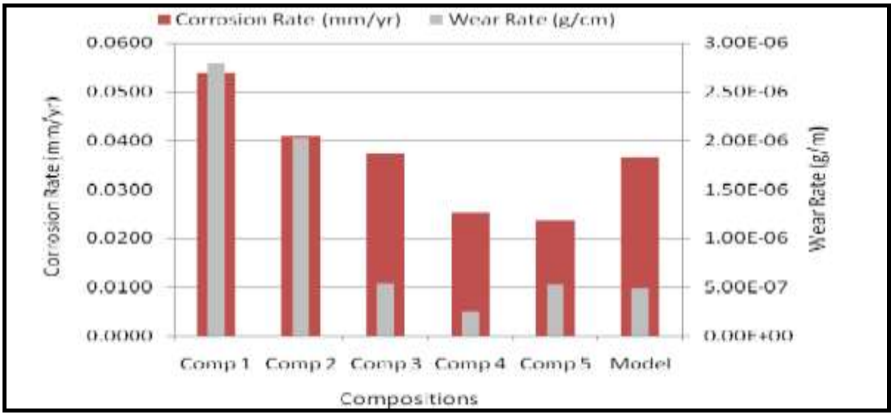

Figure 5: Comparison of wear rate for different compositions and model (Bashar *et al*. [32]).

The efforts of Darlington et al. [9] with three different samples of brake pads varying mass compositions of coconut shell powder and PKS produced results showing the properties of the newly developed samples with a density between 2.55 g/cm^3 and 2.78 g/cm^3,the wear rate of between 0.2007 g/min to 0.2733 g/min, the absorption of water of between 0.0399% to 0.0522 % and, the hardness was between 3.00Mpa and 3.41Mpa.Though the density and wear rate were high when compared with the commercial brake pad,but the study concluded that for environmental convenience,it could be used to substitute asbestos because of the carcinogenic health challenges it poses.In the report by Bahari *et al*.,[110], dried coconut husks (Figure 4) were used as the filler material with phenolic resin as the binding material.The 10 % and 30 % of coconut husk particles with size 80 mesh and 100 mesh paremeter were adapted and investiagted. The friction coefficient and characteristics of the heat resistance investigated showed that the brake pads with 100 mesh and 10 % coconut husk particles composition had the highest coefficient of friction while the 100 mesh and 30 % of coconut husk dust showed the highest decomposition temperature which increased the thermal stability due to the high proportion of the coconut husk particles in the composition.These results imply that the brake pad from coconut husk particles had better heat resistance than commercial brake pads.

Maleque et al. [109] in their investigation, of different compostions namely BP1, BP2, BP3 and BP4 varied from 0, 5, 10 and 15 volume friction.Using a metallurgy technique,the coconut fibers as filler material reinforced with aluminum composites bound with phenolic resin with properties such as density,microstructural analysis,porosity and hardness determined with densometer, Scanning Ellectron Microscopy (SEM), hardness tester and universal testing machine. The properties of the sample with 5 % (BP2) and 10 % (BP3) of the coconut fiber composites improved with lower porosity, higher density, and higher compressive strength indicating that the 10 %coconut fiber had the best strength to bear the load applications and compressive force. The microstructure show an uniformly distributed resin and coconut fiber in the matrix.

2.5 Periwinkle Shell Based Brake Pad

Periwinkle shells as shown in Figure 6 was used to replace asbestos in brake pad production by Yawas, *et al*.,[111].In this work, non-asbestos brake pad of periwinkle shell materials was developed and its properties characterized.

Figure 6: Periwinkle Shells [108]

The formulation included powdered periwinkle shell, engine oil, water and phenol formaldehyde was used as the binder.The periwinkle shells were grounded and particulated into five sieve sizes of 710 µm, 500 µm, 335 µm, 250 µm, and 125 µm while the binder used was 35% phenolic resin.The reports indicated that five different brake pads were produced by compression moulding at a processing 40 kg/cm^2 pressure at 160^{o}C moulding temperature and a curing time of 1.5 hours. All the samples were reported to have been subjected to standard procedures of brake pad production and post cured with the summary that the periwinkle shell particles homogeneously distributed as the sieve sized decreases.

The hardness compressive strength, and density of the produced brake pad samples increases as the particle size decreases from 710 µm to 125 µm while the wear rate,oil absorption and water absorption rate decreases wth a decreasing particle size. The results futher concluded that the 125 µm particles size compared well with the commercial brake pad with the optimal values of 1.01g/cm^3 specific gravity,0.41 value of coefficient of friction,116.7HRB Hardness,Compressive strength 147 N/mm^2, and 0.39 % swell in water and 0.37 % swell in oil. Aku *et al.*,[112] and Yakubu *et al.*,[113] used periwinkle shell (Figure 6) as asbestos-free brake pad material and the results indicates suitabilty in the asbestos repalcement research drives.While Aku *et al.*,[112] uses spectroscopic and wear analysis to investigate and characterize the products, Yakubu *et al.*,[113] carried out the experiment using X-Ray Diffractometer (XRD), Thermogravimetric Analysis (TGA/DTA), Fouriertransform Infrared Spectrometry (FTIR), and X-Ray Fluorescent Spectrometry (XRF).

2.6 Kaolin Mineral, Ceramic and Fly Ash Based Brake Pad

To further widen search for asbestos replacement, Aderiye [114] in his research work carried out a study on kaolin clay from Emure Local Government Area, Ekiti State of Nigeria. The clay was examined, beneficiated, characterized and processed for automotive brake pad material. The results as reported revealed that kaolin clay group with good heat resistance is a good friction based material in automobile industry, refractoriness, electronic products, technical works and ceramic manufacturing industries. Thermal property of kaolin samples was investigated between 1000 to 1400^{o}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. It was reported that 45 micron kaolin was eventually adopted as the fillers in the waste glass matrix composite for the automobile brake pad experimentally developed. The result showed that kaolin grain sizes higher than 45 microns depressed the quality of kaolin required for the ceramic brake pad biding and filling.

Fly ash as shown in Figure 7 is a finely divided residue that is obtained when Coal (pulverized) is combusted and transported by exhaust gases by a particle filtration equipment such as electrostatic precipitators before the flue gases reach the chimneys of coal fired power plants. Though the generated waste poses a great environmental concern Anushree & Alka[115], Natarajan *et al.*,[116] was still able to used the fly ash as one for brake pad production investigating the effect of the various composition on the mechanical and tribological properties of different brake pad materials.

Figure 7: Fly ash (Source: Natarajan *et al.*[116]).

Fly ash is composed of significant quantity of calcium sulphate, silica, alumina, and un–burnt carbon ranged 10-60% as the filler material for the brake pad production and aonther formulation without the fly ash.These work studied the effect of the ingredients on the tribological(coeficient of friction and wear) and the mechanical properties of different brake pad materials indicating coefficient of friction of the fly–ash in the range of 0.35 to 0.48 and better than the barites based (which do not contain fly–ash) and asbestos based brake pads. The wear resistance of the friction material was reported to have been greatly influenced by the amounts of rockwool, zircon, ceramic wool and a solution of calcium hydroxide in the samples while the presence of terraces (potassium titanate),friction dust powder, and wollastonite ($CaSiO_3$) influence in strong term the frictional coefficient of the brake pad.Likewise,the presence of para-aramid fiber and glass fiber increased the strength of the friction material.

Zaharudin *et al.*[27] in their attempt, used a semi-metallic ceremic friction materials along other compostiuon as shown in Table 4 to produce another asbestos free brake pad via powder metallurgy method.

Table 4:Ingredients of the Compostion Formulation [27].

Ingredients	%Weight	Ingredients	%Weight
Steel fiber	20.0	Iron oxide	8.0
Ceramic Fiber	10.0	Magnesium oxide	3.0
Friction dust	8.0	Copper chip	10.0
Iron powder	5.0	Barium sulphate	5.0
Phenolic Resin	12.0	Calcium carbonate	4.0
Rubber	3.0	Graphite	12.0

This study investigated and optimized process parameters namely moulding temperature moulding,pressure, and moulding time deploying the Taguchi desigh of experimental design. Properties evaluated included hardness, specific gravity wear and fade.The investigation revealed that the moulding pressure determine most of the properties.

2.7 Banana Peels Based Brake Pad

Another authors Idris, *et al.* [5] in their research work produced brake pads using banana peels both carbonized and uncarbonized as shown in Figures 8a, b and c with phenolic resin. The binder was varied at 5 % by weight interval from 5 to 30 % weight

Figure 8a: Banana Peel

Figure 8b: carbonized (BCp)

Figure 8c:un-carbonized (BUNCp)
(Source: Idris *et al*., [5]).

The study investigated the various properties showing that as more resin were added, the hardness, specific gravity and compressive strength were increasing as well. The water soak, wear rate and oil soak decreased as the resin weight increased. The 25 %weight sample un-carbonized (BUNCp) and 30 % weight of the carbonized (BCp) were of better properties. They concluded that:

(a) Better bonding of the un-carbonized particles with 20% resin and the carbonized banana peels with 30% resin didn't produce high bonding.

(b) As more resins are added, compressive strength, hardness, specific gravity increased while the oil soak, water soak and wear rate decreased as more resins were added.

(c) The 25% un-carbonized samples and 30% carbonized samples have the better properties as summarized in Table 5.

Table 5:The Properties of Banana Peels Based Brake Pads [5].

Properties	Commercial brake pad asbestos based	Banana Peels Carbonized at 30% Resin	Banana Peels Uncarbonized at 25% Resin
Wear rate (mg/m)	3.80	4.67	4.15
Coefficient of Friction	0.30–0.40	0.35	0.40
Hardness Values (HRB)	101.0	71.6	98.8
Specific gravity (g/cm^3)	1.89	1.20	1.26
Thickness Swell in Water (%)	0.9	3.0	3.21
Thickness Swell in SEA oil (%)	0.30	1.12	1.15
Flame Resistance (%)	Charred ash 9%	Charred ash 12%	Charred ash 24.67%

2.8 Egg Shells (EG) Based Brake Pad

Edokpia *et al.*, [117] used Egg Shells (EG) as asbestos replacement in developing brake pad samples for its eco-friendly and biodegradable properties. In their work, a plant gum binder called Gum Arabic (GA) was used and the properties of the braked pads evaluated. The Egg Shells and Gum Arabic were alternative additives for asbestos and formaldehyde resin respectively which have always been found to be carcinogenic in nature and non-biodegradable. The composition of the Gum Arabic was varied from 3% to 18%weight and the compressive strength, hardness values wear rate, swelling in water and SAE oil, thermal resistance, specific gravity and microstructure were all investigated. The 15% to 18 %weight Gum Arabic has fairest bonding. The sample with 18% Gum Arabic has properties with maximal temperature decomposition higher than asbestos and other alternative material used.

3. Brake Pad Composites from Cashew Nuts Shells and Plant Gum Binder

This study was experimentally based and 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 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 (8) Testometric Universal Testing Machine (TUF-C 1,000KN) (9) Tensometer (M500-25KN,Gunt Hamburg Hardness Tester and WP300) while other equipment used were BS 410 standard sieve sizes of aperture 300µm, micrometer screw gauge Stirrer, Bowls, Optical Electron Microscope(OEM), Steel Spatula, and desiccators.

3.1 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 [118]. 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 6.

Table 6: 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

3.2 Development of the Composites

The Compression moulding method as successfully adopted and reported by Yewas *et al.*, [111], Koya and Fono [100,101] and Bashar *et al.*, [32] were used to develop 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 being 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 were characterized using standard procedures for Brinell hardness, Compressive strength, wear rate, Coefficient of friction and Ash content.

4. Results and Discussion

The results obtained from the tests and characterization of the twenty-seven (27) differently formulated samples are presented in table 7.

Table 7: Properties of the composites from Cashew Nut Shells and Plant Gum Binder

Samples	Hardness (BHN)	Compressive Strength (N/mm^2)	Young Modulus (N/mm^2)	Wear Rate (mg/m)	Coefficient of Friction	Flame Resistance (%)
1	31.83	3.643	68.398	2.31	0.3868	97.71
2	47.49	6.714	141.188	4.24	0.4554	96.67
3	31.83	6.332	100.016	3.47	0.3868	97.71
4	76.66	8.417	235.454	0.77	0.426	96.94
5	47.49	7.976	121.073	8.48	0.4162	96.95
6	76.66	5.879	83.375	4.62	0.4358	98.98
7	47.49	4.398	107.604	1.16	0.3966	97.21
8	31.83	7.138	58.906	1.54	0.426	96.69
9	76.66	9.863	182.783	8.48	0.4456	96.18
10	76.66	4.209	119.088	7.71	0.4064	96.71
11	76.66	6.956	117.789	6.55	0.4456	96.43
12	47.49	5.145	97.484	5.01	0.3868	97.22
13	47.49	6.365	147.826	8.48	0.475	95.91
14	47.49	5.509	75.071	5.78	0.4848	95.65
15	47.6	12.187	169.358	3.47	0.4456	96.18
16	31.83	4.781	106.285	8.86	0.475	95.66
17	47.49	7.851	136.013	6.17	0.4848	95.65
18	47.49	5.432	95.143	3.08	0.4064	97.2
19	31.83	3.568	80.162	3.85	0.4554	95.93
20	47.49	3.927	85.627	3.08	0.4848	95.41
21	76.66	3.758	65.04	8.09	0.4554	95.93
22	47.49	5.699	145.694	3.85	0.4554	96.17
23	76.66	3.099	71.829	2.7	0.4554	95.69
24	31.83	3.081	55.408	7.71	0.426	96.69

25	22.26	2.267	161.697	4.24	0.478	95.91
26	47.49	4.437	73.32	5.01	0.4848	95.65
27	47.49	6.405	152.709	2.31	0.4848	95.65

From the table,it is observed that substatial values evaluated for all the properties such as hardness,compressive strength,wear rates,ash content and coefficient of friction compares favourably with values reported by Ademoh and Olabisi [119],Asotah and Adeleke [120] and Isiaka and Temitope [121],Bala et al.,[12] and Mayowa et al.,[102] who used Cow bones to replace asbestos.Idris et al.,[5] reported properties of commercial brake pads thus: Wear rate-3.80mg/m, Co-efficient of friction-0.3-0.4, Hardness value-101HRB,Compressive Strength-110N/mm2 and 9% of charred ash. From table 7, the best values obtained are 1.16mg/m, 0.4848 76.66BHN, 12.187N/mm2 and 97.71% of ash content retained. It is clear that these value compare favourably therefore suggesting the promising prospect of replacing asbestos with cashew nut shells while the plant gum binder(Nigerian Gum Arabic) replaces the toxic resins such as epoxy, phenolic and formaldehyde binders.

5. Conclusion

From the study, the following conclusion can be adduced

(1) Agro based materials especially fibres from plants are good replacements for asbestos and resin components of brake pads material

(2) Cashew nuts shells is suitable as frictional or base material to replace asbestos in brake pads production

(3) Plant Gum such as Nigerian Gum Arabic is an alternate binding material in the composites mix for automobile brake pads

Recommendations

With this promising outlook of using cashew nut shells and plant gum binder in the composites mix of automobile brake pads, it is recommended that smaller sieve sizes say 100µm and 150µm be used and Signal-to-Noise ratios, contour plots be used to optimize the best formulations and the properties.

Grey Relational Analysis (GRA) can also be used to compress the multi-response properties to a single response optimization.

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