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A Review of the Compositions, Processing, Materials and Properties of Brake Pad Production

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Abstract

This is a review and overview of the trending researches in automobile brake pad production processes, formulations, materials, and properties. Most of the works attempt mainly on replacing asbestos found to be carcinogenic with base materials with other ingredients in various formulations and particle sizes. Though most of the replacements are non-hazardous with properties such mechanical and tribological cauterizations comparing well with the traditional asbestos based brake pad. 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. These reviews has 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

Keywords: Brake pad, Compositions, Properties, Materials, Cashew Nutshell, Plant Gum

1. Introduction

Brake pads are disc components in automobiles of steel plates backed friction materials bound to the surface. They bound unto the surface facing the brake disc and are placed in wheel 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 use in various parts of an automobile. The many advantages of abundance, comfort and cheap cost of natural fibers for industrial use thrust 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 composite 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 that 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 Brake Pad Materials

The trending issues with researches all over the world today is focused on achievable ways of utilizing either industrial or agricultural wastes as a source of raw materials in the industry especially the replacement of asbestos and inorganic resins in brake pad production. These utilization of wastes will not only be non hazardous 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 confirmed by Lee [37].
- (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 compositions 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 have 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/N	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	9-11	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	10-30	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.

3. Research Trends in Brake Pad Production

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 sawdust 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 research gap in the quest to improve quality and properties of brake pads as discussed below:

3.1 Palm Kernel Shells Based Brake Lining

Quite 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 125 μ m. 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 150–170 $^{\circ}$ C, 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, 24 and 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 developed 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 satisfactory properties and hence palm kernel fibers can be another good replacement of asbestos in brake pad production. Another investigated 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 asbestos 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 composition 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 increasing filler content.

Using **palm slag** as base material with phenolic 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 compositions 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 with Phenolic and alkyd resin 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 thermal 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 investigated 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 matrix compared well with single fillers as well as the commercial ones.

3.2 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 ingredients 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	Percentage Composition (%)				
		Comp 1	Comp 2	Comp 3	Comp 4	Comp 5
1	Matrix	20.00	30.00	40.00	50.00	60.00
	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 710 μ m 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.

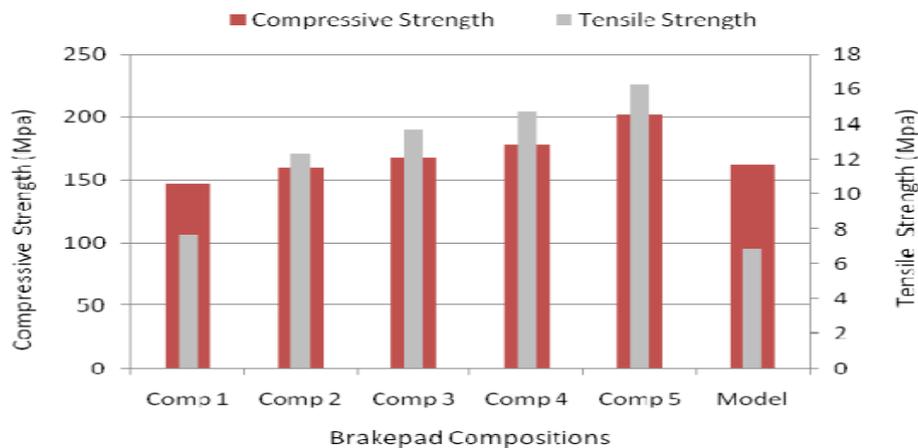


Figure 4: Comparison of compressive and breaking strength for the different compositions and model(Bashar *et al.*,[32])

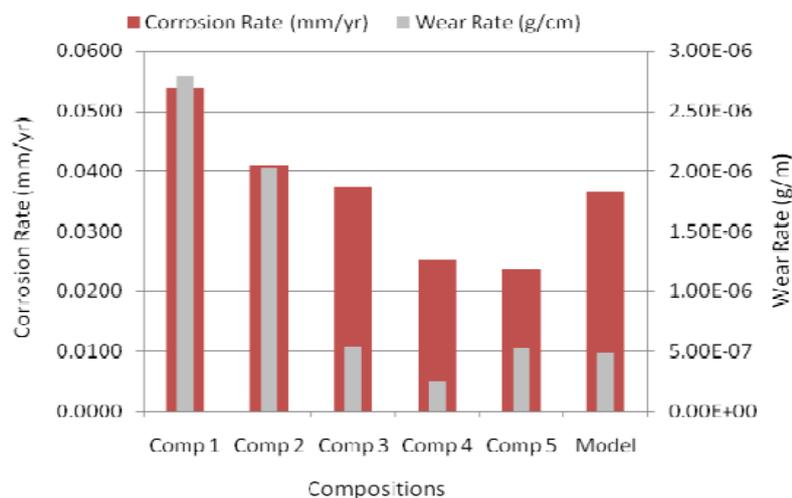


Figure 5: Comparison of wear rate for different compositions and model(Bashar *et al.*,[32]).

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 3.00 Mpa and 3.41 Mpa . 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 parameter were adapted and investigated. 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 compositions namely BP1, BP2, BP3 and BP4 varied from 0, 5, 10 and 15 volume fraction. 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 Electron 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.

3.3 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°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 with a decreasing particle size. The results further concluded that the 125 μm particles size compared well with the commercial brake pad with the optimal values of 1.01 g/cm^3 specific gravity, 0.41 value of coefficient of friction, 116.7 HRB 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 suitability in the asbestos replacement 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).

3.4 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°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 bidding 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 another formulation without the fly ash. These work studied the effect of the ingredients on the tribological (coefficient 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 ceramic friction materials along other composition as shown in Table 4 to produced 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 design of experimental design. Properties evaluated included hardness, specific gravity, wear and fade. The investigation revealed that the moulding pressure determines most of the properties.

3.5 Banana Peels Based Brake Pad

Another author, 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 was 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%

3.6 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.

4.0 Research Direction and Conclusion

It has been established that many research works have been done in efforts to replace asbestos with other environmentally friendly reinforcement materials as reviewed and overviewed by **Oluwafemi *et al.***, [50] and **Abutu *et al.***, [108] respectively. However, not is much has been reported on the replacement of resin used as binder which are equally dangerous to health and its corrosive effects on plates of brake pad assembly. It is imperative that sourcing alternative materials that is environmentally friendly for these binder is worth researching into. Some of such efforts include Ademoh and Olabisi [118] and Asotah and Adeleke [119] who developed a new composite brake pad using maize husks. While Ademoh and Olabisi [118] used maize husks as a filler material, silica sand, calcium carbonate, anhydrous iron oxide, powdered graphite. and epoxy resin as a binder with sievie size of 300 μ m and three samples from varying the maize husks compositions and the resin, the other researchers Asotah and Adeleke [119] used 100 μ m and 200 μ m particle size varying the maize husks composition and that of the silica sand. Similarly, Isiaka and Temitope [120], Bala *et al.*, [12] and Mayowa *et al.*, [102] placed their attempt on replacing asbestos with Cow bones and a mix. While Isiaka and Temitope [120] studied the effects of the distribution of the powdered cow bone with unsaturated polyester resin, Methyl Ethyl Ketone Peroxide (Catalyst), Polyvinyl Acetate (releasing agent), 2% cobalt solution (accelerator) and ethanol as cleaning agent. This is aimed at investigating the mechanical properties suitability for brake pad production using similar methods with other researcher. Bala *et al.*, [12] with a 710 μ m particle size, used pulverized hooves from cow between 10–40 %, epoxy resin (10–40 %) graphite, aluminium oxide, barium sulphate to produce seven different samples there were investigated. The reviews and overviews reported similar other alternate materials such as shells of Cocoa Bean as Adeyemi *et al.*, [121] reportedly carried out, Bagasse (Sugar Cane Fiber) by Aigbodion *et al.*, [1], Rice husk dust by Shahril Anuar Bahari *et al.*, [110], pineapple by Felix and Prasanth [122], lemon peel powder by Ramanathan

et al.,(123) and effect of process parameters on the properties of brake pad produced from sea shells by Abutu *et al.*,[108].

From the overviews, it is concluded that most efforts were geared towards replacing asbestos for cancer related concerns without recourse to trying an alternative materials also to replace the inorganic Resins (Phenolic or Formedehyde and the epoxy) with equally corrosive tendencies. It was also observed that most of the researches focused more varying (few in number say 3-7 except in the case of Abutu *et al.* with 27 samples to investigate) and process parameters, composition of filler materials, resin and sieve sizes for investigations and characterizations. Finally, it had been observed that sieve sizes ranges of 100 μ m to a little over 300 μ m gave favourable morphological, mechanical and tribological properties in brake pads.

In conclusion, a research direction can emerge with the replacement of the asbestos and inorganic resin with a plant based agro-waste material such as Cashew Nut Shells (CNS) and Plant Gum (Nigerian Gum Arabic-NGA) respectively with a robust design of experiments for more number of sample formulations. A third ingredients can be varied as well to investigate the contributions of the various components of the compositions to the properties of the product. This will definitely complement efforts to address health concerns posed by asbestos in friction lining manufacture, eliminate the corrosiveness of inorganic resins often used, green wastes utilization and environmentally friendly friction brake lining materials.

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