International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 11 Issue: 05 | May 2024 www.irjet.net p-ISSN: 2395-0072

REVIEW ON AUTOMOTIVE BRAKE FRICTION MATERIALS

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Abstract *Frictional brake lining materials are broadly made of asbestos as their constituent. But asbestos is dangerous for handling due to health hazardous. Asbestos has ample physical, mechanical and tribological properties. The material replacing it should have all these properties with no undermine. In this paper a study on asbestos base and asbestos free brake lining material is presented. Purpose behind this is combining the demerits of asbestos free and asbestos base materials with comparable properties. Some organic waste from farm like banana peel, palm kernel shell, were also tested for the replacement of asbestos and they found worth through comparison with each other*

Key Words: material, mechanical properties, tribological properties, environment, friction

1. INTRODUCTION

Brake pad material is a heterogeneous substance composed of different elements. Each constituent element has its own functions which include improvement of at low and high temperature, reduce noise, prolong life, increase strength and rigidity as well as reduce porosity. Changes in the weight percentage or types of elements in the formulation may result to the alteration of the chemical, mechanical and of the brake pad materials developed (Jang et al., 2004; Cho et al., 2005 and Mutlu et al., 2005; Zaharudin et al., 2012)[1]. Early researchers have concluded that no simple correlation exist between wear and friction properties of frictional materials with the mechanical and physical properties (Talibet.1al.,2006;Todorovic, 1987 and Tanaka et al., 1973)[6]. As a result, each new formulation developed requires to be subjected to several tests to evaluate its wear and friction properties using on–road braking performance test as well as abrasion testing mechanism to ensure that the developed friction pad material meets the minimum requirements of its intended use (Talib et al., 2006).Modern brake pad development has history spanning over the past 100 years. Herbert Frood was credited to be the first to invent brake pad materials in 1897. This pad was a cotton–based material that was used for wagon wheels as well as early automobiles and coupled with bitumen solution. This invention led to the formation of the manufacturing company known as Ferodo Company, a firm which still supplies frictional materials till date. Bertha Benz, the wife of Carl Benz was the first to invent patented automobile friction pads. This invention came during her first long and historic distance trip by a car in 1888(Blau, 2001)[8]. The earliest brake pad material was woven, but in the early1920's, moulded materials which were made of crysotilefibres, a plentiful mineral were used to replace it. In the 1950's, metallic pads that were resin–bonded were introduced, and semi–metals which contain higher amount of metal additives were developed in the 1960s (Nicholson 1995). Industrial brake pads usually contain many constituents such as ceramic particles and fibres, metallic chips, minerals solid lubricants and elastomers in a matrix material like phenolic resin. Also, Ole–Von et al. (2005) investigated the use of antimony in brake pads. The results show that the use antimony (Sb) in friction materials should be suspended as it posed a human cancer risk due to considerable concentrations of Sb in the material. Agricultural products are also emerging as inexpensive and new materials in the development of brake pad material with commercially viability and environmental acceptability (Bledzki and Gassan, 1999)[11]. Cyraetal.(2001) reported that among the different kinds of agricultural products investigated, lignocelluloses fillers are most times considered as attractive materials to be utilised as fillers of thermoplastic polymers due to its excellent properties. It is possible to obtain composite materials with properties very similar to the existing synthetic–filler reinforced plastics with their superior properties such as low density, energy recovery, low cost, enhanced recyclability and biodegradability. Garcia et al. (2007), Bledzki and Gassan (1999) and Seki, (2006), also reported the use of rice husk thatone of the agricultural products which can be potentially utilised as fillers in friction pad production is the. It was stated that rice is the most important food crop grown and planted in the world today and they can be grinded and burned at low temperature. This burning and grinding process produced white ashes which consist of about 80% silica. The rice straw comprises of 20% hemicelluloses, 30% cellulose and lignin, 10% water and about 15% mineral ash. This mineral ash is composed mainly of 95% silica, insoluble silicates of iron, aluminium, calcium and magnesium (Van–Hoest, 2006)[15].Concerted efforts have been channelled towards replacing asbestos and other carcinogenic materials in the production of brake pads. In the work of Nakagawa et al. (1986), metal fibres were used in the production of brake pads so as to counter the environmental pollution caused by asbestos.During this study, a semi–metallic type of pad material was developed from chattered–

machined metal fibres as it exhibits good properties in line with brake characteristics and also good wear resistance. This pad contained close to 60 %by weight of the steel fibres having 60 microns (μm) in diameter and length of 3mm [16]. Dagwa and Ibhadode (2008)and Deepika et al. (2013), also developed a non–asbestos–containing friction pad material using an agro –waste material base, palm kernel shell (PKS) as a reinforcement material. It was reported in their work that palm kernel shell was selected because it exhibited more favourable properties than the other agro–waste they investigated. Aigbodion et al.(2010); Bashar et al. (2012) and Ruzaidi et al, (2011), also developed a non–asbestos brake pad by utilizing bagasse, coconut shell and palm ash respectively as reinforcement materials. The result of their study showed that the selected reinforcement materials were comparable with other commercially available brake pad materials [19].

2 MATERIALS

2.1 Non–Hazardous Reinforcement Materials

Medical research carried out has shown that asbestos fibres can lodge in the lungs thereby inducing adverse respiratory conditions. Environmental (EPA) in1986 announced a proposed ban on asbestos. This proposed ban by EPA may have required all new automobile vehicles to possess non–asbestos brakes and clutches by 1993, aftermarket would have had until 1996 to convert to non–asbestos which is non–hazardous (Blau, 2001).Though the use of asbestos in brake pads has not been fully banned, but most brake pad producing industries are moving away from the use of asbestos as reinforced material to using on–hazardous reinforced material in friction pad production. This is because of the concerns regarding airborne particles in the factories and disposal of asbestos containing wastes (Dagwa and Ibhadode, 2006). Several studies have been carried out using different reinforced materials to find a possible replacement for asbestos whose dust has been reported to be carcinogenic (cancer causing

Some of these studies are discussed in the following section

2.2. Coconut Shell

Coconut shells shown in Figure 1 are agricultural wastes used in the preparation of various attractive articles (antiques) and also applied in the production of activated charcoal as well as reinforcement material in the production of composites. Salmah (2013) reported that coconut shell is lingo cellulosic filler which exhibits excellent properties compared to mineral fillers (kaolin, calcium carbonate, mica and talc). Some of the outstanding properties reported by Salmah (2013) include minimal health hazard, high–specific strength–to–weight ratio, low cost, biodegradability, environmental friendly and renewability. Matthew (2012) reported that moisture desorption of coconut shells takes place between 25 and150°C and at 150°C, degradation of sclerenchyma cells, which are responsible for holding water in the shell occurs. Further heating of the shells between 190°C to 260°C may result to the degradation of hemicelluloses present in the shell and at240°C to 350°C, degradation of cellulose take place. The final stage of thermal degradation involves the breakdown of lignin which occurs between 280°C and 500°C (Matthew, 2012).

Fig 1: Coconut shells

Bashar et al. (2012) conducted a study with the aim of finding possible replacement for asbestos, used coconut shell powder to develop brake pad material. This material was mixed with other ingredients such as catalyst, epoxy resin, cast iron fillings, silica, and accelerator. The coconut shell was dried in the sun for some days in order to get rid of the shell moisture and then reduced into smaller sizes using anvil and hammer and then pounded using mortar and pestle. Finally, a grinding machine was used to ground it into powder and sieved with a mesh size of 710 μm. In the study, the weights of epoxy resin and the coconut shell powder were varied while the weight of the other ingredients remained unchanged. Mechanical (tensile, hardness, compressive, wear and impact) and corrosion tests were conducted to study the effect of process on the products. The results show that as the percentage of the coconut shell powder increases, the hardness, breaking strength, compressive and impact strength reduces. Therefore, it was reported that higher percentage of coconut powder results to brittleness and that brake pad samples with 50% matrix and 10% reinforcements well as samples with 60 % matrix and 10% reinforcement can be adopted in friction pad production since they are far lighter and possesses better properties when compared with the other compositions. The report also suggested that the coconut shell reinforced brake pad. Possessing this composition may be a better alternative to asbestos as it possesses lower wear resistance though; the presence of iron filings in the samples causes poor resistance to corrosion Darlington et al. (2015) in their study also produced an asbestos–free brake pad from locally sourced raw materials using coconut shell powder and palm kernel shell as reinforcement materials, graphite as lubricant, polyester resin as binder material, carbides and metal chips as the abrasives. According to the report of their study, three different samples of brake pads were produced by varying mass compositions of coconut shell and palm kernel shell while the composition of the binder, lubricant and abrasive materials remained unchanged throughout the experiment. The tests results obtained shows that developed samples have density which falls between 2.55–2.78 g/cm^3, wear rate of 0.2007–0.2733g/min, percentage water absorption of 0.0399–0.0522% and hardness of 3.00 – 3.41.Samples of commercial brake pads were also tested and it was found that the commercial pads possesses a density of3.36 g/cm^3, wear rate of 0.1873 g/min, water absorption of 0.0327% and hardness of 2.53. These results showed that the developed samples though could not meet up with properties of commercial brake pads due to its high density and wear rate but compared well with commercial brake pads and can serve as an alternative to commercial products. Therefore the study concluded that locally sourced palm kernel and coconut shell can be used as a replacement for commercial pad.

2.3 Palm Kernel Shell and Fibre

Ndoke (2006) showed that palm kernel shell as shown in Figure 2, has an average dry density of 0.65mg/m^3, porosity of 28% and an impact value of 4.5%. The report suggested that the dry density, porosity and impact value of palm kernel shell place it in the same category as lightweight aggregate and good substitute for asbestos.

Fig 2: Palm kernel Shell

Fono–Tamo and Koya, (2013), developed brake pad materials for automobile using standard factory procedure from palm kernel shell. Mechanical properties of the material developed were studied. The results showed that the developed pad has an average hardness of 32.34 and average shear strength of 40.95 MPa. The coefficient of friction of the product was also tested and the result indicated that the pad possessed a frictional coefficient of 0.43. This result was in agreement with the work of Koya et al. (2004) in which it was stated that the coefficients of friction of palm kernel shell on metal surfaces are in the range of 0.37–0.52. In contrast, friction coefficient that falls within the range of 0.30–0.70 is desirable when using brake pad material (Roubicek et al.,2008). The bonding of the material to the back plate was also tested and the result indicates a value of 3375 N/s. All the values of the responses though not as excellent as asbestos–based brake pads whose coefficient of friction falls within 0.37–0.41 as the recommended by SAE was reported to be good and can be applied as automotive friction material therefore making palm kernel shell a good substitute for asbestos and suitable for brake friction pads production. Ikpambese et al. (2014) also developed asbestos free automobile brake pads from palm kernel fibers together with epoxy resin as binder. The fibers (PKFs) were soaked in caustic soda solution (sodium hydroxide) for 24 hours to get rid of the remnant of red oil in fiber. The fibers were then washed with water to remove the caustic soda and then dried under the sun for a period of one week. The binder used during the study was varied in formulations during production. The physical, morphological and mechanical properties of the composite were investigated to examine the effect of composition on the friction material. The results obtained from the study indicated that then coefficient of friction, temperature; wear rate, stopping time and noise level of the pads increases with increasing speed. The results also show that moisture content, porosity; surface roughness, hardness, specific gravity, water and oil absorption rate remained stable with increasing speed. From the microstructure analysis it was observed that worm surfaces wear where the asperities ploughed were characterized by abrasion thereby exposing the white region of the fibers and increasing the smoothness of the composite material. The report showed that the brake pad sample with composition of 10% palm wastes, 40% epoxy–resin, 15%calcium carbonate, 6% Al_2O_3, and 29% graphite gave optimum properties. Therefore, it was concluded that palm kernel fibers can be used effectively as a good replacement for asbestos in friction pad production.

2.4 Banana Peels

Banana peels shown in below figure 3 they can also be called as banana skin. They are the casing of the banana fruit. It is admired fruit consumed worldwide with a yearly production of over 145 million tonnes. Once the fruit is consumed, the peel is generally discarded. Because of this removal of the banana peel, a significant amount of organic waste is generated (Babatunde, 1992).

Fig 3: Banana peel

The coefficient of friction of banana peel on a linoleum (a tough washable floor covering) surface was measured at just0.07. This is about half that of lubricated metal on metal surface. Several researchers have attributed this to the crushing of the natural polysaccharide follicular gel, releasing homogenous sol (Kiyoshi et al., 2012). It has been reported that at increased temperature, banana peel powder becomes more gelatinous and at much higher temperatures, the hardness increases. Therefore, because of these properties of banana peel, it is suggested for use in the formulation of new friction pad material as it increases the binding ability of resin at higher temperatures (Idris et al., 2013). Idris et al. (2013) carried out a work for the correct substitute for asbestos and phenolic resin (phenol formaldehyde) binder formulated a new brake pad using banana peels waste. The composition of the resin varied from5 to 30 wt% with interval of 5 wt%. The banana peels used in the study was dried and ground into powder (uncarbonized, BUNCp). Analysis of the particle size of the peel particles was carried out in accordance with BS1377:1990. During the study, two sets of samples were produced using the carbonised and uncarbonised banana peels particles. Physical, wear, morphology and mechanical properties of the formulated brake pads were investigated.

2.5. Cow bone

Due to large number of cows being slaughtered daily in the Nigeria, cow bones as shown in Figure 4 are abundantly available. These natural fibers are obtained from cow wastes which causes environmental pollution. Isiaka and Temitope(2013) reported that cow bone exhibit excellent structural compatibility in addition to the surface compatibility requirements as biomaterials. Mayowa et al. (2015) also reported that cow bone consists of living cells which are renewed constantly in the bone and widely scattered within non–living material known as the matrix formed byosteoblasts cells. It was also reported that this osteoblasts in the bone secrete and makes protein collagen, which gives the bones elastic property which help it withstand stresses generated by lifting, walking, and other related activities.

Fig 4: Cow Bones

Isiaka and Temitope (2013) investigated the influence of particle size distribution of cow bone powder on the mechanical properties of polyester matrix composites with the aim of considering how suitable it is to be applied as biomaterials. During the study, the cow bone used was thoroughly washed to get rid of unwanted materials and then crushed into smaller particles sizes using hammer. Sieve size analysis was conducted on the crushed bones and was sieved into three sieve sizes of 300, 106 and 75µm.Other materials used during the experiment include unsaturated polyester resin which serves as the binder, a catalyst known as methyl ethyl ketone peroxide (MEKP), polyvinyl acetate which serves as the mould releasing agent,2% cobalt solution (accelerator) and a cleaning agent known as ethanol. Though, from the results obtained, the authors reported that cow bones can serves as reinforcement material in polyester matrix as well as a good replacement for asbestos but tribological properties such as wear resistance and friction coefficient which majorly affect the frictional behaviour of a brake pad was not investigated.

2.6 Periwinkle Shell

Periwinkles shown in Figure 5 are small marine snails belonging to the family Littorinidae (class Gastropoda,phylum Mollusca). They are widely distributed shore snails which are usually found on stones, rocks or pilings. Some are found on mud flats while some tropical forms are found on the prop roots or mangrove trees. The shell of periwinkles is the outer casing of the animal which is usually discarded after the flesh inside is consumed. They are usually considered as agricultural waste products in riverine area of southern Nigeria (Yawas et al., 2013)

Fig 5: Periwinkle shell

Yawas et al., (2013) developed an asbestos–free brake pad using periwinkle shell as reinforced material. The periwinkle shells used during the study was grounded and sieved into grain sizes of 125, 250, 335, 500 and 710 µm, and was mixed with 35% phenolic resin binder. Five test samples were developed using compression moulding machine at a pressure of 40 kg/cm2, a moulding temperature (160oC) and a curing time (1.5 hours). All the prepared samples were post cured in an oven of temperature 140oC for 4 hours. The microstructure (surface morphology) of the produced friction materials was analysed using scanning electron microscope and the results indicate that the microstructures of the developed samples showed a homogeneous distribution as the periwinkle shell particles sieve size decreases. Mechanical, physical and tribological properties of the periwinkle shell based brake pads were also investigated and contrast with the properties of asbestos–based brake pads. It was concluded that the hardness, compressive strength and density of the prepared brake pads increases as the size of periwinkle shell decreases from 710 to 125 µm while the oil absorption, wear rate and water absorption rate decreases as the particle size of the periwinkle shell decreases. Therefore, the results obtained for the sieve size of 125 μm of periwinkle shell particles contrast with commercial brake pad. The best values of the test results reported include specific gravity (1.01 g/cm3),coefficient of friction (0.41), hardness (116.7 HRB),Compressive strength (147 N/mm2), and thickness swell in water (0.39 %) and thickness swell in SEA oil (0.37 %). It was therefore decided that periwinkle shell particles can effectively substitute for asbestos in the production of brake pads.

2.7 Rice Husk and Rice Straw

Rice husks and rice straw are agricultural wastes which are abundantly available mostly in rice producing countries like Nigeria. Rice husk dust and rice straw dust shown in Figure 6 are known to have high silica and low lignin content which gives friction materials a ceramic–like behaviour (Ibrahim, 2009). These materials are used as filler or reinforcement materials in the development of composites like friction pads. Acharya and Samantrai (2012) studied the wear and friction behaviour of rice husk using randomly oriented unmodified and modified rice husk as reinforcement in epoxy matrix(Araldite LY556 and hardener HY 951). A pin on–disc apparatus was carried to study the wear behaviour of rice husk composites reinforced with 5–20 wt%. The pin of each sample was attached to a holder and then abraded under different loads of 5, 7.5,10 and 15N. Each test was conducted for duration of 5 minutes. The results of the coefficient of friction and wear rate of the composite were found to be the functions of sliding velocities, normal load and the filler volume fraction. Scanning electron microscope (SEM) was used to also study morphology of the worn surface of the composites.

Fig 6: Rice straw (a) and Rice husk (b)

According to the report of Acharya and Samantrai (2012), the test result shows that wear rates decreases with increase in the rice husk fibres addition under all testing conditions. It was then concluded that the addition of the rice husk fibres in epoxy is very effective in the improvement of the composite wear resistance and the optimum fibre fraction which gave the optimum wear resistance to the composite is found to be 10 w%. The morphologies of scanning electron micrograph of worn surface for the untreated rice husk composite and the benzoyl chloride treated rice husk composite showed that surface damage and cracking of the matrix (longitudinal and transverse crack) are more pronounced for the untreated composite. Reverse is the case for the benzoyl chloride–treated composite as the surface damage seems to be minimal and only longitudinal cracks are identified on the surface of the material in the rolling direction. It was therefore concluded that the treatment of the surface of the fibre restricts the propagation of the cracks in the transverse direction thereby improving the wear resistance of the composite.

2.8 Bagasse

Bagasse as shown in Figure 7 is a fibrous residue that remains after crushing the stalks. It is composed of fibers, water and little amounts of soluble solute. The percentage contribution of each of these components in bagasse depends on the maturity, variety, efficiency of the crushing plant and the harvesting techniques. Bagasse contains about 30%hemicelluloses, 40% cellulose, and 15% lignin

Fig 7: Bagasse

Aigbodion et al. (2010), with the conducted a study using bagasse to produce brake pads in the ratio of 30% resin and70% bagasse using compression moulding machine. The bagasse's used in the study were sieve into grades of 100, 150,250, 350 and 710μm. The binder used during the study was phenolic resin (phenol formaldehyde). During the experiment, the compression moulding machine was set toa moulding temperature of 140oC, moulding pressure of 100KN/cm2 pressure and a curing time of 2 minutes and the final product was cured in an oven for 8 hours. The optimal values of the properties examined during the study include hardness (92 at 3000 kgf), density (1.65 g/cm3), microstructure analysis, compressive strength (103.5 MPa), flame resistance(charred with 46% ash), water and oil absorption (5.04 and0.44 %). From the result obtained, it was reported that the compressive strengths of the produced samples followed similar trend with that of the values of the hardness as each of the properties increases with decreasing sieve sizes. The microstructure of each sample was reported and the results showed that as the particles size of the bagasse decreases, there was more uniform distribution of the resin with the bagasse which was attributed to the proper bonding between the resin and the bagasse as the sieve grade decreases. It was therefore concluded in the study that better properties of friction pad can be achieved using a lower sieve grade of 100µm of bagasse with a composition 70% and 30%of resin.

2.9. Seashell

Fig 8: Sea shell

Natural materials such as seashell (exoskeletons of mollusks)is made up of three distinct layers which include the smooth inner layer composed mainly of calcium carbonate, intermediate layer (calcite) and the outer layer of horny Substance known as conchiolin (Schaeffer, 2014). Norazlina et al. (2015) reported that seashell as shown in Figure primarily consist of calcium carbonate (CaCO3), been naturally above 80% CaCO3 by weight with only about 2 % protein content and no complex extraction process is needed to use it for composite production. Seashells exhibit significant combinations of low weight, toughness, stiffness and strength which are in some cases unrivaled by mineral fillers (Vignesh et al., 2015). The seashell powder used in the study was utilised as filler by the authors to produce a composite using polyester binder. The test results indicate that the commercial CaCO3 based composite possesses an impact and tensile strength of 918 MPa and 3.2 kJm−2 respectively while seashell based composite exhibit an impact and tensile strength of 904 MPa and 3.4kJm−2 correspondingly. The authors therefore concluded that seashell can be used in place of commercial $CaCO_3$ to produce composites since commercial $CaCO_3$ and seashell (mussel or oyster shells) produces similar results regardless of their variation in distribution of particle size and particle sizes.

2.10 Maize Husk

Maize husks as shown in Figure 9 are the outer covering of maize. For most applications, the husks need to be soaked in hot water to become flexible. This type of husk is regularly used to encase foods for baking or steaming thereby imparting light maize flavour. Ademoh and Adeyemi (2015) conducted a study using maize husks as reinforcement material to produce automotive brake pads. Three friction composite compositions were developed using the maize husks as strengthening material with varied epoxy resin binder.

Fig 9: Maize husk

Maize husks were crushed and sieved to a mesh size of 300µm. Other ingredients used during the study include silica sand, epoxy resin, calcium carbonate, anhydrous iron oxide, talc as release agent and powdered graphite. Three samples were produced using curing time of 80–120minutes and varying wt% of maize husk and binder (epoxy resin and hardener at 1:2) while the weight of friction modifier (graphite powder), abrasives (silica and iron oxide), and fillers (calcium carbonate) were kept constant throughout the experiment. To ascertain suitability of the formulated composites for brake pad application, the samples were subjected to tests to determine its mechanical, physical and tribological properties. Some of the tests conducted include water and oil absorption, density, friction coefficient; wear resistance, thermal conductivity, hardness, compressive and tensile strengths. The optimal values of the developed brake pad compared with asbestos–based brake pads.

3 CONCLUSIONS

A comprehensive review of application of non–hazardous reinforcement materials as possible replacement for asbestos has been highlighted in this study. The physical, mechanical and tribological properties of these brake pads compared favorably with the commercial brake pad. The need for results obtained from these research works to evolve from laboratory will address the current gap in making available eco–friendly and low–cost brake pads for commercial consumption.

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