Effect of Moulding Pressure on Brake Lining Produced from Industrial Waste Material: Sawdust

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Abstract—In this study, asbestos-free brake lining was developed with sawdust. Sawdust was considered an alternative to asbestos, whose dust is carcinogenic. The sawdust from hard wood (mahogany and iroko trees) and other components such as abrasive, reinforcer, lubricant, were sieved into grade of 100 µm and used in production of brake linings. The percentages of sawdust for the samples are 40, 45, 50, 55, and 60. The percentages of abrasives (silicon carbides) were 27, 22, 17, 12 and 7, while binder (resins) lubricant (steel dust) and carbon black (reinforcer) were constant at 13%, 15% and 5% respectively on each sample. The molding pressure load was varied at 10 Mg, 20 Mg, 40 Mg, 60 Mg and 80 Mg during compression process. The brake lining properties examined are hardness, compressive strength and density. Also, the effects of molding pressure on these properties were evaluated. The results obtained show that the higher the molding pressure, the better the physical and mechanical properties. Furthermore, at high molding pressure, the properties reached a limiting point which they tend to be constant. The brake linings based on sawdust were then compared with commercial (asbestos-based) brake lining and the results are in close agreement. Hence, sawdust can be effectively used as filler for replacement of asbestos in brake linings.

Index Terms—Sawdust, Brake Lining, Mould Pressure, Hardness, Compressive Strength.

I. INTRODUCTION

Brake pads are one of the most important safety and performance components in automobiles. The major component in the brake is the lining materials, which are made up binder, reinforced fibers or structural materials, filler and frictional additives and modifiers [1]. The binder holds the ingredients together, to maintain structural integrity of the brake lining, while filler make up the free volume of the brake lining while friction modifiers stabilize the coefficient of friction and wear. These components perform synergistically in controlling friction and wear performances of the brake pad.

Fillers are used to maintain the overall composition of the friction material, as well as to improve physical, mechanical and tribological properties of brake pad [2]. Fillers are also included in a brake pad lining in order to improve its manufacturability and also to reduce the overall cost of the brake pad [3]. The amount of filler is one of the highest constituents in a brake pad composition. Thus, to some extent, fillers affect the final properties of brake performance, especially in terms of resistance to heat, abrasion, and strength.

Asbestos has a few engineering properties that made it very suitable for inclusion in brake lining, and was the most preferred filler materials up till 1989 when the use of asbestos is being averted due to its carcinogenic nature [1]. Consequently, new asbestos-free friction materials and brake pads are being developed and researchers have struggled to come up with an equally efficient alternative. Organic and Inorganic fillers such as barite, mica, cashew dust, fly ash and palm kernel shell are some of the materials that have been considered for use as fillers [4-6]. Even though they offer some similar performance characteristics but none is exactly like asbestos [7]. While some inorganic fillers such as barium sulphate, mica, vermiculite, sodium titanate and calcium carbonate possess a relatively high melting point and able to suppress low frequency brake noise [8-10], their stratified structure results in a low interlayer strength causes interlayer splitting of the friction lining, especially at high braking loads [11].

Common organic fillers such as rubber and cashew dust are usually incorporated into brake pads for the purpose of reducing brake noises due to their superior viscoelastic characteristics [12, 13] and also as under-layer material because their low thermal conductivity prevents heat from transmitting to the backing plate of the brake friction material [10]. However, these particles, especially cashew; fall off the friction surface easily, leaving behind large pores that eventually crack [14, 15].

The purpose of using fillers in brake materials is to improve the mechanical, thermal or tribological properties. However, the reduction of the overall cost of the brake pad through utilization of cheap materials like industrial waste in preparing filled friction composites is equally important. Generally, researchers are focusing on ways of utilizing either industrial or agricultural waste as a source of raw materials for brake pad production. The utilization of these wastes would help control their associated health hazards associated and also reduce the rate of depletion of natural resources. In addition, the abundance of industrial wastes at very low or zero cost is an attractiveness that has stimulated the awareness of exploring their possible incorporation into friction composite.

Used of coconut shell, palm ash, fly ash from coal combustion, palm kernel shell and etc. in the brake pad composites as replacement for asbestos have been investigated, and also, their results have been promising [16,
17]. Furthermore, it is very important to examine the mechanical and as well as morphological changes in the brake pad as a function of material composition and processing load. Hence, the processing parameters such as effects of molding pressure during the production on the structure of brake pad have been investigated [18].

In the present study, sawdust particle materials were employed as fillers in a typical brake pad formulation together with phenolic resin as binder, silicon carbide as abrasive component, steel dust as lubricant and carbon black as reinforcing material. Sawdust used in this study was found as waste from the processing of hardwood: mahogany (swietenia macrophylla) and Iroko (milicia excels) trees in sawmill. Sawdust (by-product produces after the milling of wood) is usually spread on the ground and disposed indiscriminately. Hence, the use of sawdust as alternative filler in brake pad formulation to replace the existing filler especially asbestos will help to prevent environmental degradation and pollution.

II. MATERIALS AND METHOD

A. Materials

The materials needed for the production of the brake pad lining include binder, filler, reinforcer, abrasive and lubricant. Phenolic resin was selected as the binder and this was obtained from a of retail shops in Ojota, Lagos, Nigeria. Hardwood (Mahogany and Iroko) sawdust used as filler in the research was industrial waste material collected from the saw mill industry in Ikorodu, Lagos. Carbon black was used as reinforcer, it also helps to conduct heat and reduce thermal damage [19], and it was gotten from retail shop in Ojota, Lagos, Nigeria.

Silicon carbide was used as the abrasive because of its very good chemical, thermal and mechanical properties; its resistance to acids, alkalis or molten salt attacked up to 8000C, it possesses high thermal conductivity coupled with low thermal expansion and high strength gives the material exceptional thermal shock resistant qualities, maintain their strength to very high temperature approaching 16000C with no strength loss. The silicon carbide used was bought from retail shop at Mushin, Lagos, Nigeria. Steel dust from steel slag was used as lubricant for the pro...
Samples produced were of cylindrical shape with diameters of 10 mm, and these were compacted further and cured to produce brake pad lining samples.

2) Hot press curing

The produced samples were cured in a hot press at five different molding pressures of 10 Mg, 20 Mg, 40 Mg, 60 Mg and 80 Mg, and at temperature of was 160 °C. The curing process took 5 minutes, after which the samples were allowed to cool at room temperature. Then the samples were post cured in an oven with air circulating at temperature of 160 °C for 4 hours to allow for full cure. The weights and diameters of the samples were measured before and after the curing process. The measurements were used to calculate the percentage of change in weights dimensions of the samples. Samples of the produced brake pad lining are shown in Fig. 1.

F. Characterization of the brake lining samples

Hardness of the samples: Hardness value describes the durability of the friction material. In this research the Rockwell type E hardness values of the samples were obtained using a digital Rockwell hardness tester. The tests were conducted using a 12 mm diameter steel ball indenter with a load of 100 kg on the samples.

Density: Density measures the relative “heaviness” of objects with a constant volume. The density of composite samples was obtained using a digital Rockwell hardness tester. The tests were conducted using a 12 mm diameter steel ball indenter with a load of 100 kg on the samples.

Morphology: The morphology of the surfaces of the brake pads also was observed by using a scanning electron microscope (SEM) JEOL JSM-6460LA. The samples were scanned with a high-energy beam of electrons in a raster scan pattern and the images of the surfaces of the sample of brake pads with different percentage of filler were obtained before and after the wear test.

Compressive strength test: The compressive strengths of the brake pad samples were measured based on ASTM D695 standard using an Instron Universal Testing Machine (Fig. 2). The samples were placed in such a manner that compressive load was applied at a crosshead speed of 5mm/minute. The machine used the load at which failure occurred to calculate compressive strength. For each sample, the test was repeated five times.

III. RESULTS AND DISCUSSION

A. Chemical Composition

Chemical compositions and the concentration of elements in sawdust obtained from the XRF analyses are presented in Table II. The data obtained were compared with the properties of asbestos that were found from the literature. Loss On Ignition (LOI) of sawdust is very high, this explain why steel dust and silicon carbide were used in certain proportion to control the thermal deficiency in the filler material. The material was found to contain silica in small amount, the same elements also were found in the analysis data for asbestos obtained by Dellisanti et al. [20].

| Compound | Sawdust | Asbestos |
|----------|---------|----------|
| SiO₂     | 0.022   | 43.74    |
| Al₂O₃    | 0.063   | 2.16     |
| Fe₂O₃    | 0.007   | 14.87    |
| CaO      | 0.214   | 16.97    |
| MgO      | 0.030   | 6.143    |
| Na₂O     | 0.831   | Trace    |
| K₂O      | 0.542   | 0.43     |
| MnO      | 0.005   | 1.31     |
| Moisture | 0.003   | -        |
| LOI      | 97.152  | -        |

B. Effect of molding pressures on the density of the sample

Fig. 3 shows the density obtained by different compression pressures used in making sawdust composites for brake lining. It is obvious that higher molding pressures produce more compact sawdust composites. Subsequently, the increase in density makes it possible to decrease the height of the compressed composite samples, as shown in Fig. 4.
As shown in Fig. 4, increasing the molding pressure will increase the density and decrease the height (thickness) of the composite. This can be attributed to the fact that the different materials used in the composite under compaction pressure, were subjected to sufficient force that caused plastic flow to occur, thereby increasing the density of the composite. The trend of this result was supported by Kawabe et al. [18], in their mechanical and morphological studies on the compressive properties of brake materials. They found that the higher the molding pressure the smaller the thickness of the specimen. Also, in the study of Guo et al. [21] on the effect of the fabrication process of carbon-carbon composite, it was discovered that molding pressure had significant effects on density and compressive strength. The various ingredients used in the brake lining are squeezed and push against each other in response to the application of high molding pressure. Because of the movements of these particles, the gaps between the particles become smaller and this resulted in decreased height and increased compaction of the sawdust composite, and it also resulted in decreasing in the sizes of the void. This can be related to the classical bi-modal/multi-modal packing effect where small particles are used to fill in the pores in the packed structure obtained with large particle; then even smaller particles are used to fill in the remaining pores and this process is continued until most of the pores are filled [22].

C. Effect of molding pressures on the hardness of the samples

The hardness values of the composite are shown in Fig. 5. It is apparent that hardness values of the samples increase as the molding pressure increases. The high hardness, i.e., a 61.1 Rockwell type E value, for the sample prepared by 60 Mg molding pressure was a result of high compaction caused by the high molding pressure. Increasing the molding pressure will help the composite materials pack together more closely and eliminate voids. This observation was supported by the previous finding by Elinn, and Nash et al. [23, 24]. They noted that it is important to keep porosity to a minimum to obtain compact, dense composite materials with increased mechanical properties. Yussoof and Jamaludin [25] in their studies of the influence of particle sizes and compaction pressure on surface hardness of aluminum composite fabricated via powder metallurgy also give a significant evident that the higher compaction pressure result in higher surface hardness.

In Fig. 6, the effect of the different molding pressure on density and hardness is shown. The relation between them in solid composite form seems to be very significant when the composite is subjected to different molding pressures. The higher the molding pressure, the higher the density of the composite becomes, and the hardness values of the samples are increased as a result.
To make this relation clearer, the direct correlation between hardness and density for the sawdust composite was again plotted in Fig. 7. This could be seen as a master curve plot for sawdust friction composite sample. It could be predicted that the higher molding pressure 100 Mg would result in the sawdust composite having higher values of density and hardness.

D. Effect of molding pressure on compressive strength of the samples

Fig. 8 shows the compressive strength of the sawdust brake pad composite for different molding pressures used during the process of making the brake lining composites. It can be observed that compressive strength exhibits a trend that is similar to that of hardness. Compressive strength of the brake pad increases with increase in the molding pressure. As the molding pressure increases, the compressive strength seems to reach a plateau. Once again, the compactness of the composite material through the processing load can be seen clearly.

![Compressive strength of the sawdust composites at different molding pressures.](image)

![Modulus of the sawdust composites with different molding pressures.](image)

The same trend exhibited by the effect of molding pressure on compressive strength was also observed with the modulus of the composite as presented in Fig. 9. The higher the molding pressure used in preparing the composites, the higher the modulus became, and also reaching a plateau at the highest explored pressures. This observation was due to the compactness of the composite product. Up to a certain limit of applied pressure, the compactness will reach its maximum point and remain at that point. At this stage, the mechanical properties of the product also reach their maximum limit, which explains the occurrence of the plateau. It can also be observed that as compressive strength increases with increase in the molding the hardness also increases (Fig. 10).

E. Microstructural Test

The microstructural assessment of all samples show color patches which indicate the difference in additives or constituents (Fig. 11). The brownish region on the micrograph indicates the sawdust particles. Agglomerates of tiny brownish spot represent sawdust reinforcement while there are also conspicuous brownish areas of sawdust region which are enclosed with yellow dotted line. The black spots in the figures represent the carbon black constituents used as a lubricant for the brake pad composite matrices, whereas the spread carbon region indicate region with a combination of phenolic resin and carbon black. Similarly, the whitish region and spots indicate iron waste rich region because the utilized iron waste for the brake pad had coloration similar to that of calcium carbonate.
The properties of brake linings based on sawdust were compared with that of commercial (asbestos-based) brake lining [26] and the results are in close agreement (Table III). Hence, sawdust can be effectively used as filler for replacement of asbestos in brake linings.

IV. CONCLUSION

Based on the mechanical properties, wear properties, morphology and the effect of molding pressure on the brake pad lining produced using saw dust composite as filler, the following conclusions are derived from the study:

- The molding pressure has a significant effect on the properties of the brake pad composite products. Composite with higher density and hardness were produced by higher molding pressure.
- Even though higher molding pressure produced higher density and hardness, it was observed that the compressive strength and modulus reach a limit point at which they tended to remain constant.
- There was an inverse correlation between hardness and compressive strength of the brake lining composite with the wear rate. The higher the hardness and compressive strength, the lower the wear rate, which means that the composite with higher hardness and compressive strength gives higher wear resistance.

Further research work will be focused on the tribological properties of the developed sawdust brake pad lining.

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