Manufacture of Automotive Brake Pads from Sawdust Composites.

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ABSTRACT: Development of asbestos-free brake pad using sawdust was study with a view to replace the use of asbestos whose dust is carcinogenic. The sawdust was sieve into sieve grades of 100,280,355μm and 1mm. The sieve sawdust was used in production of brake pad in ratio of 20% resin, 10% graphite, 15% steel, 35-55% sawdust and 0-20% SiC using compression moulding. The properties examined are microstructure analysis, hardness, compressive strength, density, flame resistance, water absorption. The microstructure reveals uniform distribution of resin in sawdust. The results obtained showed that the finer the sieve size the better the properties. The results obtained in this work were compared with that of commercial brake pad (asbestos based and optimum formulation laboratory brake pad sawdust based; the results are in close agreement. Hence sawdust can be used in production of asbestos-free brake pad.

Keywords— Compressive strength, Density, Flame Resistance, Hardness, Micro-structure,Porosity, Sawdust and Wear,

1. INTRODUCTION

This chapter consists of an overview about the raw materials which is used in automotive industry to manufacture car brake pads. The following includes a brief explanation about properties of *sawdust*, review about it and concept of brake pad used in automotive industry. The information and the review are taken from the journals, books, and information from websites.

Sawdust is recovered as by-product in wood production. Large quantities of sawdust are generated annually and only some fractions are used for fuel and other applications such as and in producing activated carbon.

The unused *sawdust* is dumped around the processing mill, constituting environmental and economic liability for the mill.

Although, *sawdust* must be ground into fine particles to be suitable for inclusion in brake lining, available information in the literature are on the ungrounded shell particles.

Coefficients of friction of coconut shell on metal surfaces were in the range of 0.37-0.52 [Koya et al, 2004]. In contrast, friction co efficient in the range of 0.30-0.70 is normally desirable when using brake lining material [Roubicek et al, 2008]. It has been found [Teo, 2006] that incorporation of coconut shell in the production of structural light weight concretes increased the mechanical strength. Thus, *sawdust* appeared suitable for use as base material in friction composites, because they are subjected to hard and variable braking forces. Akporhonor etal . (2007) reported that *sawdust* did not change significantly in physical structure and weight, for appreciable time duration, when exposed to organic solvent. It is also important that the friction materials experience very little or no changes on contacting varying environmental conditions, wet or dry weather, or hydraulic fluid spilling over.

These observations therefore, stimulated the interest in considering *sawdust* for use as friction material in brake lining.

The compositional design of friction materials is a well-known problem of multi-criteria optimization that involves handling four prime classes of constituents, i.e., 1) binders (e.g., phenolics); 2) fibers (e.g., carbon, aramid, glass, rock wool, cellulose, and basalt); 3) fillers (e.g., barites, kaolin, wollastonite, and cashew dust); and 4) friction modifiers (e.g., abrasives and lubricants). The compositional design of such materials is complicated further by the requirement that the materials exhibit a suitable and desirable level of performance characteristics, such as low fade, high recovery, low wear, low frictional undulations, and low sensitivity to load-speed variations [Elzey et al., 2000; Satapathy, 2002].

Combustion waste, specifically fly ash, consists of a mixture of fine-sized particles (mean particle size of 10-30 um) (of SiO2, Al2 O3, CaSO4, and unburned carbon. These particles, when used in friction braking applications, exhibit high-temperature resistance and provide good integrity/compatibility with the resin, thereby enhancing the friction and wear performance of the composite materials of which they are a part [Satapathy, 2002; Hee and Filip, 2005; Malhotra et al., 2002; Mohanty and Chugh, 2007].

The most attractive factors associated with the utilization of waste materials in friction composites are their abundance and the fact that they have very low, or even zero, cost. Thus their attractive performance-to-cost ratio has stimulated the idea of exploring their possible incorporation into friction composite formulations.

In addition, the successful utilization of waste material, such as fly ash, also would indirectly contribute to the reduction in the rate of depletion of valuable natural resources [Kumar and Patil, 2006]. It has been reported that the use of combinations of several fibers in friction composites can help to mitigate the thermal and frictional undulations that sometimes originate from hard, particulate ingredients, such as vermiculite, wollastonite, silica, zircon, and alumina (Chan and Stachowiak, 2004). Earlier studies [Malhotra et al., 2002; Mohanty and Chugh, 2007] assessed the performance of fly ash-based friction composites. Malhotra et al. (2002) claimed that the presence of an adequate amount of fly ash, i.e. about 20 wt%, enhanced thermal resilience and frictional stability. [Mohanty and Chugh, 2007] reported that the fly ash content in the formulation of the friction material could be as high as 65 wt% without much adverse impact on the material's performance attributes.

The brake pads generally consist of asbestos fibers embedded in polymeric matrix along with several other ingredients. The use of asbestos fiber is now being avoided due to its carcinogenic nature. Therefore new asbestos- free friction materials and brake pads are been developed. It is envisioned that future developments in the trend of brake friction materials will closely mimic the current trends of the automotive industry. The shift towards environmentally friendly cars has already seen the release of hybrid cars such as Toyota Prius, Honda Insight, and Ford Escape SUV [Dagwa and Ibhadode, 2006].

The brake pads were formally generally made from asbestos fibers. Because of its properties and risks, asbestos is being withdrawn from all the applications, where there is a possibility of alternate material for making non-carcinogenic materials [Aigbodion and Agunsoye, 2010].

There are two basic types of automobile brakes: drum brakes and disc brakes. In drum brakes, the brake shoes are located inside a drum. When the brakes are applied, the brake shoe is forced outward and presses against the drum. Disc brakes consist of two brake pads and a rotor. When the brakes are applied, the two pads squeeze against the rotor. One of the major differences between drum brakes and disc brakes is that drum brakes tend to be enclosed where disc brakes tend to be exposed to the environment [Bono and Dekyrger, 1990].

Although use of asbestos for brake pads has not been banned, much of the brake pad industry is moving away from asbestos brake pads because of concerns regarding airborne particles in

the factories and disposal of wastes containing asbestos. There are several patents for asbestos free organic friction materials [Dagwa, and Ibhadode, 2005].

A lot of research has been carried out in the area of development of asbestos- free brake pads. The use of coconut shell, palm kernel shell (PKS) etc. [Dagwa and Ibhadode, 2006] has been researched on over the years. Researches all over the world today are focusing on ways of utilizing either industrial or agricultural wastes as a source of raw materials in industry. Utilization of these wastes will not only be economically, but may also result in foreign exchange earnings and environmental controls.

The development of modern friction materials has a history spanning over the past 110 years. Herbert Frood is credited with inventing the first brake lining material in 1897 [Blau, 2001]. His invention led to the founding of the Ferodo Company, a firm that still supplies brake lining materials today. In 1901, Herbert patented a block made from layers of textile material impregnated with rubber, if the block was to be used against steel, or wax, if it were to be used against rubber. As the duty of the brakes increased, the cotton tended to char, so in 1908, Herbert replaced it with asbestos.

Brake pads were generally made from asbestos fibers. Despite its good properties, asbestos is being withdrawn from all its applications, because of its carcinogenic effect on human, so where there is a possibility of alternative material for making non-carcinogenic brake pad.

The aim of this research is to examine the design and production of automotive brake pads with a view to improving their properties.

The objective is to characterized and pulverized *sawdust* and incorporates it as base material in the production of automotive brake pad.

EXPERIMENTAL

Materials

The materials used during the course of this work are: Phenolic resin, phenol formaldehyde, sawdust, steel dust, silicon carbide, graphite with compositional analysis and photo as shown in Table 1 and Figure 1.

Figure1. Photo of all the ingredients

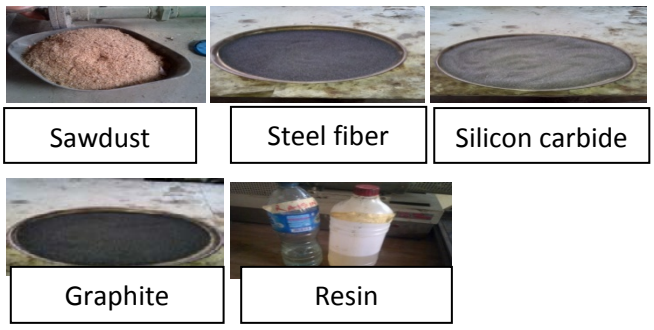

Table1: Elemental Composition analysis of sawdust particles.

S/N	Parameter	Level of Detection (%)
1	SiO_2	0.022
2	Al_2O_3	0.063
3	Fe_2O_3	0.007
4	CaO	0.214
5	MgO	0.030
6	Na_2O	0.831
7	K_2O	0.542
8	MnO	0.005
9	Moisture	0.003
10	L.O.I	97.152

Raw Material Preparation

The sawdust was sun dried for about 1 month after collection. The dried sawdust was milled into powder using a ball milling machine (Model 87002 Limoges-France, A50……43) and then sieved into different sieve sizes of aperture 1mm, 355µm, 280µm and 100µm. Using a set of BS 410 standard sieves (Endecotts Ltd., London) [8] in the brake lining formulation.

The samples were produced using a compression moulding machine. With compression moulding, the counter mould was used to close the mould after impregnated. Different composition and sieve grades (i.e. 1mm, 355µm, 280µm and 100µm) of sawdust, silicon carbide, graphite, steel dust and phenolic resin were added together in the ratio shown below respectively.

Table 2.

S/N	MATERIALS	A	B	C	D	E
1.	Sawdust	35	40	45	50	55
2.	Steel dust	20	20	20	20	20
3.	SiC	20	15	10	5	0
4.	Graphite	10	10	10	10	10
5.	Epoxy resin	20	20	20	20	20

The combination were properly dry mixed in a mixer, to achieved a homogenous state and transferred to a mould kept in a hot platen press at temperature of 180°C at 1160KN/cm² pressure for 2 minutes. After removing from hot press, the brake pad was cured in an oven at a temperature of 120°C for 8 hours [8, 9]. The photos of the produced samples and the process flow chart are shown in Figure 3 & 4 below.

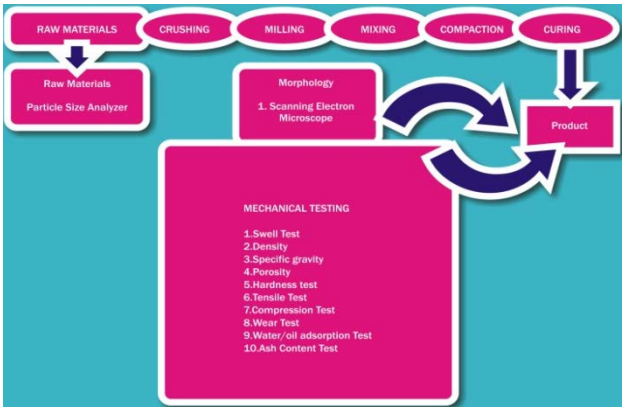

Figure 2. *Process technology flow chart of brake pad manufacturing from sawdust composite.*

Figure 3. Photo of the produced samples (Products)

Sample Characterization

Brinell hardness test.

The resistance of the composites to indentation was carried out through the Brinell hardness testing equipment to BS240, using a Tensometer (M500-25KN, Gunt Hamburg Hardness Tester and WP300) pressing hardened steel ball with diameter *D* into a test specimen. Based on ASTM specification, a 10 mm diameter steel ball was used, and the load applied Pwas kept stable at 3000 kg/f. The diameter of the indentation d was measured along two perpendicular directions, using an optical micrometer screw gauge. The mean value was taken and incorporated into Eqn. 1 to obtain the Brinell Hardness Number (BHN).

$$BHN = 2P \div \pi D(D-\sqrt{D^2-d^2}) \quad \ldots\ldots\ldots\ldots (1)$$

Where P is the load applied, D is the diameter of hardened steel ball into a test specimen and d is the diameter of indentation

Compressive strength test

The compressive strength test was done using the Tensometric Machine. The samples of diameter 29.40mm was subjected to compressive force, loaded continuously until failure occurred. The load at which failure occurred was then recorded.

Ash content test

Weigh about 1.20g ± 0.1g of the samples in a cooled crucible previously oven dried by heating in a furnace at 550^{0}C for 1 hour. Then the samples were charred by heating in a hot plate thereafter the charred samples were taken into the furnace and heat at 550^{0}C for 1 hour. Then cool in a dessicator and weigh. This processing of heating, cooling and reweigh were repeating until a constant weight is obtained.

Calculation:

$$\%ash = \frac{(W_2-W_0)}{(W_1-W_0)} \times 100 \quad \ldots\ldots\ldots\ldots (4)$$

Where W_0=weight of empty crucible
W_1-weight of crucible + sample
W_2=weight of crucible and residue i.e. after cooling.

Density test

The density of the samples was determined by weighing the samples mass on a digital weighing machine and divided by measuring their volume by liquid displacement method. The formula is show in Eqn. 4 below.

$$\text{Density } (\varrho) = M \div V \times 10 \quad \ldots\ldots\ldots\ldots\ldots (6)$$

Where M is the mass of test piece (g) and V is the measuring volume of test piece (cm^3) by liquid displacement method

Wear Rate Test

The wear rate for the samples were measured using pin on disc machine by sliding it over a cast iron surface at a load of 10N sliding speed of 125rev/min and sliding distance of 2000m. All tests were conducted at room temperature. The initial weight of the samples was measured using a single pan electronic weighing machine with an accuracy of 0.01g. During the test, the pin was pressed against the counterpart rotating against a cast iron disc (hardness 65 HRC) of counter surface roughness of 0.3μm by applying the load. A friction detecting arm connected to a strain gauge held and loaded the pin samples vertically into the rotating hardened cast iron disc. After running through a fixed sliding distance, the samples were removed, cleaned with acetone, dried, and weighed to determine the weight loss due to wear. The differences in weight measured before and after tests give the wear of the samples. The formula used to convert the weight loss into wear rate is [Osterle, W., Griepentrog, M., Gross, T. And Urban. I(2001), Blau, P(2001)]:

$$\textit{Wear rate} = S/W \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where ΔW is the weight difference of the sample before and after the test in mg, S is total sliding distance in m.

Porosity

A samples of diameter 29.40mm with a different height thickness of as thick as possible was used. The specimens were weight to the nearest in mg, and then soak in oil and water container at 90-100oC for 8hrs. The samples were leave for 24hrs and then taken out from the oil container. Finally, the test samples were weight to the nearest mg. this formula was noted in Eqn 11. (Malaysian standard).

$$\text{Porosity } (\varrho) = [(M_2-M_1) \div (D)] \times 100 \div V \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

D is the density of test oil and water M_2 is the mass of test piece after absorbing oil and water (g), M_1 is the mass of test piece (g) and V is the volume of test piece (cm^3).

Micro-structural Analysis

The microstructural analyses of the samples were carried out by grinding the samples using 300, 400, and 600 grit papers respectively. Dry polishing was then carried out on these samples and the internal structures were viewed under the computerized Metallurgical microscope [1]

The products are in compliance with National and International Standards:

Table 3

S/N	Test procedure	Standards
1	Rockwell Hardness Test	MS 474:PART 2: 2003
2	Compressive Strain Test Method	MS ISO 6310:2003, PART 4
3	Resistance to Water, Saline Solution, Oil & Brake Fluid	MS ISO 6314:2003, PART 8
4	Assessment of Friction Materials and Wear/ Microstructure	MS 474:PART 10: 2003
5	Porosity Measurement	JIS D 4418 – 1996
6	Vehicle Braking Test	ECE R13
7	Field Test on LRT Test Track	Company's Specifications
8	Ash test	SAE J160 Jun80

RESULTS AND DISCUSSION.

Brinell hardness test.

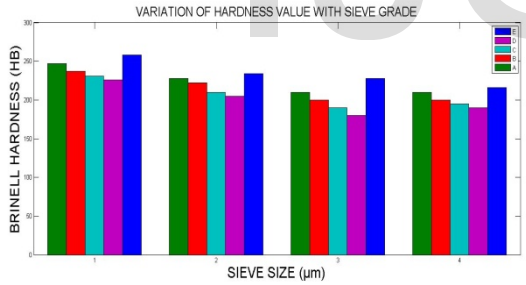

Figure 4 show the result of the Brinell hardness with sieve size particle. The sample with 100µm sieve grade of different proportion from A-E has the highest hardness value of 158HBN, 247HBN, 237HBN, 231HBN & 226HBN. A sharp drop in hardness was observed in the samples with higher sieve grades (280µm, 355µm & 1mm). The high hardness for the 100µm sieve grade was as a result of reduced particle size of sawdust i.e. increases in surface area which resulted to increase bonding ability with the resin. The hardness value for this material was compared with other materials from other researches [12], [13] as shown in the Table7 which indicated an acceptable result with the findings of other researchers.

Compressive Strength Test.

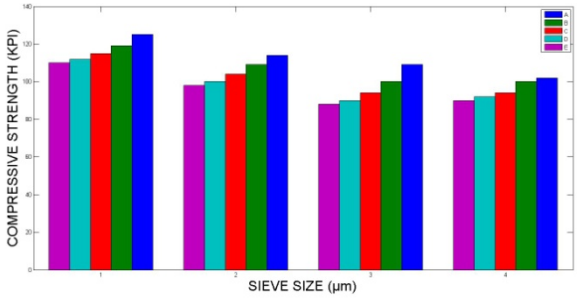

Figure 5 show the result of the compressive strength and peak value with sieve size.The 100µm sieve grade also has the highest compressive strength of 125N/mm² and peak value of 33.345N/mm². The gradual decrease in compressive strength and peak value as the sieve size increases can be attributed to the decreasing surface area and pore packaging capability of the sawdust particles in the resin. Hence, compressive strength increases as particle size of palm kernel shell decreases

Density Test

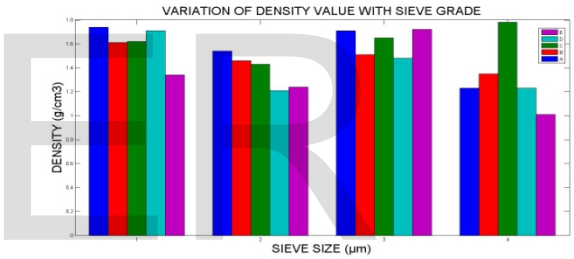

Figure 6 shows the result of the density with sieve size. The density deceased as the sieve size of the sawdust increases in the composition.

The decreased in density can be attributed to the increases in particle size i.e. increased packing of PKS. The 100µm has the highest density which is as a result of closer packing of sawdust particles creating more homogeneity in the entire phase of the composite body [12].

Wear Rate

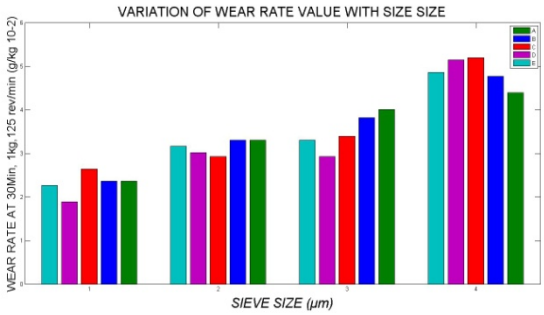

Figure 7 shows the wear rate result of the produced samples. The figure shows decrease in wear rate as the sieve grade of sawdust increases. This resulted to higher/ closer packing

which has affected stronger binding of sawdust within the composition. This may also be due to high hardness values and compressive strength of the samples as sieve size is decreased.

POROSITY

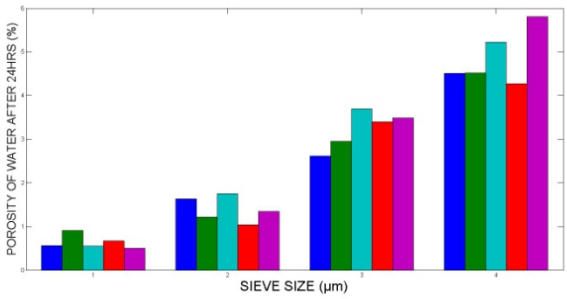

Fig.8. Show the result of the porosity with sieve size. Those properties increased as the sieve grade increases which can eventually be attributed to the increases pores as sieve size increases. These results are in par with the earlier observation of Refs. [1-5]. It can be seen from the result that sample with 100 µm gave the best properties as a result of a very good dispersion of sawdust particles as shown by the white region and dark region resin(see Figure 4a-8e) which led to a better interfacial bonding of the resin and the sawdust particles as seen in subsequent samples.

Ash Content Test

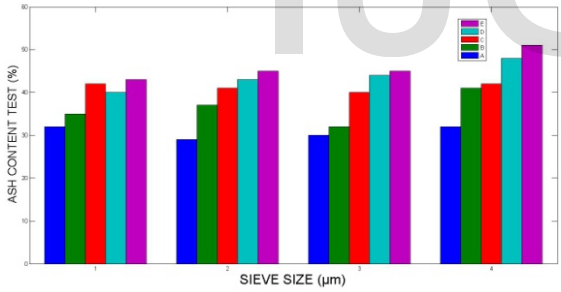

Figure 9 has shown the flame resistance of the produced samples, and it can be seen from the graph as the properties increased so as the sieve grade increases which can eventually be attributed to the increases pores as sieve size increases. It can also be observed from the result that samples with 100µm gave the best properties as a result of a very good dispersion of decreased in size particles.

Microstructural Test

A100 µm B100 µmC100 µmD100 µmE100 µm

A280 µm B280 µm C2800 µm D280 µmE280 µm

A355 µmB355 µmC355 µm D355 µm E355µm

A1mm B1mm C1mm D1mm E1mm

Figures 10. a), b), c), d) &e) -8a), b), c), d) and e have showed the microstructure of the samples. Microstructure of 100µm, 280µm, 355µm and 1mm sieve grade sample(X100).
Showing uniform dark red region of resin and white region of Sawdust.

Summary of result findings compared with existing ones (1)

Table 4

s/n	PROPERTY	BRAKE PAD COMMERCIAL (ASBESTOS BASED)	NEW FOMULATION LAB BRAKE-PAD (SAWDUST) RECOMMENDED
1	Hardness (at 3000kgH)	101	226-258
2	Compressive strength	110	110-125
3	Density	1.320	1.350-1.750
4	Porosity Measurement Water: Oil :	0.52 0.61	0.50-0.57 0.41-0.76
5	Assessment of Friction Materials and Wear/ Microstructure MS 474:PART 10: 2003	(g/km*10-2) 3.800	(g/km*10-2) 1.887-2.359
6	Flame resistance test at 1 hour	Charmed with 69% ash	Charmed with 30-40 ash

The result of this research work indicates that samples containing 100µm of formulation (A-E) gave better properties than other samples like 280µm, 355µm and 1mm size particles from formulation (A-E) tested. Hence, the lower the sieve grades of sawdust, the better the properties. The 100µm sieve size results were compared with that of commercial brake pad (asbestos based) and new formulation laboratory brake pad

(SAWDUST) based as shown in the Table 4, which were tested under similar conditions.

The results are in close agreement. Hence asbestos free brake pad can be produced with 100µm sieve size formulation. Taking into consideration, all the desired dimensions of the brake pad, a prototype of infinity (QX) and pathfinder jeep brake pad of length of 131mm, width of 50mm and depth of 8mm, the friction material was produced with this 100µm sieve size formulation (see Table 2). The produced prototypes were carried out with field test to show that the formulation can be used in the production of automotive brake-pad.

Produced sawdust composite brake pads

01-2716000

CONCLUSIONS

From the observation and discussion of this research work the following conclusions can be made:

1. The samples, 100µm sieve grade of sawdust gave the better properties in all.
2. Compressive strength, hardness, densities and porosity of the produced samples were seen to be decreasing with increase in sieve grade while there water soak, wear rate and percentage charred increased as sieve grade increased.
3. Based on the above test properties of these brake pads composite using sawdust as filler can be effectively used as an alternative to existing fillers, such as asbestos, in brake pad composites.

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