Issue 28, January-June 2016
p. 95-108

Development of automobile brake lining using pulverized cow hooves

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Abstract

Asbestos has been used for so long as automobile brake lining material because of its good physical and chemical properties. However, due to the health hazard associated with its handling, it has lost favour and several alternative materials are being increasingly used. Asbestos-free brake lining was developed in this work using pulverized cow hooves along with epoxy resin, barium sulphate, graphite and aluminium oxide. This was with a view to exploiting the characteristics of cow hooves, which are largely discarded as waste materials to replace asbestos which has been found to be carcinogenic. Samples of brake linings were produced using compressive moulding in which the physical and mechanical properties of the samples were studied. The results obtained showed that proper bonding was achieved as the percentage by weight of epoxy resin increased and percentage by weight of pulverized cow hooves decreased. The hardness, compressive strength, coefficient of friction, water and oil absorption, relative density and wear rate of the brake linings were determined and compared with existing brake lining properties. The result indicates that pulverized cow hooves can be used as brake lining material for automobiles.

Keywords

Automobile; Brake lining; Pulverized cow hooves; Asbestos; Hardness; Wear;

Friction; Palm kernel shell (PKS)

Introduction

Brake linings are the consumable surfaces in brake systems, such as drum brakes and disc brakes used in transport vehicle. Brake linings are composed of a relatively soft but tough and heat-resistant material with a high coefficient of dynamic friction and ideally an identical coefficient of static friction typically mounted to a solid metal backing using high temperature adhesives or rivets. The complete assembly is often called a brake pad [1]. Brake pads are the most important safety and performance components in automobiles [2]. They convert the kinetic energy of a moving vehicle to thermal energy by friction during braking process.

The major component in the brake pad lining materials is asbestos fibers embedded in polymeric matrix along with some other ingredients [3]. Typical formulations of brake pads linings consist of more than ten ingredients and more than 300 materials in different brands [4]. These ingredients are classified into five main constituents: binders, reinforcing fibers, fillers, friction modifiers/additives, and organic materials. Brake linings have generally been made from asbestos as filler due to its few desirable engineering characteristics. It is thermally stable at 490 - 500°C, strong and flexible, insulates thermally, and helps to generate friction surface during usage [1]. In spite of its good properties, the use of asbestos has been discontinued due to its carcinogenic nature [2].

A lot of researches have been carried out in the area of development of asbestos-free brake linings. Recent development in brake lining industry focuses on a search for non-asbestos substitute for brake lining. This has motivated researchers to explore the potentials of some agricultural wastes to be used in brake lining development. Some of these agricultural wastes poses environmental hazard as their disposal is often a thing of concern [5].

The use of coconut shell and palm kernel shell (PKS) has been investigated [6, 7, 8]; while investigation on asbestos-free brake lining using bagasse [2] concluded that bagasse can be used for automotive brake linings. The properties of periwinkle shell was evaluated and used to develop brake lining [9], and the results proved that it can be used as brake friction material. Eco-friendly brake linings using banana peels [10] was investigated and the findings concluded that banana peels can effectively replace asbestos. Palm slag was also employed for the production of brake pads and the results indicated that palm slag can be used effectively as an alternative to asbestos in brake lining composites [11]. The results on evaluation of palm kernel fibers for production of asbestos-free automotive brake pads [12] indicate that palm kernel fibers can satisfactorily replace asbestos as brake friction material. Egg shell based eco-friendly brake pads were developed and evaluated [13] with gum Arabic as binder. While most recently maize husks based brake pad as a suitable replacement for asbestos in automotive brake pad was developed [3]; and reinforced polymer composite PKS and cow bone particles was investigated as alternative for brake pad formulation [14].

The above presented information shows a paradigm shift from the use of asbestos as brake lining material to plants and animal products. The research presented in this manuscript focuses on the development of brake linings using pulverized cow hooves (an animal by-product). The pulverized cow hooves were characterized in terms of its bulk density, relative density and elemental composition. While the developed brake lining was evaluated in terms of hardness, compressive strength, coefficient of friction, oil and water absorption, relative density and wear rate.

Material and method

The materials used for this research for the development of the brake lining as shown in Figure 1 include: unpulverized cow hooves, grahite, pulverized cow hooves, barium sulphate, aluminium oxide and epoxy resin.

The cow hooves were obtained from a local abattoir, washed and properly sun-dried. The hooves were further dried in an electric vacuum oven for three hours at 250^{o}C to remove contaminating oil. The hooves were crushed using pestle and mortar and further grounded into powder in a conventional mill and thereafter sieved using sieve size of 710µm as shown in Figure 1c. Graphite was obtained from dead dry cell batteries which was crushed into powder and sieved using 710µm sieve size. Aluminium oxide, barium sulphate and epoxy resin were bought from an open shop.

The elemental composition of the pulverized cow hooves was determined by X-Ray Fluorescence (XRF) by forming the pulverized cow hooves into pellet using a pelletizer with hydraulic press. The pellet was then enclosed in the chamber of the XRF and allowed to run for 1000 seconds at a voltage of 25kV and a current of 50µA. The resulting spectrum measured the elemental composition of the cow hooves.

(a) (b) (c) (d) (e) (f)

Figure 1. *Photographs of the selected materials: (a) Unpulverized cow hooves, (b) Graphite, (c) Pulverised cow hooves, (d) Barium sulphate, (e) Aluminium oxide, (f) Epoxy resin*

Production of brake lining samples

Production of brake lining consisted of a series of operations including mixing, hot pressing, cooling, post-curing and finishing [15]. The weights of the pulverized cow hooves and epoxy resin were varied from 10% to 40% by weight at an interval of 5% to give seven samples formulation, while the weights of the aluminium oxide and graphite was 10% each, and barium sulphate at 30% as shown in Table 1.

Seven test samples were produced as shown in Figure 2 by pouring the mixtures for each of the formulation into a container and stirred thoroughly to obtain a homogenous matrix mixture. The mixture was then poured into a mould of length = 100mm, breadth = 100mm and thickness= 10mm.

Table 1. Percentage proportion of materials used for brake lining samples

Brake materials	**Samples weight (%)**						
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
Pulverized cow hooves	40	35	30	25	20	15	10
Epoxy resin	10	15	20	25	30	35	40
Barium sulphate	30	30	30	30	30	30	30
Graphite	10	10	10	10	10	10	10
Aluminium oxide	10	10	10	10	10	10	10
Total (%)	100	100	100	100	100	100	100

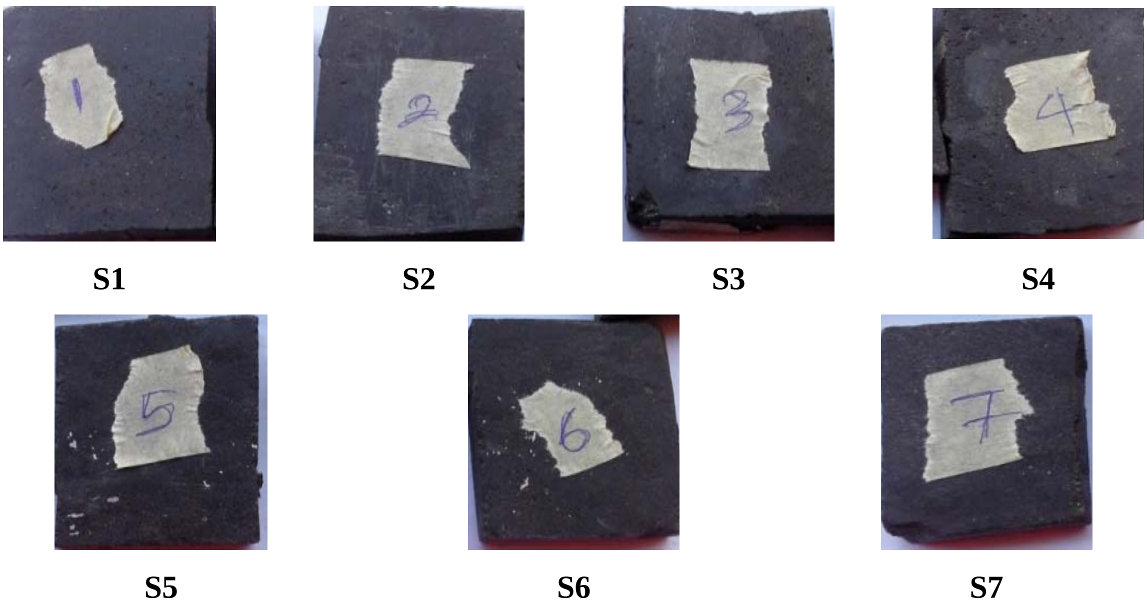

Figure 2. *Photograph of produced brake linings samples*

The mould containing the matrix mixture was transferred to a hydraulic press and subjected to hot pressing at a temperature of 70°C, and pressure of 30MPa for ten minutes. The product was then allowed to cool at a room temperature between (27-30°C). It was subsequently post cured in an electric oven at a temperature of 180°C for one hour and allowed to cool to room temperature. The developed brake linings were subjected to the several tests as presented below.

Hardness

The resistance of the produced brake linings to indentation was carried out using the Shore D hardness tester. It was done according to the provisions in American Society of Testing and Materials (ASTM) D2240. Each sample was placed on a hard flatten surface. The indenter of the instrument was then pressed into the specimen with an applied load of 50N for 15 seconds. The hardness value was read from the durometer.

Compressive strength

The resistance of the developed brake linings to compression under compressive force or load was performed using the Enerpac universal hydraulic material testing machine. Each sample was placed between the plates of the load frame. Force was applied gradually and the value was displayed on a digital device. Three samples from each formulation were tested for compressive strength and the average calculated. Equation 1 was used to calculate the compressive strength (σ_c) of the linings.

$$\sigma_c = \frac{F}{A} \tag{1}$$

where F = Applied force, A = cross sectional area.

Coefficient of friction test

The coefficient of friction between the linings and steel was determined using a steel inclined plane. The plane was kept at 180° (horizontal position). Each sample was attached to a string and placed on the plane. The string was passed through a pulley, which was connected to a mass hanger. Standard masses were added to the mass hanger until the lining began to slide along the surface of the steel plane. The coefficient of friction is the ratio of frictional force (equivalent to mass at hanger to initiate sliding) to the normal reaction (weight of break lining). Equation 2 was used to calculate the coefficient of friction (μ) between the linings and steel.

$$\mu = \frac{F_r}{F_n} \tag{2}$$

where F_r = friction force (N), F_n = normal reaction (N).

Relative density

The relative density of the brake linings were found using Archimedes principle. The buoyant force on a submerged object is equal to the weight of the fluid displaced [9]. The samples were weighed in air and when fully immersed in a beaker of water by means of a thread without touching the walls of the beaker. The weight difference is equal to the volume of water displaced, which is to the volume of each sample. The relative density (ρ_{br}) was calculated using Equation 3;

$$\rho_{br} = \frac{W_a}{W_a - W_w} \quad (3)$$

where W_a = weight in air (g), W_w = weight in water (g).

Wear rate

The wear test was carried out using an adopted method [16]. The method involves placing each sample (clamped rigidly in position) along the disc of a grinding machine for 10 seconds. The weights of the samples were taken before and after grinding. The weight difference from each sample indicates the lost in weight. The speed of the grinding machine and its disc diameter were 6500 revolution per minute (rpm) and 180 mm respectively. The wear rate (W_r) was calculated using Equation 4.

$$W_r = \frac{\Delta W}{2\pi NRt} \quad (4)$$

where ΔW = weight loss (weight difference before and after wear (g), R = radius of disc (m), N = speed in rpm, t = time it takes each sample on the grinding machine (min).

Water and oil absorption

The water and oil (SAE 20/50) absorption of the samples was determined by soaking the samples in water and oil for 24 hours. Before the test, the samples were oven dried and the weight measured. The samples were cleaned after 24 hours in water and oil, and weighed. The percentage absorption was calculated using equation 5 [10].

$$Absorption = \frac{W_1 - W_0}{W_0} \times 100\% \quad (5)$$

where W_0 = weight of sample before immersion (g), W_1 = weight of sample after immersion (g).

Results

The result of elemental composition of the pulverized cow hooves determined using the X-ray fluorescence is presented in Table 2 which has the following properties:

Bulk density of pulverized cow hooves = 683 kg/m^3

Specific gravity of pulverized cow hooves = 1.89

While the results shown in Figures 3 to 9 are for the tests of hardness, compressive strength, coefficient of friction, relative density, wear rate, water absorption, and oil absorption for the developed brake lining samples respectively.

Table 2. X-ray fluorescence analysis of cow hooves

Elements	**Percentage**	**Elements**	**Percentage**
Silicon	50.20	Zinc	0.246
Phosphorus	15.30	Rubidium	0.33
Sulphur	1.30	Strontium	0.092
Potassium	21.30	Yttrium	0.05
Calcium	5.50	Zirconium	0.29
Titanium	0.40	Copper	0.0001
Barium	0.19	Vanadium	0.03
Manganese	1.24	Europium	0.02
Iron	3.22	Rhenium	0.01
Silver	0.30		

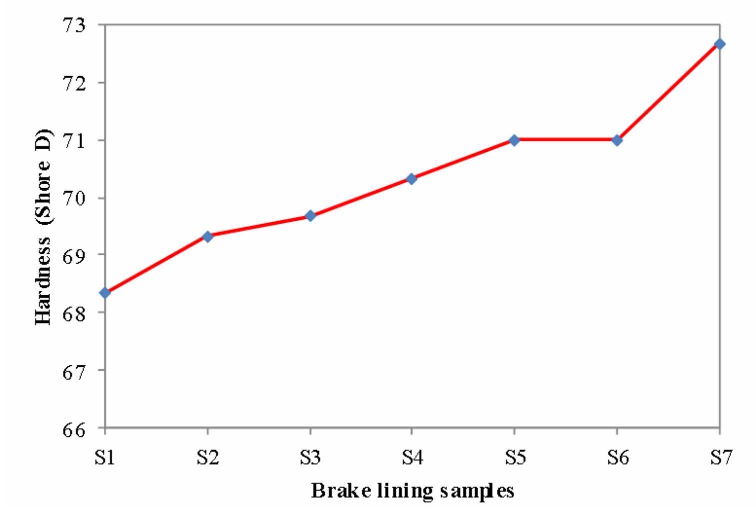

Figure 3. *Variation of hardness with different samples of brake lining*

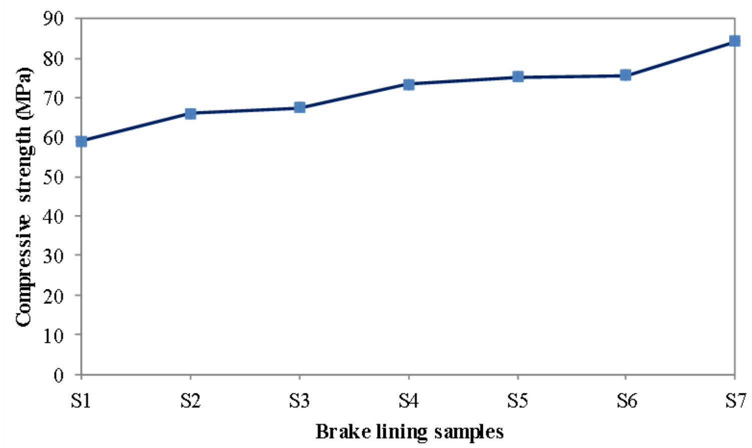

Figure 4. *Variation of compressive strength with different samples of brake lining*

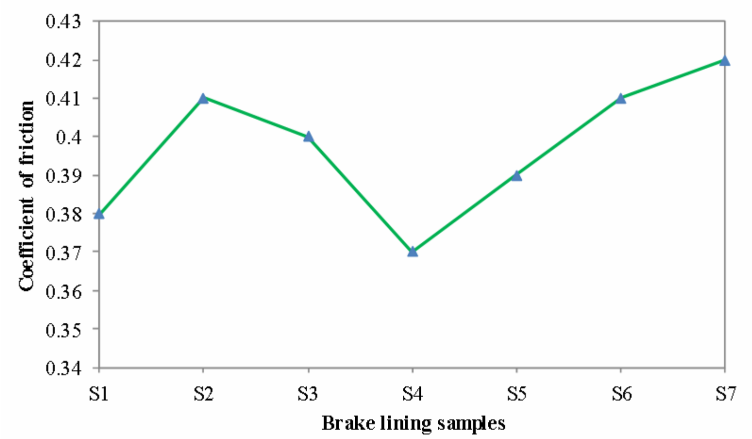

Figure 5. *Variation of coefficient of friction with different samples of brake lining*

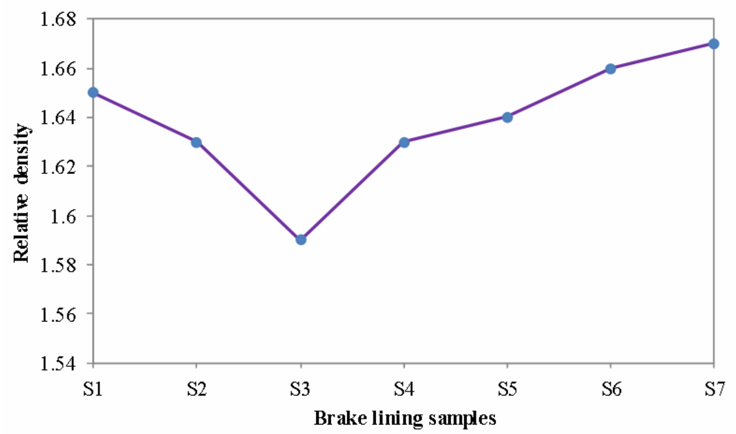

Figure 6. *Variation of relative density with different samples of brake lining*

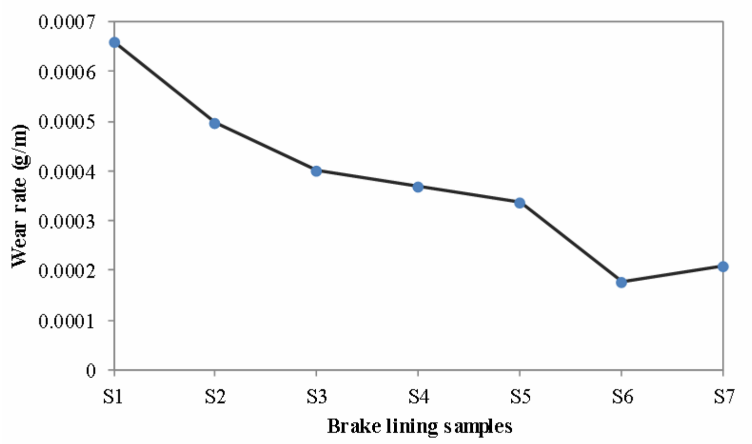

Figure 7. *Variation of wear rate with different samples of brake lining*

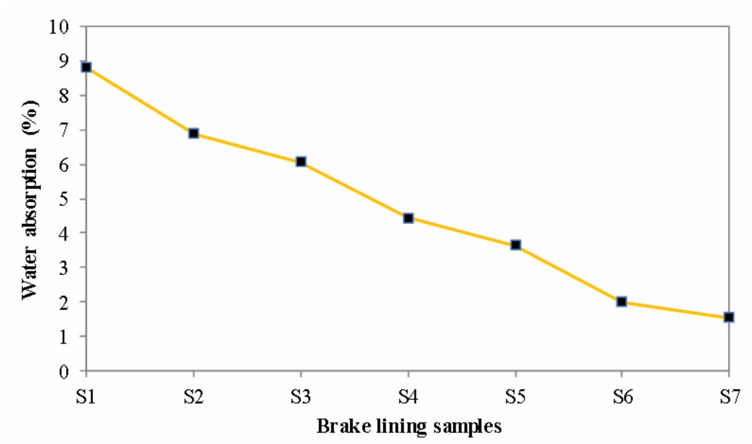

Figure 8. *Variation of water absorption with different samples of brake lining*

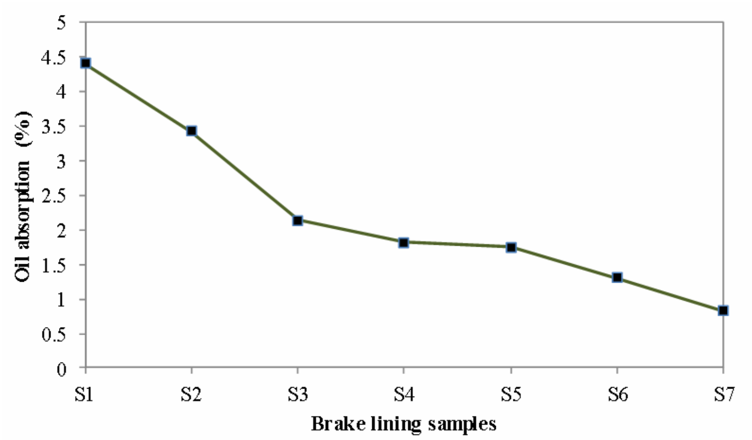

Figure 9. *Variation of oil absorption with different samples of brake lining*

Discussion

The results of the Shore hardness on D scale are shown in Figure 3. From the results, the hardness values increases as the percentage by weight of epoxy resin is increased and pulverized cow hooves is decreased. The high hardness from the increase of epoxy resin is due to the fact that the resin is a thermosetting polymer showing high strength after curing [17]. Also, may be due to better interfacial bonding achieved as more resin is added.

The results of the compressive strength shown in Figure 4 have a similar trend with that of hardness values. The values increase as the percentage of pulverized cow hooves decreases and percentage of epoxy resin increases. This may be due to good distribution and dispersion of the resin and other additives resulting in strong particles resin interaction. This good particles dispersion will improve the particles-resin interaction and consequently increases the ability of the brake lining formulation to restrain gross deformation [10].

The result of coefficient of friction is shown in Figure 5. The values vary from 0.37 to 0.42. The coefficients of friction of all the samples fall within the industrial standard ranges of 0.3 to 0.45 for automotive brake linings system [10].

The results of the relative density of the formulations are shown in Figure 6. The values decrease from sample one to three, and increases from sample four to seven as percentage by weight of epoxy resin is increased and pulverized cow hooves is decreased. This decrease in the relative density can be attributed to the decrease in percentage of pulverized cow hooves while the increase can be attributed to the increased bonding achieved between the resin and other additives [10].

The wear rate of the produced brake lining samples is shown in Figure 7. The wear rate decreases as the percentage by weight of pulverized cow hooves decreases and percentage by weight of epoxy resin increase. This may be as a result of high hardness values and compressive strength of the samples as the resin addition increased in the compositions and also be attributed to closer packing of the microstructure and better interfacial bond between the particle and the resin, reducing the possibility of particle pull out which may result in higher wear [2, 18].

The data for the water and oil absorption tests are shown in Figure 8 and 9. These properties decreased as the percentage by weight of epoxy resin increases and pulverized cow hooves decreases. These can be attributed to the decreased pores because of the increase in interfacial bonding between the resin and other additives. This is indicates that increase in hardness of a composite reduces porosity [17]. Therefore samples 6 and 7 have the best porosity that can be recommended for brake lining [2].

Comparison of cow hooves brake lining with other experimental brands

A comparison of properties of the formulated samples shows that samples (S6) and (S7) have properties comparable with that of commercial brake pad (asbestos based), Palm Kernel Shell (PKS) and Bagasse based as shown in Table 3 [2, 3, 7].

Table 3. Comparison of results of cow hooves brake lining with existing formulations

Property	**Commercial (Asbestos based)**	**Formulation (PKS based)**	**Formulation (Bagasse based)**	**Sample (S6) (Pulverized cow hooves)**	**Sample (S7) (Pulverized cow hooves)**
Hardness (Shore D)	-	-	-	71	72.67
Compressive strength (MPa)	110	103	105.6	75.53	84.23
Coefficient of friction	0.3 – 0.4	0.43	0.42	0.41	0.42
Relative density	1.89	1.65	1.43	1.66	1.67
Wear rate (g/m)	3.8×10^{-4}	4.4×10^{-4}	4.2×10^{-4}	1.76×10^{-4}	2.08×10^{-4}
Water absorption (%)	0.90	5.03	3.48	2.00	1.54
Oil absorption (%)	0.30	0.44	1.11	1.30	0.83
Toxicity	Toxic	Non-toxic	Non-toxic	Non-toxic	Non-toxic

Conclusions

The developed brake linings show that pulverized cow hooves is a suitable material for brake lining with required characteristics. The analysis of the experiments conducted shows that:

Pulverized cow hooves contain non-toxic elements. And its density values make it suitable in brake lining application. Compressive strength, hardness, relative density and coefficient of friction of the produced samples were seen to be increasing with increase in percentage epoxy resin and decrease in pulverized cow hooves. While the water and oil absorption and wear rate decreased as epoxy resin increased and pulverized cow hooves decreases. The sample (S6) containing 15% pulverized cow hooves, 35% epoxy resin and sample (S7) containing 10% cow hoof and 7% epoxy resin gave the better properties for brake lining formulation. The results obtained compared favorably with that of commercial brake lining and other experimental brake linings formulations an indication that, pulverized cow hooves can be used to replace asbestos in brake lining formulations.

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