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Comparative Study on Thermal, Compressive, and Wear properties of Palm Slag Brake Pad Composite with Other Fillers

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Abstract: The attractive performance-to-cost ratio associated with the incorporation of waste material in composite formulations used to produce brake pads has stimulated the idea of exploring the possible incorporation of additional waste materials in such formulations. Thus, the viability of adding palm slag to the composite formulation used in brake pads was investigated, and the results are reported in this paper. In addition, other fillers, such as calcium carbonate and dolomite, were used for comparative purposes. The properties examined included thermal properties, compressive strength, and wear behavior. The results showed that palm slag has significant potential for use as an alternative to the existing fillers in the composite formulations used to produce brake pads.

Key words: Palm slag, calcium carbonate, dolomite, brake pad composite, compressive strength, wear behavior

INTRODUCTION

The development of innovative friction materials for use in brake pads by using sustainable approaches, including the use of industrial waste byproducts from coal combustion and coal gasification, such as fly ash, would help control the health hazards associated with fly ash and reduce the rate of depletion of important natural resources such as forests and minerals. 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 μm) (of SiO_2, Al_2O_3, $CaSO_4$, 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.

This paper addresses the potential use of palm slag-based friction composites. Palm slag is a byproduct of the palm oil production process. The disposal of palm slag is an economic and environmental liability for palm oil producers throughout Malaysia. In order to compare the performance of palm slag-based composites with the performance of other composites, dolomite-based and calcium carbonate-based friction composites were also studied.

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Materials And Experimental Set Up:

Raw Materials

Five types of raw materials were used, i.e., phenolic resin, filler (palm slag, calcium carbonate, dolomite), graphite, steel fiber and alumina. The three filler materials were obtained as follows: a local palm oil producer (Seberang Perai) supplied the palm slag; calcium carbonate was obtained from a local supplier (Ipoh); and dolomite was supplied from Rimba Mas quary (Perlis). Phenolic resin was selected as the binder, steel fiber was used for reinforcement, graphite was used as a lubricant, and alumina was used as an abrasive. The amounts (as percentages) of each of these materials in the composite material are shown in Table 1.

Table 1: Material content (wt%) in the composite brake pad material.

Materials	Recipe 1	Recipe 2	Recipe 3
Phenolic Resin	20	20	20
Palm slag	40	-	-
Calcium carbonate	-	40	-
Dolomite	-	-	40
Graphite	10	10	10
Steel fiber	20	20	20
Alumina	10	10	10

Each recipe was mixed to obtain a homogeneous mixture of ingredients. Then, the mixtures were compacted at a pressure of 15-17 MPa using a unaxial, hydraulic hand-press machine for the green body of the brake pad composite. Then, the green body was compacted further and cured using a hot press at 150 °C with 60 tons of compressive molding pressure for five minutes. At the end of the hot-pressing process, samples were taken out of the molds, allowed to cool to room temperature, and cured further at a constant temperature of 150 °C for four hours.

Thermal Characterization:

Samples of palm slag, dolomite, calcium carbonate, and phenolic particles were subjected to thermo-gravimetric analyses (TGA). The TGA procedure monitored the weight of the respective samples as a function of temperature. For this study, the TGA test procedures were performed on a single sample during the course of a single experiment. They were also performed on the combination of palm slag, dolomite, or calcium carbonate (each as the filler) and the phenolic resin (as the binder) for representing a brake pad with the same experimental setup. The weights of the samples were monitored as a function of temperature. All of the samples were tested over the temperature range of 30-1000 °C. Nitrogen was used as the inert gas during the experiments.

Compressive Strength of the Composite:

The compressive strengths of the composite materials were determined using an Instron Universal Testing Machine (UTM). Each sample, consisting of an initial cross-sectional area of 86.6 mm^2, was placed between the lower cross member and lower cross head of the UTM, and the load was applied at a cross-head speed of 5 mm/min. The load at which failure occurred was used to calculate the compressive strength of the sample. Five replications of the compressive tests were conducted on the samples that had different types of fillers.

Wear Behavior of the Composite:

The wear of the brake pad composite materials was determined using a polisher machine with load. The setup was similar to the concept of the pin-on-disc test. The tested samples were in the form of cylindrical pins that were 10 mm in diameter and 15 mm in height. The pins were placed on a stainless steel wheel with a load of 10 N and a wheel speed of 100 rpm. The test was run for a constant distance of 1 km. The samples were weighed before and after testing to determine weight loss within an accuracy of 0.0001 mg. Wear volume and wear rate for the brake pad composites were determined using the following equations:

$$\text{Wear volume} = \frac{Wg_{\text{before}} - Wg_{\text{after}}}{\text{Density}, \rho} \quad (1)$$

$$\text{Wear rate} = \frac{\text{Wear volume } (m^3)}{\text{Sliding distance (m)}} \quad (2)$$

RESULTS AND DISCUSSION

Thermal Characterization:

Figure 1 shows the TGA curve of the phenolic resin. The small weight loss at 150 °C resulted from the curing behavior of the phenolic resin. Figures 2, 3, and 4 shows the TGA curve for the thermal behavior of palm slag, calcium carbonate, and dolomite fillers, respectively.

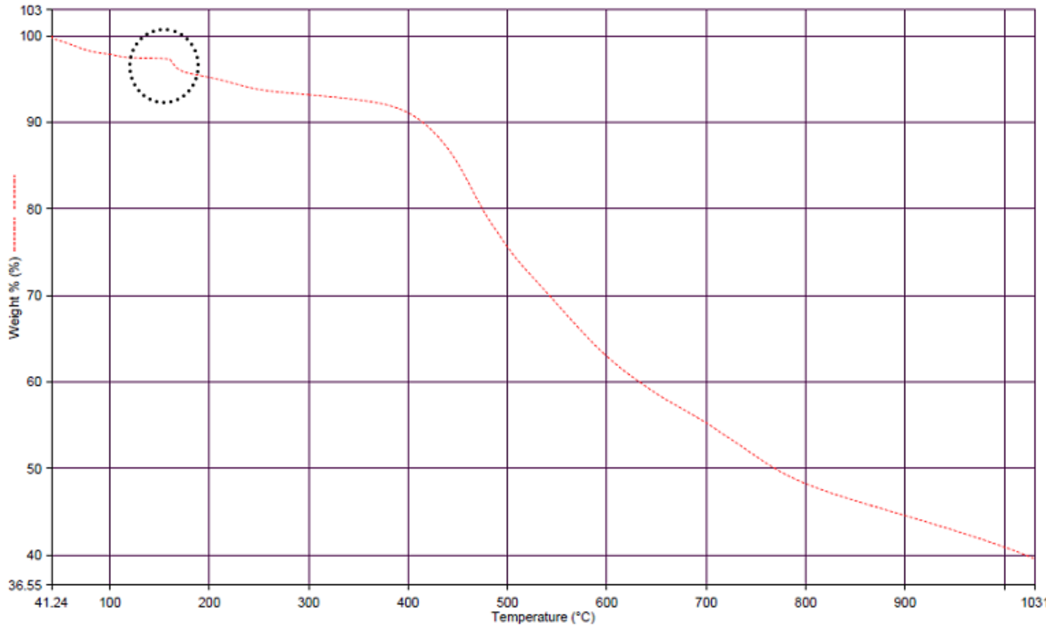

Fig. 1: TGA curve of phenolic resin as binder material.

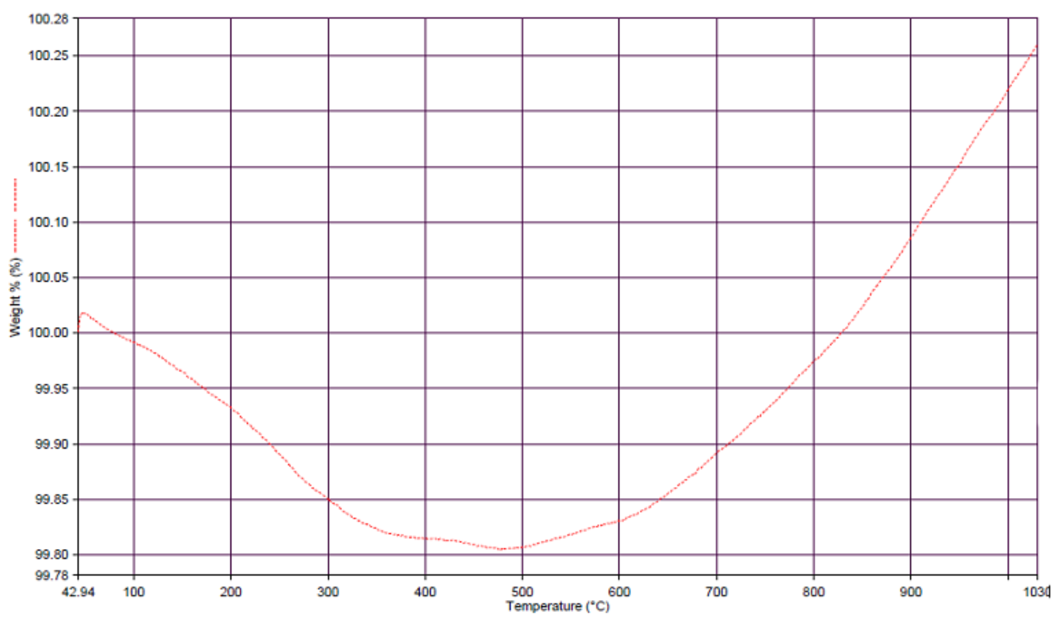

Fig. 2: TGA curve of palm slag as filler material.

These figures show that palm slag exhibited greater thermal stability than calcium carbonate or dolomite. Figure 2 shows that only small change in the mass of palm slag occurred over the test temperature range from 50 to 1000 °C. The small increase in mass that occurred between 500 and 1000 °C may be attributed by a phase change. Figure 3 shows that the mass of calcium carbonate decreased dramatically at temperatures above 650 °C, and Figure 4 shows that the mass of dolomite decreased dramatically at temperatures above 420 °C.

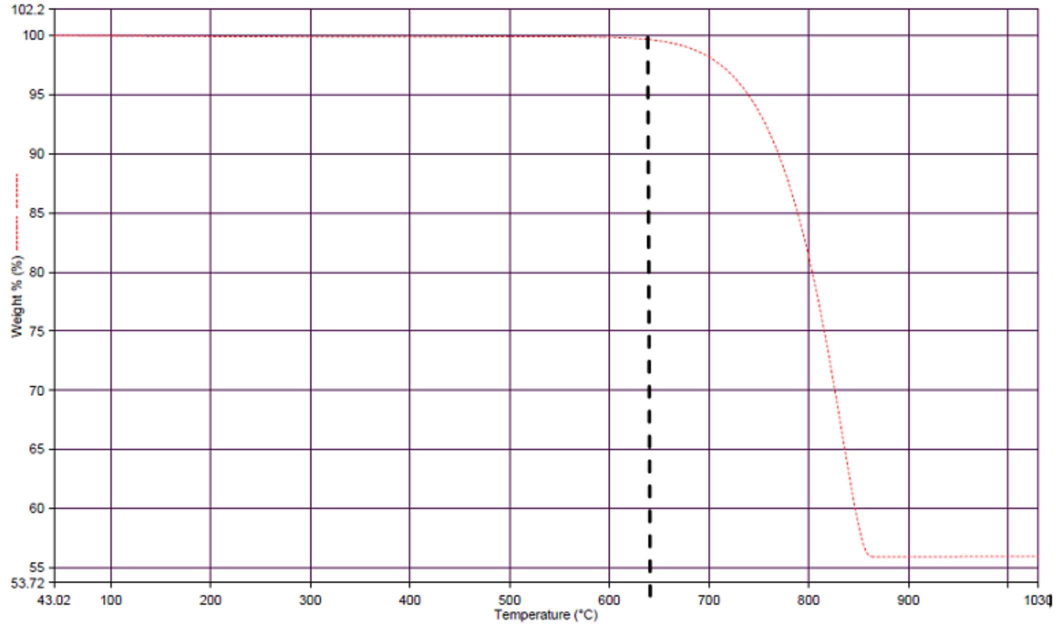

Fig. 3: TGA curve of calcium carbonate as filler material.

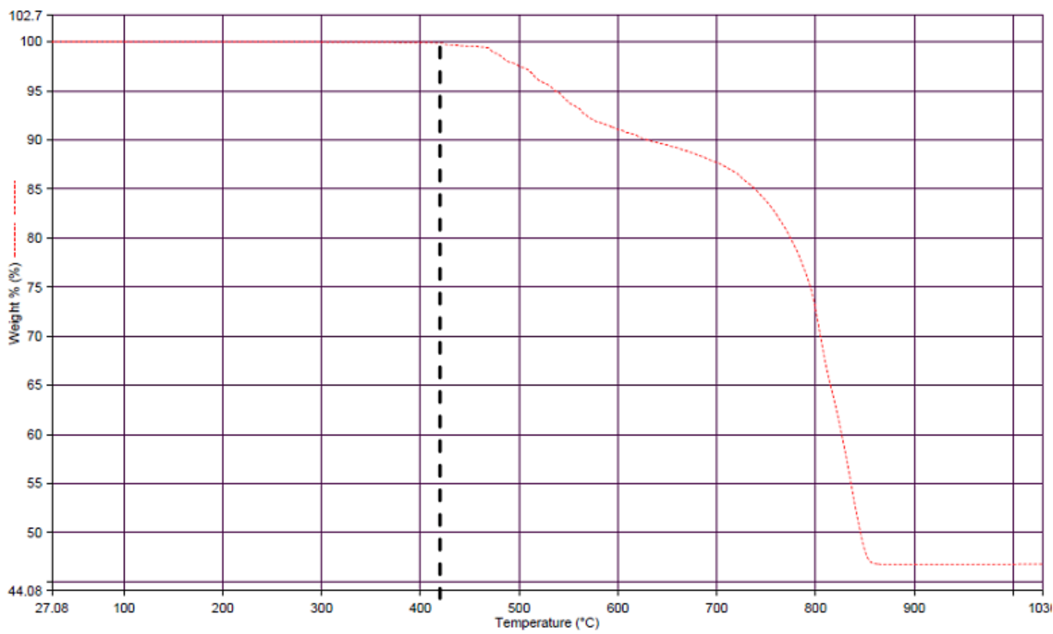

Fig. 4: TGA curve of dolomite as filler material.

Figures 1, 5, 6, and 7 show small weight losses at 150 °C in response to the curing behavior of the phenolic resin that was used as a polymeric binder in this brake pad. After that, two regions in which mass decreased can be observed, i.e., between 200 and 400 °C and between 420 and 800 °C. The decomposition of the binder should be seen as a mass loss (Ramousse *et al.*, 2001). The decrease in mass in the region between 200 and 400 °C might be due to the degradation of the organic material in the binder (Blau, 2001). The second region, between 400 and 800 °C showed larger mass losses, which are thought to be the result of the combustion of carbon.

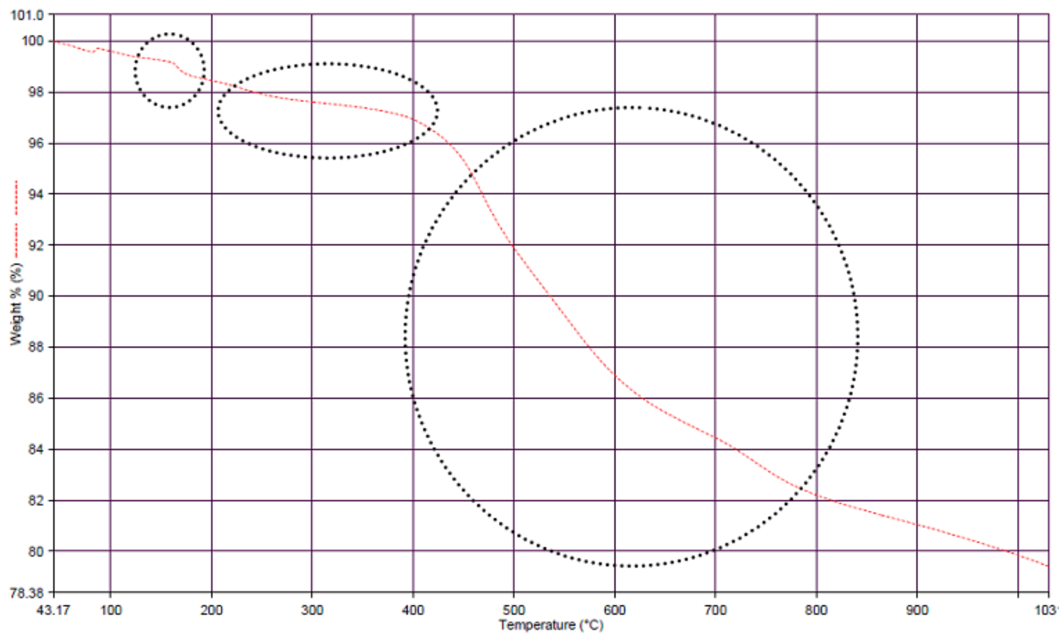

Fig. 5: TGA curve of palm slag/phenolic mixture.

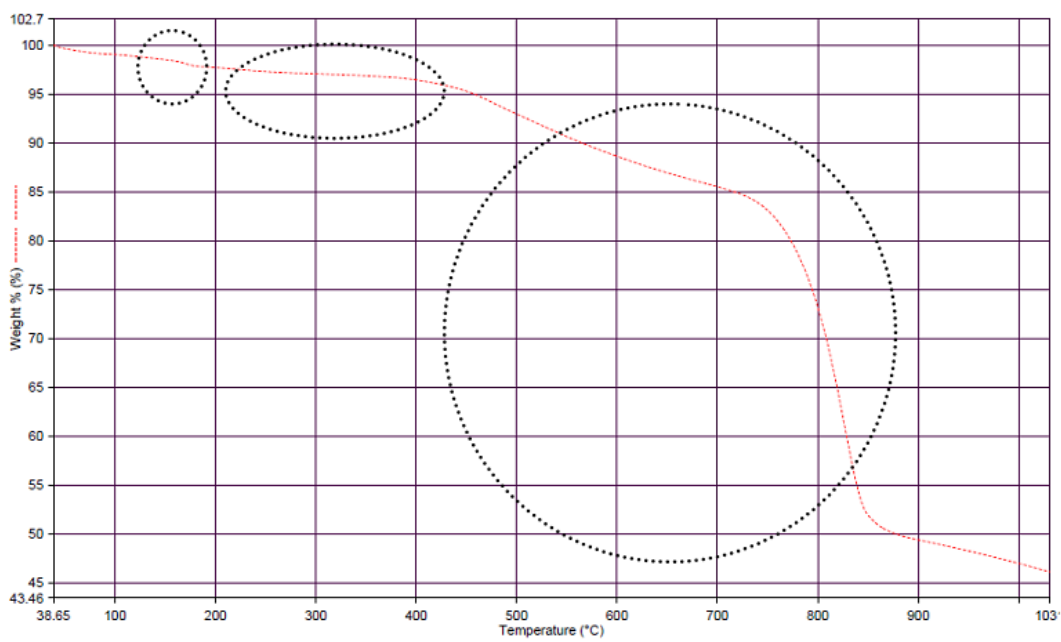

Fig. 6: TGA curve of calcium carbonate/phenolic mixture.

In these two temperature regions, two possible compounds are released, i.e., water and carbon dioxide. In a phenolic resin thermogravimetry and mass spectroscopy (TG-MS) experiment, Chang and Tackett found that carbon dioxide and water were released at in the temperature range of 420-580 °C (Cherng Chang and Tackett, 1991). Their findings were supported by work performed by Ramousse *et al.*, (2001) who also found that carbon dioxide and water were released under these conditions. Thus, it is apparent that the observed weight loss relates to the release of carbon dioxide and waterand an endothermic peak (Ramousse *et al.*, 2001).

Water is released between 230 and 450 °C, anf this release corresponds to the decomposition of the binder. The release of carbon dioxide is due to the combustion of carbon, which seems to occur between 250 and 850 °C (Cherng Chang and Tackett, 1991). The release of carbon dioxide also corresponds to the decomposition of the phenolic binder (Blau, 2001).

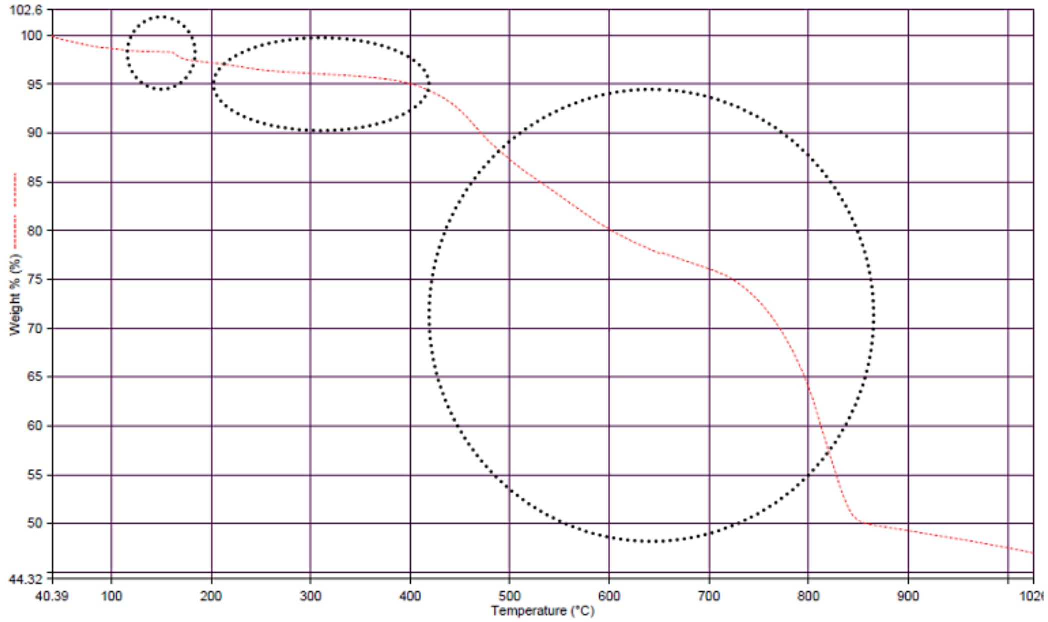

Fig. 7: TGA curve of dolomite/phenolic mixture.

Compressive Strength of the Composite:

Figure 8 shows the compressive strength of the different filler brake pad composites at 60 tons of processing pressure. It can be seen that the compressive strength of the brake pad with dolomite filler is the higher than the compressive strength of composites made with either calcium carbonate or palm slag as the filler. This result was observed due to the compactness of the composite. From Table 2, it is apparent that the dolomite brake pad composite is the densest compared to the others.

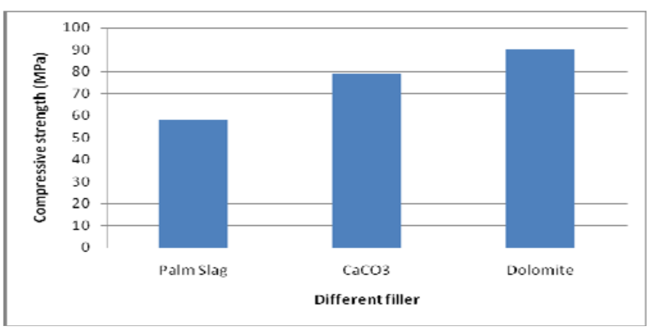

Fig. 8: Compressive strength of brake pad composites with different fillers.

Wear Behavior of the Composite:

The wear behavior of the brake pad composite under 10 N of pressure for a sliding distance of 1 km is shown in Table 2. Weight loss was measured after 1 km sliding on a stainless steel plate; then wear volume and wear rate of the palm slag brake pad composite were calculated and compared with the asbestos brake pad described in the literature.

Table 2: Wear behavior of brake pad composites using different fillers under sliding wear condition.

Sample	Density g/cm^3	Wear volume, cm^3 x 10^{-3}	Wear rate, m^3/m x 10^{-13}
Palm slag	2.02	0.89	8.9
$CaCO_3$	2.17	0.60	6.0
Dolomite	2.21	1.22	12.2
Asbestos (Chand *et al.*, 2004)	2.22	0.72	7.2

From the data shown in Table 2, one can see that the calcium carbonate and palm slag brake pad composites possess mechanical and wear properties that are similar to those of a conventional, asbestos-based brake pad. Even though the dolomite brake pad composite had the highest strength, it showed poor wear behavior compared to calcium carbonate and palm slag.

Conclusions:

Based on the thermal, compressive strength, and wear properties of a brake pad composite using palm slag as a filler, palm slag can be used effectively as an alternative to existing fillers, such as asbestos and calcium carbonate, in brake pad composites.

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