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Effect of Waste Tire Dust on the Hardness and Wear Rate of Palm Slag Friction Composites

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Abstract. Palm slag in previous studies has proven to have the potential to be used as alternative filler in friction composite. However, the reported hardness is still high and not within the proper range and might cause damage to the disc brakes. As is well known, the good damping, soft and flexible nature of rubber, being the main reason for waste tire dust to be selected as an additive to reduce or moderate the hardness of friction palm slag composite. Weight percentage and the filler size of waste tire dust used are the main parameters considered in this research paper. The hardness and wear rate of the friction composite produced are measured. The result revealed that friction composite with ratio of palm slag/waste tire dust (30/10) and the highest filler size (>600 μm) give a moderate hardness with better wear rate which comparable with the commercial brake pad used. Morphological view also give a prove that the worn surface of composite have less wear defects. Overall the used of waste tire dust can improve the hardness and wear rate properties of palm slag friction composites in order to become alternative for non-asbestos brake pads.

1. Introduction

Binder, filler, fiber and friction modifier are four classes mix basic materials normally used by researchers for compositional design of friction composites. Innovative use of alternative materials especially as filler in friction composite for the use as brake pad is keep growing [1-3]. Various materials have been studied and tested by many researches around the world. The use of industrial waste byproduct such as palm slag can open up the potential use of previously unused waste materials [2-7].

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 [5-7].

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 [8]. 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 [8].

Previous studies were indicate that palm slag can be used effectively as an alternative to existing fillers in brake pad composites. It shows a comparable thermal, compressive strength, and wear properties of the friction composite even though giving a bit high hardness, which would cause damage to the brake disc [7,9]. This paper will discuss the potential use of waste tire dust mixed with palm slag to moderate the high hardness of the friction composite without significant change on other properties and performances. Tire dust is produced from waste tire, which is often a problem to our environment when it is disposed.

2. Experimental

2.1. Material

Polyester resin has been selected as a binder in this friction composite. While the fillers used are palm slag and waste tire dust that obtained from our local suppliers. Tire dust will be added in order to moderate the hardness properties of the friction composite produced. In addition, steel fiber was used as reinforcement, graphite as a lubricant and alumina was used as an abrasive material for friction modifier. The amounts (as percentages) of each of these materials in the composite product are following based on the previous palm slag friction composite research and shown in table 1. The weight percentage of waste tire dust used varied from 10%, 20%, 30%, and 40%.

Table 1. Material contents (wt%) in the friction composite.

Materials	PS 40	PS30/WTD10	PS20/WTD20	PS10/WTD30	PS5/WTD35
Polyester	20	20	20	20	20
Metal Fiber	20	20	20	20	20
Alumina	10	10	10	10	10
Graphite	10	10	10	10	10
Palm Slag (PS)	40	30	20	10	0
Waste Tire Dust (WTD)	-	10	20	30	40

The mixture which shown the optimum hardness will be used for the investigation of different waste tire dust filler sizes as in table 2. The size used were 150-300 μm , 300-600 μm and 600 μm -1 mm.

Table 2. Mixture design used for different size of filler.

Materials	PS/WTD 1	PS/WTD 2	PS/WTD 3
Polyester	20	20	20
Metal Fiber	20	20	20
Alumina	10	10	10
Graphite	10	10	10
Palm Slag	30 (150-300 μm)	30 (300-600 μm)	30 (600 μm -1 mm)
Waste Tire Dust	10 (150-300 μm)	10 (300-600 μm)	10 (600 μm -1 mm)

Each recipe was mixed to obtain a homogeneous mixture of ingredients. Then, the mixtures were compacted and compress using hot compression moulding machine at 175 $^{\circ}\text{C}$ with 32.5 MPa of compression pressure for 10 minutes to let it cure. Schematic diagram of compression mould process was shown in figure 1.

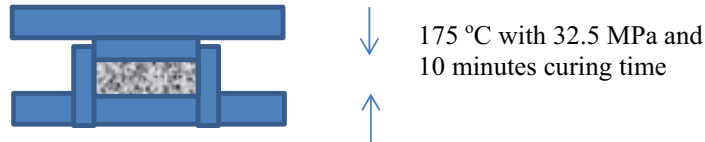


Figure 1. Illustration of molding process during preparation of friction composite.

2.2. Hardness of the Friction Composite

The hardness of the friction composite was determined using a Rockwell hardness tester. Each composite sample, was cut according to the desired dimension and placed on the hardness testing stage. The dimension of sample is 15 mm diameter with 6 mm thickness. The measurement was conducted using 1/8 steel ball indenter with the loading of 100 kgf. Five replications of the hardness tests were applied on the samples.

2.3. Wear Behavior of the Composite

The wear of the friction 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 friction composites were determined using the following equations:

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

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

2.4. Morphology Observation

Morphological study on composite surface after wear test was carried out using scanning electron microscopes instrument model JEOL JSM-6460LA, to observe the worn surface behaviour.

3. Results and Discussions

3.1. Effect of Different waste Tire Dust Composition on the Hardness of Friction Composite

The presence of waste tire dust with palm slag in the filler mixture influence the decreasing of the hardness properties of friction composite as shown in figure 2. PS40 shows higher hardness properties with 97.6 MPa. Sample PS30/WTD10 shows moderate hardness properties with a value of 80.6 MPa whereas PS10/WTD30 and WTD40 shows lower hardness properties. Palm slag composite has higher hardness because palm slag itself contributes the hardness properties to composites with strong adhesion bonding between particle and matrix [9].

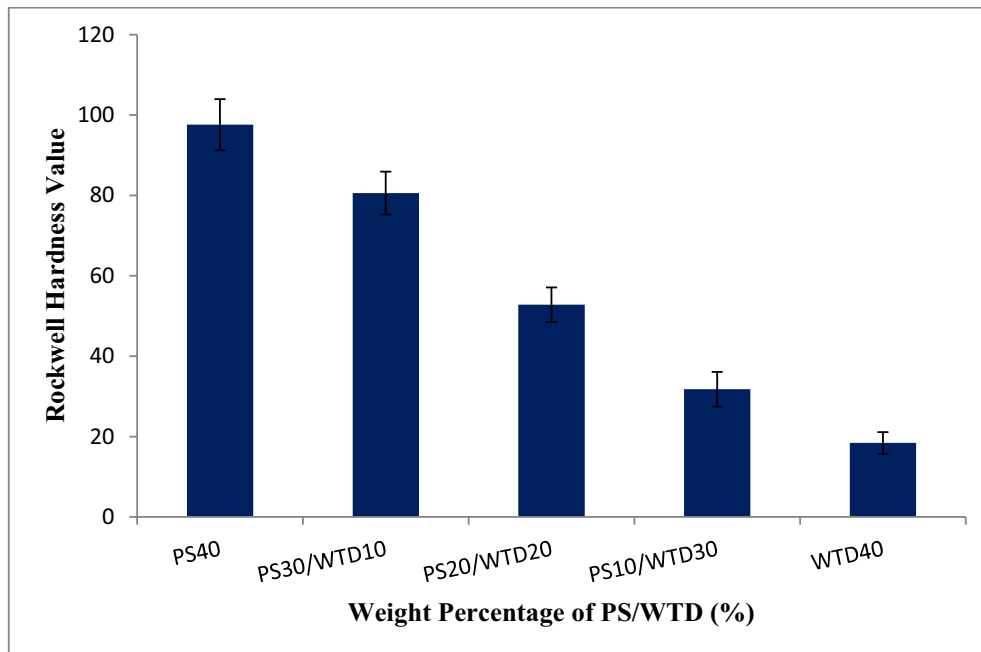


Figure 2. Rockwell hardness value of palm slag/waste tire dust friction composites.

The waste tire dust was effectively can be used to moderate the high hardness of palm slag friction composite. This result was supported by previous study made by Ibrahim et al.(2015) which found that the amount of waste tire dust higher than 12.5% has negative effect on hardness. In this manner, composites will have better stability of hardness with incorporated waste tyre dust rate between 5 to 10% [11]. In case of low WTD content in composite, elastomer phase remained as dispersed particles and thus contribute to higher hardness properties.

3.2. Effect of Different waste Tire Dust Composition on the Wear Rate of Friction Composite

Wear test was conducted at sliding distance of 1 km. Table 3 depicts the volume of wear rate of palm slag and waste tire dust filled friction composites. The result reveals the wear rate has increased as the amount of waste tire dust increased. PS40 has wear rate higher than PS30/WTD10 with $6.9 \text{ m}^3/\text{m} \times 10^{-13}$. The embedment of hard and dense particles (palm slag) in the brake pad material will increase the wear debris caused by the embedded hard particles slide against the disc in greater proportion of time. This hard particle will enhance the damage of the brake disc therefore increasing the wear rate [10, 12].

Table 3. Wear behavior of friction composite using different weight percentage of waste tire dust.

Sample	The volume of Wear ($\text{cm}^3 \times 10^{-3}$)	Wear Rate ($\text{m}^3/\text{m} \times 10^{-13}$)
PS40	0.69	6.9
PS30/WTD10	0.57	5.7
PS20/WTD20	1.08	10.8
PS10/WTD30	1.39	13.9
WTD40	2.18	21.8

PS30/WTD10 has shown better result of wear rate at $5.7 \text{ m}^3/\text{m} \times 10^{-13}$, because small amount of waste tire dust had moderated the hardness of friction composite. The nature of rubber-based materials that could not be liquidised even at a higher temperature, and remain semi-solid in the matrix increase the homogeneity and interfacial bonding between the polymers [12]. Thus, the filler has bonded with matrix properly and the existence of inter-material layer would have caused the disc to rub on the tire materials, hence less weight loss produced.

3.3. Effect of Different Filler Size on Hardness and Wear Behaviour

Figure 3 represents the hardness of the PS/WTD friction composite which has increased as the size of the filler increased. It was observed that the sample PS/WTD 3 has higher value of hardness than PS/WTD 1 and PS/WTD 2. The hardness of the composites increases from 78 MPa to 87 MPa as the size of filler increases. Consequently, better hardness properties were observed with higher filler size.

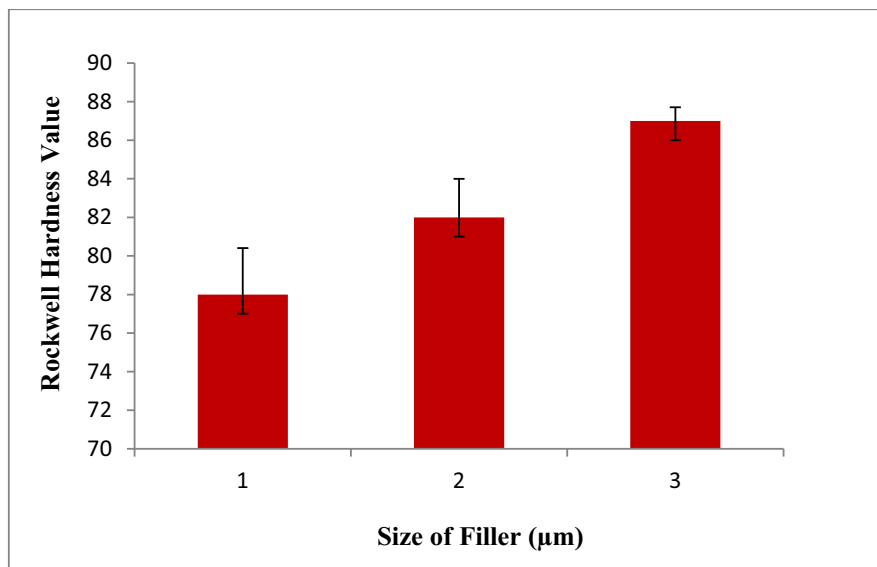


Figure 3. Hardness value of different filler size of friction composites.

Based on the results obtained, it is obviously shown that the incorporation of higher filler size of waste tire dust and palm slag has increased the hardness properties of friction composites. In addition, a further increase of hardness attributed to agglomeration and particles interaction of the waste tire dust and palm slag particle. Hardness properties are influenced by the density of composite. Hence, the material's wear decreases as the hardness of composite increases. The results are consistent with the study by Onyeneke et al. (2014). It was reported that the composites with higher particle size give better result in the proof test. The bigger size of the particle gives a positive effect on mechanical properties of the friction composites. The correlation between the size of filler and hardness shows that the larger size of filler has increased the value of hardness [13]. Wear properties of palm slag/waste tire dust filled friction composites were determined and tabulated in table 4.

Table 4. Wear rate of palm slag/waste tire dust for different size of filler used

Sample	Size of Filler (μm)	Wear Rate ($\text{m}^3/\text{m} \times 10^{-13}$)
PS/WTD 1	150 - 300	6.4
PS/WTD 2	300 - 600	5.7
PS/WTD 3	600 - 1000	5.2

Table 4 shows the wear rate has decreased proportionally as the filler size was increased. The lesser wear rate is observed on the PS/WTD 3 sample compared to another sample. The higher filler size caused the friction composite to have lower wear rate with a value of $5.2 \text{ m}^3/\text{m}$. The bigger size of waste tire dust particles contributes to the highest compact of friction composites [10]. This is caused by the fulfilment of space by other smaller size materials like alumina and graphite and make a packing is good.

The higher wear rate is observed on the PS/WTD 1 sample compared to another sample. This occur because similar particle size of the materials involved in the composite will result the imperfect packing. Its make the interfacial bonding between all particles in composite and matrix is relatively weak [14]. This will give higher weight loss of friction composite and contributed to the greater formation of wear debris at the braking surface [11].

3.3.1. Morphology Observation

Observation made on the microstructure shown in figure 4 revealed that, in the presence of waste tire dust, only debris without grove could be observed. The presence of rubber debris can form a friction layer which seems to fill the cavities on the brake pad surface in contribution to increase the effective contact are. The similar obsevasion was also mentioned by Abdul Hamid et al. in their previous research [11]. Whereas, in figure 4 (a), presence of grove is observe due to the hard palm slag debris.

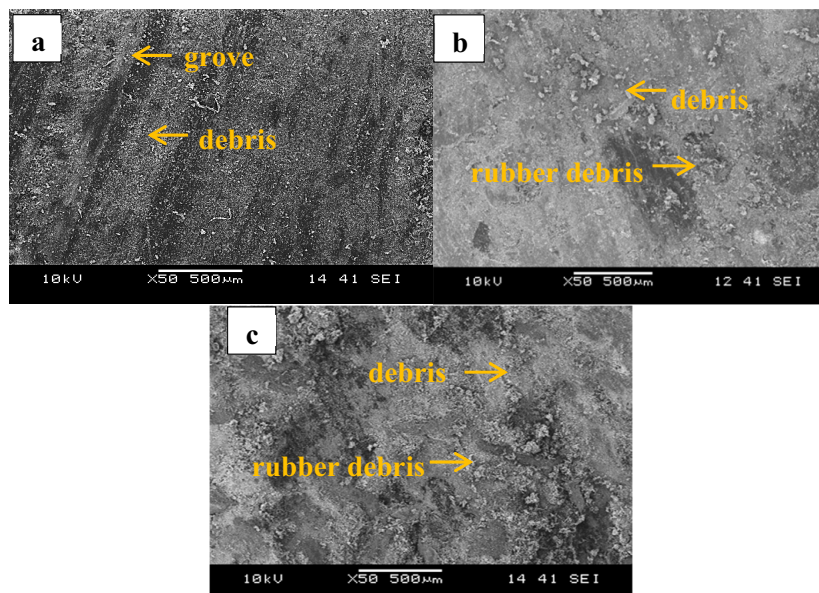


Figure 4. The after worn microstructure of friction composites with different weight percentage of palm slag/waste tire dust (a) PS40 (b) PS30/WTD10 (c) PS10/WTD30

4. Conclusions

Based on the results obtained, it shows that the presence of 25% waste tire dust in the total filler mixture with palm slag in PS 30/WTD 10 was improved the wear rate and moderated the hardness of the friction composite. Besides that, the large particle size of filler was also influence the hardness and wear behaviour of the composite.

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