Aptness of kenaf powder as a friction modifier in the fabrication of brake friction material by powder metallurgy route

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KEYWORD
Friction materials
Kenaf powders
Coefficient of friction
Thickness loss
Hardness

ABSTRACT
Braking system is one of the important passive safety features for sustaining the vehicle’s speed while driving downhill, to decelerate the motorcycle and completely stop the moving vehicle. Brake friction materials play an important role in resisting the movement of vehicle and composed of four components (binder, reinforced materials, friction modifier materials and filler materials). This work is to investigate the effect of the kenaf powder as a friction modifier on mechanical and tribological properties. Four brake friction material formulations (K, KA, KB and KC) have been prepared through powder metallurgy route. The samples were examined for their porosity, hardness, COF and thickness loss properties. Sample KA, KB, KC which composed of kenaf powders had a higher COF than sample K, without composed of kenaf powders. Test results show that sample KB which was composed of 10 volume percentage of kenaf powders is the best formulation based on COF and thickness loss results. Thus, it could be concluded that kenaf powders can be used as a friction modifier in brake friction material formulations.
INTRODUCTION

Brake friction material is used to absorb the kinetic energy during braking and converts to heat energy through brake pads and disc. Deceleration occurs as friction between tyres and roads takes place as the result of frictional force between brake disc and brake friction materials. The heat generated during braking is absorbed by brake pad and brake disc before being dissipated to the atmosphere through convection and radiation modes. The capability to dispose the heat is depend on the contact surface area, type of brake friction materials and brake disc design and material (Thiessen and Dales, 1983). This generated heat causes high surface temperature on the brake friction material and brake disc. Braking performance decreases when the temperature is above the 230°C due to the decomposition of resin which acts as a binder (Talib and Husna 1997). The decomposition of the binder takes place between 250 and 475°C (Ramoussse et al., 2001). This sudden drop of coefficient of friction (COF) results in lower braking performance and known as brake fade. High surface temperature will decrease the yield strength and leads to changes in the wear mechanism and real contact configuration (So, 1996), thus influence the COF and wear characteristics of the friction materials. Friction materials have complexes mechanical and tribological characteristics depending on type and weight percentage of ingredients in the formulation, manufacturing process parameters, design and geometry of friction mechanism, road condition and counter face material.

Earlier study shows that phenolic resin has the greatest influence on the tribological properties of brake friction materials (Zaharudin et al, 2011). Other components of the brake materials are; (i) reinforcing fibre, (ii) friction modifier, and (iii) filler. The strength, rigidity, and integrity properties are provided by the reinforced fibre materials such as steel wool, glass and ceramic fibre. Friction modifier such as graphite and iron oxide are used to improve coefficient of friction (COF) and wear properties of the brake friction materials. Graphite introduced into the formulation to provide friction stability at high surface temperature and prevents friction material from micro-stick to rotor. Iron oxide powder is used for improving the coefficient of friction as well as cleaning the brake disc. Filler materials such as friction dust, calcium carbonate and clay and calcium carbonate are used to fill up the space in the formulation.

Composition of ingredients in the formulation play a major role on the friction and wear behaviour of brake friction material, but the composition-property relationship are not well known (Österle and Urban, 2004). Each ingredient in the formulation has its own function and changes in ingredient types or weight percentage may result changes in mechanical, chemical and brake performance characteristics. It is important to note that certain ingredient in the friction material composition perform multiple functions. Changes in element types or weight percentage of the elements in the formulation may change physical, mechanical chemical properties, and wear performance of the brake friction materials to be developed (Lu, 2006; Cho et. al., 2005; Kumar and Bijwe, 2010). The selection of ingredients and weight percentages to be used in the formulation will significantly affect; (i) mechanical properties (ii) the tribological behaviour (Gudmand-Høyer et al., 1999), (iii) friction-induced noise, friction coefficient and wear resistance of the brake pad (Cho et al., 2005), (iv) chemical properties (Jacko, 1978; Österle et al., 2001)), (v) thermomechanic (Kennedy 1984; Kao et al. 1993) and (vi) wear mechanism (Rhee, 1974; Scieszka 1980; Talib et al, 2003).

Kenaf fibres are biodegradable material, an environmentally friendly and have been found to be important source powders for composites and other industrial applications (Nishino et. al., 2003). The kenaf fibre orientation influenced the friction and wear characteristics of the composite (Ramesh, 2016). Mustafa et al., (2010) in their study found that kenaf is the most
A suitable alternative friction material that passes all design stages and consumes less energy as compared to asbestos, jute, and ramie powders. Almaslow et al., (2013) using epoxidized natural rubber in the semi-metallic friction materials in getting higher COF and lower wear rate. This work investigates the adaptability of kenaf powders as friction modifier in the fabrication of brake friction materials. The effect of different vol. % of kenaf powder in the composition on the mechanical properties and tribological behaviours of brake friction materials will be also discuss in this work.

2.0 EXPERIMENTAL PROCEDURE

Four brake friction material formulations have been prepared through powder metallurgy route. Sample K was used a reference sample without composed of kenaf powders. Selecting sample KB as based formulation, volume percentage (vol. %) of kenaf powder was increased by 50 vol.% in sample KC and decreased by 50 vol.%, in sample KA. The compositions of the other ingredients are proportionally decreased and increased, respectively. The kenaf fibre volume percentage (vol. %) in the sample are shown in Table 1. The ingredients were mixed for 10 minutes and then warm compacted under a pressure of 150 kg/cm² at a temperature of 190°C in a brake-pad die with a dimension of 25 mm x 25 mm x 8 mm. The compacted brake pads were post-baked at a temperature of 180°C for 4 hours, in an oven. Figure 1 shows the SEM images of kenaf powders and microstructure of the sample KC.

<table>
<thead>
<tr>
<th>Identification</th>
<th>K</th>
<th>KA</th>
<th>KB</th>
<th>KC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resin1</td>
<td>11</td>
<td>10.6</td>
<td>10</td>
<td>9.44</td>
</tr>
<tr>
<td>Steel fiber2</td>
<td>22</td>
<td>21.1</td>
<td>20</td>
<td>18.9</td>
</tr>
<tr>
<td>Kenaf fibre</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Activated carbon2</td>
<td>22</td>
<td>21.1</td>
<td>20</td>
<td>18.9</td>
</tr>
<tr>
<td>Iron oxide1</td>
<td>17</td>
<td>15.8</td>
<td>15</td>
<td>14.2</td>
</tr>
<tr>
<td>Iron powder1</td>
<td>17</td>
<td>15.8</td>
<td>15</td>
<td>14.2</td>
</tr>
<tr>
<td>Barium1</td>
<td>11</td>
<td>10.6</td>
<td>10</td>
<td>9.44</td>
</tr>
<tr>
<td>Total (vol.%)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

2.1 Rockwell hardness test

The Rockwell hardness tests were conducted on Mikata hardness tester in accordance with Malaysia Standard MS 474: Part 2. Rockwell hardness tester in scale R was used in determining the hardness values where the sample was subjected to applied load of 60 kgf using a ball diameter of 12.7 mm. All the indentions were located 12 mm from the edges of the sample. The hardness of the sample is the arithmetic mean of the reading from ten indentations.
Porosity test

Porosity is the percentage of pore volume with the bulk total volume. The fabricated samples with a size of 25 mm x 25 mm were subjected to porosity tests in accordance with Japanese Industrial Standard JIS D 4418 using a hot bath model Tech-Lab Digital Heating. The porosity of the sample is the arithmetic mean of the reading from three samples. The tests samples were weight before and after immersed in the test oil in the container with a temperature of 90 ± 0°C for 8 hours. The test sample was rolled on a piece of cloth for 4 to 5 times after immersion to remove oil from the test sample. The porosity was calculated using the following formula.

\[ P (\%) = \frac{m_2 - m_1 \times 100}{\rho v} \]  

Where \( P \) is the porosity (%), \( m_2 \) is mass of the sample after absorbing oil (gm), \( m_1 \) is mass of sample (gm), \( \rho \) is density of the tests oil (gm/cm³) and \( v \) is the sample volume (cm³). The test sample dimension was 25 mm x 25 mm x 5mm.

2.3 Friction and wear measurement

The friction and wear assessment were performed on Link Model 600 CHASE dynamometer machine in accordance with Society of Automotive Engineer test procedures SAE J616. Samples with a dimension of 25 mm x 25 mm x 6 mm were glued to the backing plate and then attached to brake callipers on the brake drum. The sample was pressed against a rotating brake drum with a constant rotating speed of 417 rpm under a constant normal load of 647 N. Each sample was subjected to eight test runs with the following sequences: (i) conditioning (ii) baseline, (iii) first fade, (iv) first recovery, (v) wear, (vi) second fade, (vii) second recovery and (viii) baseline rerun. The details of test program can be referred in the earlier publication (Jaafar et al., 2016).

Two-letter friction codes were used, where the first letter represents normal COF and the second letter represents hot COF values as prescribed in SAE J886. The hot COF is defined as the average of the ten readings taken at 400 and 300 °F on the first recovery; 450, 500, 550, 600 and 650 °F of the second fade; and 500, 400 and 300°F of the second recovery run. The normal COF is defined as the average of the four readings taken at 200, 250, 300 and 400 °F on the second fade curve.
3.0 RESULTS AND DISCUSSION

3.1 Coefficient of friction

Table 2 shows the friction and wear test results. It was observed in Figure 3 and Table 2 that all the four samples complied with the minimum requirements specified by Automotive Manufacturer Equipment Companies Agency (AMECA) USA where COF of brake friction materials; (a) shall have normal friction coefficient of 0.25 and higher or a hot of 0.15 and above, (b) shall have friction coefficient above 0.15 between 200 and 550°F inclusive in second fade, or between 300 and 200 OF during the secondary fade.

Table 2: Friction and wear test results.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Kenaf vol.%</th>
<th>Coefficient of friction (μ)</th>
<th>Fade percentage (%)</th>
<th>Thickness loss (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Normal</td>
<td>Hot</td>
<td>Code</td>
</tr>
<tr>
<td>K</td>
<td>0</td>
<td>0.36</td>
<td>0.32</td>
<td>FE</td>
</tr>
<tr>
<td>KA</td>
<td>5</td>
<td>0.37</td>
<td>0.31</td>
<td>FE</td>
</tr>
<tr>
<td>KB</td>
<td>10</td>
<td>0.43</td>
<td>0.36</td>
<td>FF</td>
</tr>
<tr>
<td>KC</td>
<td>15</td>
<td>0.39</td>
<td>0.33</td>
<td>FE</td>
</tr>
</tbody>
</table>

Figure 2: Effect of vol. % of kenaf powders on porosity and hardness properties.
It was observed that all the samples developed with composed of kenaf have higher hot and normal COF as shown in Figure 3. The additions of kenaf in the formulation would enhance the thermal stability of the composites at the higher temperatures (El-Shekeil et. al., 2014), thus improve the COF of the sample. The Sample KB recorded the highest hot and normal COF values. Thus, it could be concluded that the optimum vol % of kenaf in the formulation is 10 %. The hot and normal COF decreases as the vol % of kenaf increased to 15 %.

The COF decreases with increasing surface temperature due to the degradation of the phenolic resin and kenaf known as brake fade. The fade percentage is depending on the vol % of kenaf...
powders in the formulation. It can be seen in Figure 4 that the fade percentage increases with increasing kenaf vol. % in the formulation. The degradation of natural powders initiating at a temperature around 260 °C due to dehydration combines with emission of volatile components (Beg and Pickering, 2008). This could be the reason why sample KC with the highest vol. % of kenaf powder, has the highest percentage of fade. Higher fade percentage requires higher pedal force to stop the moving vehicles. It was observed in Figure 4 that fade percentage increases with decreasing porosity. However, there is no simple correlation between porosity with fade percentage.

Figure 5 shows the effect of kenaf powders on the friction characteristics during second fade cycle. Under this cycle the sample was subjected to a temperature between 93°C to 315°C (200 °F to 600°F), which is above the decomposition temperatures of phenolic resin. All the three samples which composed of kenaf powders have higher COF as compared to the sample without kenaf powders in the formulation. It can be seen in Figure 5 that COF increases at the beginning of braking due to harder asperities being ploughed into the wear surfaces and the enlargement of the contact area during braking (Tanaka et. al., 1973). The formation of carbonaceous residues on surface of the sample under high temperature would also result an increase of COF (Jacko 1978). Thereafter, the COF slowly decreases with braking time due to shearing of the peak asperities, formation of friction film, and decomposition of the organic compounds. (Talib et al., 2007) The evaporation of organic material may have generated pressure at the surface between the brake friction material and mating surfaces and that this might provide aerodynamic gas lubricant, thus dramatically lowering COF (Begelinger and Gee, 1973).

The degradation of polymeric material starts at 230 °C, and the degree of degradation increases with the surface temperature of friction materials within the range of 269-400 °C (Zhigao and Xiaofei, 1991). Polymeric materials carbonized at approximately 450 °C and beyond this temperature; it decomposes through evaporation and charring (Yesnik, 1996). The char is removed when the brake friction material is forced onto the rotating brake disc during braking process. Once the char has been removed from the surface, the remainder of the friction material is now fully functioning as normal. All the sample almost recover to their respective base line COF values when the brake is cooled to 93.3°C (200 °F) as shown in Figure 6. Thus, it could be postulated the addition of kenaf in the formulation does affect second recovery

![Figure 5: COF characteristics of different vol. % of kenaf powders in the formulation.](image-url)
3.3 Thickness loss

Wear of brake friction material was due to the decomposition of organic materials, microstructural changes and transition of wear mechanism (Talib et. al., 2007). The degradation of the organic components in the brake pad composition reduces the bonding of ingredients in the formulation and structure integrity, thus which increase thickness loss. Figure 7 shows that sample KB which composed of 10 vol.% of kenaf powders has the lowest thickness loss while sample KC which composed of 15 vol.% of kenaf powders has the highest thickness loss. Excess in vol. % of kenaf powders would result a higher thickness loss, thus increase weight loss of the sample. The rapid weight loss above the temperature of 260°C was due to oxidative decomposition corresponding to the formation of char and the bond between metal fiber and resin is weakened by thermal metal grains (Zhigao and Xiaofei, 1991), thus increase thickness loss.

Characteristic of friction materials is a critical factor in brake system design and braking performance. COF and wear characteristic of friction materials are very complex to predict. To achieve ideal material characteristic, some requirements must be compromised in order to achieve some other requirements by changing the type and weight percentage of the ingredients in the formulation. CHASE dynamometer is used for quality control, lining development and friction materials property assessments (Sander, 2001). This dynamometer uses a small sample of friction material with a size of 25 mm x 25 mm x 25 mm, thus could not simulate the COF and wear characteristics during vehicle testing performance on the test track. In this study CHASE dynamometer test is used for screening of new material formulations prior to vehicle performance tests based on friction and wear test results. All the samples developed meet the requirements of AMECA as tested on CHASE dynamometer. Prototype samples for PROTON WAJA will be fabricated and all the prototype samples will be subjected to vehicle performance testing on the test track in accordance with Annex 3, ECE R13. Vehicle performance testing on the test track is the ultimate judge for overall brake performance testing. Thus, the final selection of the best formulation is based on road performance test results.
CONCLUSION

The following phenomena on the influence of kenaf powder on the mechanical and tribological properties of friction materials can be concluded as follows:

(a) porosity decreases with increasing of vol. % of kenaf powders, while hardness increases with increasing of vol. % of kenaf fibre

(b) hardness of the brake friction material is not simply correlated with porosity.

(c) Sample KB which composed of 10 vol. % of kenaf powders is the best formulation which produced highest COF and lowest thickness loss results,

(d) The addition of kenaf in the brake friction material formulation has increased COF values, thus kenaf powder can be used as a friction modifier in the formulation.

(e) Further investigations on the braking performance of the developed brake pads will be conducted on actual intended application on various real road conditions.

ACKNOWLEDGEMENT

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