TRIBOLOGICAL STUDY OF Al-BASED NATURAL FIBRE REINFORCED COMPOSITE BRAKE PAD MATERIALS

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ABSTRACT

Tribological behavior of Al–based natural fiber reinforced composites (NFC) brake pad materials was studied using CHASE Dynamometer machine in accordance with Society of Automotive Engineer standard procedure SAE J661. In this study, the NFC sample with a size of 25 mm x 25 mm x 6 mm was fabricated using powder metallurgy route for friction and wear test. Five different laboratory formulations such as S1, S2, S3, S4 and S5 were prepared with varying coir fiber contents from 0, 5, 10, 15, and 20 % volume fractions along with binder, friction modifier, abrasive material and solid lubricant. Characterization techniques such as SEM and CHASE Dynamometer machine are used to characterize and analyze the properties of brake pad materials. Out of the five formulations, S2 and S3 showed better properties in terms of wear and friction compared to others. Formulation S2 exhibits better thermal stability and wear resistance. The microstructure reveals uniform distribution of constituents materials along with the coir fiber in S2, S3 and S4. It can be concluded that S2 and S3 showed better tribological properties compared to other formulations. Hence, natural coir fiber can be used as a candidate fiber or filler material for the mass-scale fabrication of asbestos-free brake pad without any harmful effect.

Keywords: Coir fiber, Natural fibre Composite (NFC), Friction coefficient, Wear, Microstructure.

INTRODUCTION

Friction material is a heterogeneous material and composed of a few elements and each material has its own functional properties such as to improve friction property at low and high temperature, increase strength and rigidity, prolong life, reduce porosity, and reduce noise (Talib et al., 2003). Brake system is used to slow down and finally stop a moving motor vehicle and to hold vehicle stationary when in parking position. Friction is required in the braking system even though it might cause wear of lining material and counter face component. Friction and wear characteristics depend on the brake design, the content of friction materials and its behavior in service. Brake pad materials are mainly composed of more than five different materials and can be categorized into four main constituents, namely fibre, resin, modifier, and filler (Talib, 2001). In the brake pads material generally asbestos fibers are embedded in polymeric matrix along with several other ingredients. The use of asbestos fiber is decreasing due to its carcinogenic nature (Langer, 2002). No single fibre is known that function effectively by itself as an asbestos replacement in friction materials.

Current research towards the eco-friendly brake pad material has shown promising interest for the use of natural fibres such as, hemp and coir fibre, which can be obtained from natural resources and could offer a more sustainable solution. The outcome is expected to provide up-to-date solutions to the global transport industry and its friction material supply base (Savage, 2007). Several research works have been carried out for the development of asbestos-free brake pads (Dagwa and Ibhadode, 2006; Savage, 2007; Aigbodian et al., 2010). The use of bagasse (Aigbodian et al., 2010), palm kernel shell (Dagwa and Ibhadode, 2006) and hemp (Savage, 2007) have been investigated in order to replace the asbestos-free brake pad material.

No information is also available in literature on the use of coir fibre for the formulation of new brake pad material. Therefore, a new asbestos free brake pad material has been developed with the aim of using natural coir fibre as a...
reinforcement or filler material in aluminium matrix. Aluminum metal matrix composites (Al MMCs) are attractive for their lightweight (three times lighter than cast iron) properties, higher thermal conductivity, specific heat, superior mechanical properties and higher wear resistance. Particulate reinforced aluminum composite are promising candidate for automotive applications since they offer high specific stiffness and strength, good wear resistance and suitable thermal properties (Telang et al., 2010).

Tribological behaviour of brake pad material plays an important role in deciding which formulation is suitable for brake system design for a particular vehicle (Maleque et al., 2010). CHASE Dynamometer test is used in a laboratory scale in order to assess the tribological behavior of brake pad materials and to help in the screening of new material formulations prior to dynamometer tests. The test procedure using CHASE machine has been described in Society of Automotive Engineer standard SAE J661 (SAE J661, 1997). The edge code of the ‘normal’ and ‘hot’ friction values has been described in SAE Recommended Practice J866 (SAE J866, 1996). The current research attempts to examine the tribological properties of Al-based natural fibre reinforced composite brake pad materials. Finally, the best formulation was obtained based on the characteristics performance of the candidate formulations.

2. METHODOLOGY

2.1 Materials
The raw materials in the form of powders and long fibre are used in the preparation of laboratory sample for brake pad materials. The ingredients contained filler, abrasive, solid lubricant, binder, friction modifier and additives. The coir fibre was used as a filler material in this investigation which was collected from waste coconut fruit and cleaned thoroughly using ethanol to remove impurities. It was crushed and ground to a fine powder (with a range of 100-200 μm), and sieved using sieve analyzer.

2.2 Sample Preparation
Five formulations such as S1, S2, S3, S4 and S5 which have different composition of coir fibre contents (as shown in Table 1) were developed for friction and wear properties. However, abrasive, solid lubricant, binder, friction modifier and lubricants were kept same for all formulations. The brake pad material was developed using powder metallurgy (PM) technique. This PM technique used in order to obtain uniform part and reducing tedious and expensive machining cost. The process begins with selection of raw material, weighing, mixing, compacting and sintering. Raw materials were blended together in mini mixer to get evenly distributed ingredients. The pre-form of the samples were fabricated using Automated Hydraulic Presses Machine to the sizes of 25 mm x 25 mm x 6 mm. These pre-form samples were heated to 170°C and then the compacted using 20 kg compression load with 60 seconds holding time inside the compaction die. After removing from compaction, the samples were sintered using automated oven at temperature of 200°C for 5 hours. Finally, was ground using grinding machine according to the size required for friction and wear test. Figure 1 shows the samples for tribological test.

Table 1 : Formulation of Al-based natural fibre reinforced composite brake pad materials

<table>
<thead>
<tr>
<th>MATERIALS</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S1</td>
</tr>
<tr>
<td>Aluminium powder</td>
<td>45</td>
</tr>
<tr>
<td>Silicon carbide</td>
<td>20</td>
</tr>
<tr>
<td>Graphite</td>
<td>10</td>
</tr>
<tr>
<td>Coir fibre</td>
<td>0</td>
</tr>
<tr>
<td>Alumina</td>
<td>13</td>
</tr>
<tr>
<td>Zirconium oxide</td>
<td>2</td>
</tr>
<tr>
<td>Paper ash</td>
<td>0</td>
</tr>
<tr>
<td>Phenolic resin</td>
<td>10</td>
</tr>
</tbody>
</table>
2.3 Tribological Test

The NFC brake pad samples were tested using a CHASE Dynamometer machine. The sample was fixed against a rotating brake drum with a constant rotating speed of 417 rpm under the load of 647 N in accordance with SAE J661. Each sample was subjected to seven test runs with the following sequences: (i) baseline, (ii) first fade, (iii) first recovery, (iv) wear, (v) second fade, (vi) second recovery, and (vii) baseline rerun. In the baseline run, the sample was subjected to an intermittent braking with 20 applications, 10 seconds on and 20 second off. This was followed by continuous braking where the temperature was allowed to rise from 82 ºC to 288 ºC. In the first recovery run, the brake was applied continuously but the drum temperature is allowed to cool from 288 ºC to 93 ºC. The wear run was under intermittent braking with 100 applications, 10 seconds on and 20 second off while temperature was maintained between 193 ºC to 216 ºC. Subsequently, second fade and second recovery run was performed similar to the first fade and recovery except operated under higher temperature where it rises to 343 ºC. Finally, baseline rerun was performed similar to first test condition. The weight and thickness of NFC brake pad materials were taken before and after the friction test. In order to obtain average thickness value, three measurements were taken at different locations on the brake pad samples.

2.4 Morphological Analysis

The evolution of the surface morphology after the friction tests were studied by using scanning electron microscopy (SEM) with an EDX system. The surface of the samples was examined with SEM in which an image is created by secondary electrons ejected from the surface. The EDX analysis was performed as a spot and area using a primary energy of 15KeV. The samples were coated in order to obtain better image and micrograph on non-conductive brake pad materials.

3. RESULTS AND DISCUSSION

3.1 Friction from Link-Chase Dynamometer Machine

The friction from CHASE dynamometer test is shown in Figs 2 to 6 at different temperatures. Figure 2 showed the samples run for first baseline. This condition represents the friction level at 93 ºC as measured during 20 braking applications of 20s duration. The friction coefficient of S1 and S5 reveals constant profile during the application. Sample S2, S3 and S4 showed higher friction coefficient with the value of 0.48, 0.54 and 0.55 respectively. The friction coefficient decreases with increasing rotating speed due to the formation of graphite/carbon layer within matrix surface.

![Figure 2: The friction coefficient of the NFC brake pad materials at first baseline condition.](image2)

![Figure 3: The friction coefficient of the NFC brake pad materials at first fade condition.](image3)

![Figure 4: The friction coefficient of the NFC brake pad materials at first recovery condition.](image4)

Figs 3 and 4 showed friction coefficient from the first fade and recovery condition respectively for all samples. Fade refers to when the friction material is subjected to successively elevated temperatures and recovery is when the condition returns to the ambient temperature.
For the first fade condition, the temperature (drum temperature) arises from 93 °C to 288 °C. During the first fade, the S2 and S3 samples showed consistent friction coefficient with higher friction coefficient during fade application with the value of 0.58 and 0.62 respectively. The rest of the samples did not show any trend of friction during the test run, but the friction coefficient decreases with increasing the drum temperature. This phenomenon is called fade, and the resistance to fade at high temperature is a critical requirement for brake friction materials.

Figs 5 and 6 showed the friction behavior at second fade and recovery conditions. For second fade the drum temperature was increased to 343°C. Sample S2 showed that the friction coefficient started to decrease at point of 150 °C until meet the lowest friction coefficient of 0.18 at temperature of 369 °C. This trend also can be discovered in sample S3, where the friction coefficient of the sample decrease at point of 150 °C until meet the lowest friction coefficient of 0.21 at temperature of 369 °C. As compared to S2, friction coefficient of sample S3 is much higher even at higher temperature with the value of 0.21 at 369 °C. For samples S1, S4 and S5, the friction coefficient decreased with increasing of drum temperature during the test run.

Figure 5: The friction coefficient of the NFC brake pad materials at second fade condition.

Figure 6: The friction coefficient of the NFC brake pad materials at second recovery condition.

Table 2 shows that all the developed brake pad materials exhibited lower friction coefficient and average thickness loss. Even though friction coefficients of the developed formulations are lower than those of the commercial sample (0.5-0.62µ (Talib, 2001)), but they are still higher than the minimum requirement of 0.15 as stated in SAE J866 (1996). All the samples passed during the second recovery test except sample S5. This is due to the lower value of friction coefficient (0.026) in the minimum requirement which is shall not be lower than 0.15. From the table, sample S1 and S3 showed no change in the class of friction coefficient either in normal or hot condition which is F-F. For sample S2 the class changes from G to E, while for sample S4 the class also change from F at normal condition to E at hot temperature. Table 2 shows the classification of friction coefficient of NFC brake pad materials. The values were taken from second recovery condition.

Table 2: Classification of friction coefficient of brake pad materials

<table>
<thead>
<tr>
<th>Sample</th>
<th>Normal Friction</th>
<th>Hot Friction</th>
<th>Observations/Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>µ</td>
<td>Code</td>
<td>µ</td>
<td>Code</td>
</tr>
<tr>
<td>S1</td>
<td>0.414</td>
<td>F</td>
<td>0.368</td>
</tr>
<tr>
<td>S2</td>
<td>0.462</td>
<td>G</td>
<td>0.281</td>
</tr>
<tr>
<td>S3</td>
<td>0.434</td>
<td>F</td>
<td>0.374</td>
</tr>
<tr>
<td>S4</td>
<td>0.368</td>
<td>F</td>
<td>0.273</td>
</tr>
<tr>
<td>S5</td>
<td>0.274</td>
<td>E</td>
<td>0.158</td>
</tr>
</tbody>
</table>

Figure 7 revealed the graph of friction coefficient which was obtained from wear test. Sample S3 showed that after 20 cycles of braking application the friction coefficient of the sample started to decrease. But the trend is really different from other samples. Sample S1 and S2 showed that the friction coefficient increased with increasing the cycles of braking application. As in sample S1, there is not much change in friction coefficient during wear test.

Figure 7: The friction coefficient of the NFC brake pad materials during wear test.
3.2 Wear Properties of NFC Brake Pad Materials

Figure 8 shows the wear properties of NFC brake pad materials of CHASE Dynamometer wear test. The result shows the weight loss after friction test. Sample S5 has the highest value of 34.3 %, followed by sample S4 with its value of 17.7 %. The sample with the lowest weight loss was sample S1 with its value of 4.7 %. Meanwhile, the thickness loss for sample S5 has the highest value which is 34.1 % because it is softer than others, followed by sample S4 with value of 14.6 %. The sample with the lowest thickness loss is sample S1 with value of 4.5 %. Analysis of test results shows sample S4 and S5 do not meet the requirements as stated in SAE J866 (1996). Higher thickness loss means shorter brake pad life and this incurred more material and maintenance cost. Whereas, higher friction coefficient results in wheel locking at a very much lower brake pedal force which could drastically change the vehicle braking characteristics.

![Figure 8: Wear properties of NFC brake pad material during wear test using CHASE Dynamometer](image)

3.3 Wear Morphology of NFC Brake Pad Materials

The evolution of the surface morphology after friction tests were studied by scanning electron microscopy (SEM) and EDX analysis. After interaction between the static partner and the sample, marks are usually left on the sliding surface. These marks can convey useful information about the contacting process. Each wear mechanism leaves its own features and the mechanism can often be identified by SEM photomicrograph. Fig. 9 illustrates the microstructure of NFC brake pad after wear testing using Link-CHASE dynamometer machine. The grind section of brake pad was clearly visible with shiny metallic constituents and dark/grey non-metallic in the surface. In general, the distribution of the ingredients was heterogeneous structure due to complex formation of new NFC material. Figure 9 (b) and (c) showed the secondary electron image of the worn surface of the NFC brake pad materials. In these figures, the direction of the wear test is obvious especially on the darker region indication that this region is softer than the other region. In Fig 9(c), there are some porous area which were not abraded by the counterpart drum. The percentage of the porosity in this material is approximately 10%. The surface topography is clearly revealed. However, some abraded regions are not revealed in this figure. This is because secondary electrons provides the information slightly below the worn surface not on the very near surface. Bright regions in this figure showed the element of higher atomic number and the darker region is for the element with lower atomic number.

![Figure 9: SEM micrograph of worn surface (a) S1, (b) S2, (c) S3 and (d) S4 samples after Link-CHASE Dynamometer test.](image)

Table 3 shows the percentage (in weight) of the compositions in each element analyzed by EDX. EDX analysis shows the constituents present are aluminum oxide, iron, silicon and carbon. From the observation, carbon is clearly shown by the dark colour. Meanwhile, the less dark colour showed the compound that still dominated by the carbon. Sample S2 and S3 contained more carbon and less oxide. In this case, both SEM and EDX analysis show a very good agreement in order to demonstrate the morphology and surface chemical composition of the new NFC brake pad materials.
4. CONCLUSION

This research was focused on the tribological study of Al-based natural fiber reinforced composites (NFC) brake pad materials using CHASE Dynamometer machine. Friction and wear assessment tests were conducted on five new friction material formulations with varying coir fiber contents from 0, 5, 10, 15, and 20% volume fraction along with binder, friction modifiers, abrasive material and solid lubricant. Based on tribological test results and morphological study on the worn surface, the following conclusions can be drawn:

(a) The friction coefficient decreases with increasing rotating speed due to the formation of graphite/carbon layer within matrix surface.
(b) The weight and thickness loss increases with increasing temperature.
(c) Sample S2 and S3 are showed better properties in terms of friction coefficient and wear.
(d) The current coir natural fibre can be used as a candidate fibre or filler material for the mass-scale fabrication of asbestos-free brake pad without any harmful effect.

Based on the observations obtained from this study, it is possible to modify a specific tribological property of a brake friction material by changing the amount of coir fibre in a systematic manner while expecting possible changes in other tribological properties.

ACKNOWLEDGEMENT

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REFERENCES


SAE J866, 1996, Friction coefficient identification system for brake lining, Society of American Engineers, Warrendale, USA.

Table 3: EDX analysis of the NFC brake pad materials in weight%

<table>
<thead>
<tr>
<th>Element</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>56.46</td>
<td>63.89</td>
<td>58.43</td>
<td>57.73</td>
</tr>
<tr>
<td>O</td>
<td>34.58</td>
<td>24.64</td>
<td>33.53</td>
<td>34.05</td>
</tr>
<tr>
<td>Al</td>
<td>6.22</td>
<td>7.86</td>
<td>5.92</td>
<td>6.12</td>
</tr>
<tr>
<td>Si</td>
<td>2.66</td>
<td>3.50</td>
<td>2.01</td>
<td>1.84</td>
</tr>
<tr>
<td>Zr</td>
<td>0.08</td>
<td>0.11</td>
<td>0.11</td>
<td>0.25</td>
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</tbody>
</table>