NEW NATURAL FIBRE REINFORCED ALUMINIUM COMPOSITE FOR AUTOMOTIVE BRAKE PAD

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ABSTRACT
The aim of this paper is to develop new natural fibre reinforced aluminium composite for automotive brake pad application. Four different laboratory formulations were prepared with varying coconut fibre contents from 0, 5, 10 and 15 volume fraction along with binder, friction modifiers, abrasive material and solid lubricant using powder metallurgy technique for the development of new natural fibre reinforced aluminium composites. The properties examined are density, porosity, microstructural analysis, hardness and mechanical properties using densometer, SEM, hardness tester and universal testing machine. The better properties in terms of higher density, lower porosity and higher compressive strength were obtained from 5 and 10% coconut fibre composites. The microstructure reveals uniform distribution of resin and coconut fibre in the matrix. It can be concluded that 5 and 10% showed better physico-mechanical properties compared to other formulations. Hence, natural coconut fibre is a potential candidate fiber or filler material for the automotive brake pad material.

Keywords: natural fibre, composite material, density, hardness, compressive strength and microstructures.

1. INTRODUCTION
The braking system is composed of many parts, including brake pads on each wheel, a master cylinder, wheel cylinders, and a hydraulic control system. Different types of brake materials are used in different braking systems. They are often categorized into four classes of ingredients: binders, fillers, friction modifiers, and reinforcements. The brake pads generally consist of asbestos fibers embedded in polymeric matrix along with several other ingredients. Over the few years, several research works have been carried out in the area of development of asbestos-free brake pads. The use of bagasse (Aigbodion et al., 2010), palm kernel shell (Dagwa and Ibhadode, 2006) and palm oil clinker (Zamri et al., 2011) have been investigated in order to replace the asbestos-free brake pad material. Current trend in the research field is to utilization of industrial or agricultural wastes as a source of raw materials for composite development (Leman et al., 2008). This will provide more economical benefit and also environmental preservation by utilize the waste of natural fibre. Moreover, many factors should be considered to develop brake materials as to fulfill the requirement such as, a stable friction coefficient and a lower wear rate at various operating speeds, pressures, temperatures, and environmental conditions in the automotive sectors (Wannik et al., 2012; Adebisi et al., 2011). This is important of having appropriate combination of materials in order to have those requirements with reasonable cost of materials. Selection of the material is not an easy task rather a complex process (Maleque and Dyuti, 2010). The constituents are often based on experience or a trial and error method to develop a new formulation in any application including brake pad material.

Recently, more research has been focused on the potential of warm compaction method to manufacture cost-effective and highly-dense brake pad materials through powder metallurgy (PM) technique (Jones et al., 1997; Asif et al., 2011). The prime reason for using the PM process is the possibility of obtaining uniform parts and reducing tedious and expensive machining processes.

The use of asbestos fiber is decreasing day by day due to its carcinogenic nature (Rinek and Cowen, 1995). In order to avoid this carcinogenic asbestos, efforts are ongoing for the replacement of material. However, no information is available in literature on the use of coconut fiber for the formulation of new brake pad materials. Therefore, new natural fibre brake pad materials have been formulated with the aim of using natural coconut fibre as reinforcement filler material in aluminium matrix for the automotive application.

2. EXPERIMENTAL PROCEDURES
2.1 Raw Materials and Formulations
The main raw materials used in the research were filler, abrasive, solid lubricant, binder, friction modifier and additives. The current natural fibre brake pad material was developed through the process beginning with the selection of raw materials, weighing, mixing, compacting and sintering. There are four formulations with different composition of coconut fibre content. Grouping was made based on the variation of the coconut fibre material in the formulation and aluminium used as a matrix material. However, abrasive, solid lubricant, binder, friction modifier and lubricants were kept same for all formulations. Table 1 shows the detail formulation of four different types of new materials.
The mixing process exist in combination of various elements. Friction elements often have a higher density than an organic element. The hardness of the sample is the arithmetic mean of the hardness of five arbitrarily selected areas and uniformly spaced on the surface of the specimen. The hardness test was performed at a distance of 0.2 mm away from the edge of the sample and the load was applied for 10 seconds.

The Rockwell hardness measurements were conducted under test load of 980.7 N and steel ball diameter of 12.7 mm using Scale S as stipulated in Malaysian Standard MS 474 PART 2: 2003. The measurements were performed at a distance of at least 12 mm from any edge and uniformly spaced on the surface of the specimen. The hardness of the sample is the arithmetic mean of the readings from ten indentations.

The compressive strength test was done using a universal tensile testing machine. The sample of 25mm x 25mm x 7mm was subjected to compressive force, loaded continuously until failure occurred. The load at which failure occurred was then recorded.

For morphology study scanning electron microscopy (SEM) with EDX was used in order to observe and investigate the distribution of microstructural features along with elemental constituents of new natural fibre reinforced aluminium automotive brake pad materials.

3. RESULTS AND DISCUSSION

3.1 Density and Porosity of Brake Pad Materials

A density measurement test has been carried out on a laboratory scale to examine the density of the material after sintering. Density is depends upon the ingredients in the pad material. A metallic element will have a higher density than an organic element. Friction elements often exist in combination of various elements. The results shown in Figure 2 are the average density of three readings for each formulation.

It is seen from Figure 2 that the density of the 15 % coconut fibre composite shows lower than 0% coconut fibre which have more coconut fibre. However, formulation BP1 has better properties because of having higher density with the value of 2.176 g/cm³. This

## Table 1 Formulation of coconut fibre reinforced aluminium brake pad materials

<table>
<thead>
<tr>
<th>Raw Materials</th>
<th>BP1 (%)</th>
<th>BP2 (%)</th>
<th>BP3 (%)</th>
<th>BP4 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Silicon carbide</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Coconut fibre</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Graphite</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Alumina oxide</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Zirconia oxide</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Phenolic resin</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

2.3 Characterization of Brake Pad Material

Specific gravity measures density which depends upon the ingredient of the brake material formulation (Talib, 2007; Nirmal et al., 2011). The true density of the specimen was determined by weighing the specimen on a digital weighing machine and measuring their volume by liquid displacement method. The specific gravity formula is [as Eq. (1)]:

\[ \rho = \frac{\text{mass (m)}}{\text{volume (v)}} \]

Porosity test was performed in accordance with Japanese Standard JIS D 4418: 1996. The specimen was cut to a dimension of 25 mm x 25 mm x 7 mm, then left in a desiccator for 24 hours at room temperature and cooled to room temperature in desiccator. The sample was weighed to the nearest 1 mg before test sample placed in the test oil in the container and kept at 90±10 °C for 8 hours. The test sample was left in the oil container for 12 hours until the oil cools to the room temperature and then withdrawn from the oil container, finally the sample was rolled on a piece of cloth for 4 to 5 times to remove oil from the test sample. The sample was weighed again to the nearest 1 mg.

The Rockwell hardness measurements were conducted under test load of 980.7 N and steel ball diameter of 12.7 mm using Scale S as stipulated in Malaysian Standard MS 474 PART 2: 2003. The measurements were performed at a distance of at least 12 mm from any edge and uniformly spaced on the surface of the specimen. The total test specimen was used for 10 indentations.

The compression test was done using a universal tensile testing machine. The sample of 25mm x 25mm x 7mm was subjected to compressive force, loaded continuously until failure occurred. The load at which failure occurred was then recorded.

For morphology study scanning electron microscopy (SEM) with EDX was used in order to observe and investigate the distribution of microstructural features along with elemental constituents of new natural fibre reinforced aluminium automotive brake pad materials.

2.2 Preparation of Material

Four different combinations (such as BP1, BP2, BP3 and BP4) were prepared with varying coconut fibre contents from 0, 5, 10 and 15 volume fraction along with binder, friction modifiers, abrasive material and solid lubricant using powder metallurgy technique for the development of natural fibre reinforced aluminium automotive brake pad materials. The coconut fibre was used as a filler material in this investigation which is shown in Figure 1.

![Figure 1 Coconut fibre from waste](image)

This 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 crusher machine.

Raw materials were blended together in mini mixer to get evenly distributed ingredients. The mixing process proposes to get the uniform and homogeneous of metallurgy powder. All materials were prepared in powder form. The method for fabrication of brake pad material was powder metallurgy technique. Graphite-4071 was added to minimize fracture in the mixing process. Then, the pre-form samples were heated to 170°C and at the same time and compacted using 20 kg load 60 seconds holding time in a hot compaction die. The compaction was performed using a hydraulic press machine under a predetermined temperature and pressure. After removing from compaction, the material was sintered in an oven at a temperature of 200°C for 5 hours.
formulation has no coconut fibre in its constituents, hence, shows higher density of this composite material. The formulation, BP2 shows the second highest density with the value of 2.099 g/cm³.

3.2 Hardness of the Brake Pad Materials
Figure 4 shows the hardness values of the four formulations brake pad materials.

Porosity, a gross measure of the pore structure, gives the fraction of total volume which is void. The pore structure should be preserved during specimen grinding and polishing. Distortion by excess working will smear material over the pores, giving the appearance of a low porosity (German, 1997). From the porosity results as shown in Figure 3 it can be seen that two brake pad formulations such as, 5 and 10 % of coconut fibre composite shows lower percentage of porosity compared to other two.

3.3 Mechanical Properties of Brake Pad Materials
Table 2 shows the compressive mechanical properties for BP2 and BP3 (with 5 and 10 of coconut fibre) formulations only as other combinations showed very low strength during testing. The speed used for this testing is 0.5 mm/sec.

The compressive strength value in Table 2 for 5 % of coconut fibre shows higher with the lower compressive strain and able to withstand higher compressive load compared 10% of coconut fibre composite. The ultimate strength of the formulation BP2 is corresponds to the stress of 414.75 MPa. The sample starts to break at stress of 408.74 MPa. The breaking strength of the sample is 0.66 MPa.

3.4 Surface Morphology
The surface morphology of the new pad materials was analyzed using SEM followed by elemental analysis of the materials using EDX. Figures 5 to 7 showed the SEM micrographs for BP1, BP2 and BP3 specimens while Table 3 showed the EDX analysis results.

Formulation BP1 (as in Figure 5) showed that the aluminium clumps with graphite and zirconium oxide
and corresponding EDX analysis (in Table 3) showed that this formulation content more aluminium element.

On the other hand, formulation BP2 (as in Figure 6) showed that the resin binder is in dark region together with alumina oxide and the EDX analysis showed that this formulation content less aluminium element compared to formulation S1.

![Figure 5 SEM microstructure for 0% of coconut fibre (Magnification 500x)](image)

![Figure 6 SEM microstructure for 5% of coconut fibre (Magnification 500x)](image)

![Figure 7 SEM microstructure for 10% of coconut fibre (Magnification 500x)](image)

The resin binder in dark region can be seen in Figure 7 along with alumina distribution in white region. The graphite and coconut fibre content in BP3 formulation also can be visualized in Figure 7.

From the SEM study it can be postulated in generally that microstructures of 0 to 10% of coconut fibre composites showed the homogeneous distribution of abrasive, solid lubricant, binder and friction modifier in the aluminium matrix. This might be only confirmed by either EDX or XRD. The EDX analysis results of the present investigation are shown in Table 3 and again showed very good combination of the elemental distribution which reflect to the heterogeneous distribution. Finally, it can be said that the structures showed the heterogeneously distribution of elements where they contributed to inconsistent result. Different size and weight of particles or elements are also contributed to heterogeneous distribution. Besides, it is evident that there is no such thing as a typical brake friction composition because a composition that can represent the majority of the brake pad in existence will not be accurate. Morphology of the structure also might change due to sintering of material at different temperatures.

**Table 3 Elemental composition based on EDX analysis**

<table>
<thead>
<tr>
<th>Elements</th>
<th>BP1</th>
<th>BP2</th>
<th>BP3</th>
<th>BP4</th>
</tr>
</thead>
<tbody>
<tr>
<td>C K</td>
<td>38.29</td>
<td>40.69</td>
<td>48.36</td>
<td>44.30</td>
</tr>
<tr>
<td>Si K</td>
<td>10.79</td>
<td>11.61</td>
<td>16.92</td>
<td>20.34</td>
</tr>
<tr>
<td>O K</td>
<td>23.59</td>
<td>19.84</td>
<td>9.08</td>
<td>10.79</td>
</tr>
<tr>
<td>Al K</td>
<td>24.83</td>
<td>25.57</td>
<td>23.02</td>
<td>22.00</td>
</tr>
<tr>
<td>Zr L</td>
<td>2.50</td>
<td>2.29</td>
<td>2.61</td>
<td>2.56</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

From Table 3, it can be seen that, the amounts of C, Si, O, Al and Zr are comparable with the amount present for each constituent before formulation. The atomic composition had been changed after the samples were thermally treated through sintering process. Less amount of aluminium is present in BP4 due to more coconut fibre in the formulation. Higher amount of aluminium can be seen in the formulation BP2 followed by BP1.

4. CONCLUSIONS

From the results and discussion of this work the following conclusions can be made:

Formulation with 5 and 10 volume fractions of coconut fibres (BP2 and BP3) have higher density and lower porosity compared to other formulations.

The compressive strength showed the formulation BP3 (with 10% coconut fibre) exhibited higher strength to withstand the load application and higher ability to hold
the compressive force. From the morphological study of the materials, it was found that the coconut fibre well distributed to the matrix and acts as filler in the friction materials.

It can be concluded that BP2 and BP3 showed almost similar properties from the four formulations, hence coir could be a candidate fibre or filler material for the mass-scale fabrication of asbestos-free brake pad without any harmful effect.

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