Sustainable Analysis in the Product Development of Al-Metal Matrix Composites Automotive Component

N. Fatchurrohman\textsuperscript{a}, Ismed Iskandar\textsuperscript{b}, S. Suraya\textsuperscript{c}, Kartina Johan\textsuperscript{d}
Faculty of Manufacturing Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
\textsuperscript{a}n.fatchurrohman@gmail.com, \textsuperscript{b}ismed_iskandar@yahoo.com, \textsuperscript{c}surayas@ump.edu.my, \textsuperscript{d}kartina@ump.edu.my

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Abstract. In this paper sustainable analysis is performed due to the increasing demand for fuel efficiency. Current research focuses on high strength-light weight components in automobile which lead to the development of advance material parts with improved performance. A specific class of advanced material which has gained a lot of attention due for its potential is aluminium based metal matrix composites (Al-MMCs). Al-MMCs have some prospects for several applications in automobile parts. The analysis in this paper is a part of product development which plays a crucial role in determining a product's environmental impact. The objective was accomplished and thus to identify the potential of Al-MMCs rake disc for replacement of the conventional cast iron brake disc. The result indicated that the Al-MMCs have the potential to substitute the cast iron brake disc.

Introduction

There are several ways to approach sustainability in product design, namely, the design with consideration of recyclability, minimal energy consumption, minimal weight, reducing air and water pollution, the gradual substitution of non-renewable materials by renewable ones and more. These are mostly connected to the philosophy and methods of design selection, in other words, selection in product design is one of the ways of approaching the sustainability in the progress of modern society [1,2]. While, Petala et al. [3] differentiate two primary ways to incorporate sustainability into product development. One alternative is to develop products with lower environmental impact. Another way is to incorporate environmental considerations into the regular development process, as an integrated part of the mandatory design criteria and methods.

Product design in automotive braking system must consider mechanical and thermal stresses, it depends on a combination of few material properties. Thus it is hard to select a material based only on one of these properties. The material applied in brake disc must bear thermal fatigue, moreover it should absorb and dissipate quickly heat generated during braking [4]. Although Al-MMCs have been applied for brake disc, the product has not yet been highly produced and used widely for replacement of the existing iron brake disc due to high manufacturing cost for mass production [5]. Therefore, this indicates a potential avenue of further research in the field of Al-MMCs and to identify its potential as a replacement for the existing conventional brake disc.

The objective of this study is to validate manufacturing process and material selections using sustainable analysis and thus to identify the potential of Al-MMCs brake disc for replacement of the conventional cast iron brake disc.

Sustainable analysis

The sustainable analysis was divided into two parts, which include the evaluation of manufacturing process and material aspects. The production of Al-MMCs brake disc rotor involves heating of aluminium billet in a furnace and simultaneously mixed with SiCp using stir mixing
technique. The metallic slurry mixture is transferred into the mould prepared for the casting process. The as-cast part is machined into its final dimensions and heat treated to obtained its desired strength (Fig. 1a). The manufacturing process of cast iron brake disc is illustrated in Fig. 1b. The energy consumption during cast iron production is mainly used in steel making when smelting iron ore. It is the result of the reduction of ferrous oxides under the action of the carbon in metallurgical coke. The next process involves sand casting of molten metal, then cleaned and machined according to the specified dimensions. Finally, the iron brake discs are then tempered to attain the required strength.

![Diagram](image)

Fig. 1 (a) Manufacturing of Al-MMCs and (b) cast iron for brake disc

Meanwhile, for the diposition of Al-MMCs, the producer must arrange the supply of bauxite and aluminium oxide for aluminium alloy production [6]. While, the particulates are extracted out of crude ceramic material which is a layer of dissimilar crystals. The particulate reinforcement production consumed a significant amount of energy due to combustion process and purification of crude ceramic material [7]. Fig. 2a shows the disposition of aluminium alloy and ceramic particulate reinforcement.

![Diagram](image)

Fig. 2(a) Composition of Al-MMCs and (b) cast iron for brake disc

The total expense for Al-MMCs material was estimated by using Eq. (1), where $w_1$ is the weight fraction of the Al-alloy and $w_2$ is the fraction of the particulate reinforcement, whereas, $C_1$ is the cost of the Al-alloy and $C_2$ is the cost of the ceramic reinforcement [8].

$$C = w_1.C_1 + w_2.C_2$$

(1)

Whereas, to produce iron brake disc, a producer must prepare iron ore, coke and scrapper steel. Ore is exploited and crushed for iron production, while the use of scrapped steel varies from 50-100% in cast iron for brake discs production. The disposition of raw materials for producing iron brake disc is clarified in Fig. 2b and from here the total usage of iron as raw material for brake disc could be identified.
Results and discussion

In this research, the Proton Wira 1.3L cast iron brake disc was used as the study object. It contained more than 2% carbon within its matrix but less than 4.5% and referred to as gray cast iron which is classed under SAE J431 G3000 [4,9]. The actual weight of cast iron brake disc was 2.91 kg.

As performed using the idea for conceptual selection presented in Fatchurrohman [10], the selected Al-MMCs brake disc comprised of 90% volume fraction of 2124 Al alloy (Al–4.0%Cu–1.5%Mg–0.5%Mn–0.3%Fe) and 10% volume fraction of SiC particulates. To find the material cost, the weight fraction of 2124-Al alloy was 89%, as calculated using the density ratio of matrix composite; whereas, the weight fraction of SiCp was 11%, as calculated using the density ratio of particulate-composite. As analysed from the brake disc design, the total weight of Al-MMCs brake disc was 1.65 kg. The detail information of manufacturing process and material aspects comparison between Al-MMCs brake disc and cast iron brake disc is presented in Table 1.

The result shows that the total cost of Al-MMCs brake disc is lower than the cast iron brake disc. Although, the material cost for Al-MMCs brake disc exceeds that of cast iron for single unit component, but Bruski [11] informed the value of weight reduction in the automotive industry at could save a maximum of USD 3.50/kg depending on vehicle platform in this case the reduction is 1.26kg hence a price reduction of USD 4.41. Moreover, a total of 2.52kg reduction in the two front brake discs could result in value of weight savings up to USD 8.82. Furthermore, the weight reduction of about 50% influences the cost of other internal systems of the wheel positively. Additionally, by considering Al-MMCs brake disc, the life cycle cost could save up to 50% compared to cast iron disc [12]. Although, it was found that the processing cost of Al-MMCs brake disc was higher than the processing cost of cast iron brake disc since it involved the pre-heating of SiC particulates. Also it required more energy than cast iron brake disc in processing due to difficulty in machining of the Al-MMCs component. However, Al-MMCs consumed lower energy when recycling due to the lower melting point of Al-alloy. Besides that both of the components are 100% recyclable, but more waste deposits are produced during the manufacturing of cast iron brake disc compared to Al-MMCs brake disc [13].

Table 1 Comparison between Al-MMCs brake disc and cast iron brake disc

<table>
<thead>
<tr>
<th></th>
<th>Al-MMCs brake disc</th>
<th>Cast iron brake disc</th>
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<tbody>
<tr>
<td>2121-Al</td>
<td>25.75</td>
<td>5.17</td>
</tr>
<tr>
<td>SiCp</td>
<td>1.5</td>
<td>3.23</td>
</tr>
<tr>
<td>Nett energy (kWh)</td>
<td>27.25</td>
<td>8.40</td>
</tr>
<tr>
<td>Price of energy (USD/kWh)</td>
<td>0.118</td>
<td></td>
</tr>
<tr>
<td>Cost of energy (USD) # A</td>
<td>3.2155</td>
<td>0.99</td>
</tr>
<tr>
<td>Material aspect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight of finished product (kg)</td>
<td>1.65</td>
<td>2.91</td>
</tr>
<tr>
<td>Weight fraction</td>
<td>0.89</td>
<td>0.11</td>
</tr>
<tr>
<td>Weight of refined raw material (kg)</td>
<td>1.69</td>
<td>0.16</td>
</tr>
<tr>
<td>Price of refined raw material (USD/kg)</td>
<td>3.2</td>
<td>52.65</td>
</tr>
<tr>
<td>Cost of material (USD) # B</td>
<td>13.83</td>
<td>12.18</td>
</tr>
<tr>
<td>Weight reduction saving (USD) # C</td>
<td>4.41</td>
<td>N/A</td>
</tr>
<tr>
<td>Total cost 1 unit brake disc (A+B-C)</td>
<td>12.64</td>
<td>13.17</td>
</tr>
</tbody>
</table>
Conclusion

The objective was accomplished by sustainable analysis and thus to identify the potential of Al-MMCs brake disc for replacement of the cast iron brake disc. The results indicated that the Al-MMCs have the potential to replace the conventional cast iron brake disc. Although, the Al-MMCs brake disc had more expensive manufacturing process and material costs when compared to cast iron brake disc, but this was compensated by reduction in price due to weight saving. Therefore, the proposed concept of MMCs brake disc is to be further studied by performing braking simulation analysis which may lead to detail design and prototyping.

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References