Microstructural Characterization And Dry Sliding Wear Behavior Of Adc12 Alloy-B₄C-Rha Hybrid Composites

R Murali Mohan, U N Kempaiah, Seenappa, Madeva Nagaral

Abstract: In the current work, the effect of dual particles on the dry sliding wear behavior of ADC12 alloy has been investigated. Boron carbide (B₄C) and Rice husk ash (RHA) particulates were used as the reinforcements in the ADC12 alloy base matrix. Hybrid composites were prepared by using liquid melt method, keeping 5 wt. % of B₄C reinforcement constant and varying Rice husk ash particles in steps of 3 and 6 wt. % in the ADC12 alloy. Samples were tested for microstructural characterization by using SEM and EDS. A pin-on-disc wear testing machine was utilized to assess the wear loss of specimens, in which a solidified EN32 steel Disc was utilized as the counter face. Dry sliding wear tests were conducted on ADC12 alloy, ADC12 alloy-5 wt. % B₄C-3 wt. % RHA and ADC12 alloy-5 wt. % B₄C-6 wt. % RHA hybrid composites at varying loads of 10 N, 20 N and 30 N with varying sliding speed of 250 rpm, 500 rpm and 750 rpm for constant sliding distance of 1000 m. The wear resistance of ADC12 alloy enhanced with the addition boron carbide and Rice husk ash particulates. The decrease in wear rate was observed in the hybrid composites as compared to base ADC12 alloy. Further, the various wear mechanisms were studied by using worn surfaces SEM micrographs.

Index Terms: ADC12 Alloy, Boron Carbide, Rice Husk Ash, Stir Casting, Microstructure, Wear Behavior

1. INTRODUCTION
Due to low density, aluminium based alloys find applications in several manufacturing areas from automotive to aeronautics. The properties of Al alloys can be enhanced with the addition of ceramics, nitrides and particles in the form of oxides [1-2]. Much research has been carried out to increase the properties of aluminium based alloys. The best properties are obtained when the Al matrix was combined with the dual phase particles and thus prepared composites are called hybrid composites. Several aluminium matrix composites have been prepared in the literature, by dispersing tough ceramic particles e. g. TiC, B₄C, Si₃N₄, TiO₂, WC and SiC in the aluminium alloys like Al6061, Al7075, Al2014 and Al2219 [4-6]. Stir casting process is the most renowned technique for MMCs, as it guarantee a improved microstructural control and wide range of components can be fabricated. Vijayababu et al. [7] and co-authors investigated the properties Al7075-B₄C and fly ash reinforced composites fabricated by stir casting. Also, detailed the impact of dual reinforcement addition on the tensile and hardness behavior of Al7075 alloy. A review on the tribological behavior of Al7075 alloy has been made by Mohammed et al. [8]. The impacts of hard particles addition on the wear behavior of Al alloy based composites were discussed. It is very important to study the wear behavior of composites. Several components in the real time applications subjected to the sliding motions. During sliding or contact between the two surfaces the material loss will be more in general. Especially, Al based alloys are less wear resistance in these contact conditions. The wear resistance characteristics of these alloys are enhanced with the addition of several reinforcements. Boron carbide (B₄C) is the hard ceramic material and having good wear resistance with low density of 2.52 g/cc [9]. Alizadeh [10] studied the effect of B₄C particles on the wear behavior of Al5083 alloy composites. The enhanced wear resistance was observed in the Al5083-B₄C composites. In recent years, reinforcements obtained from converting the bio-waste have emerged as an important class of newer materials. Along with the ceramic and oxide reinforcement to prepare the hybrid composites bio reinforcement like Rice husk ash (RHA) particles are considered to be most effective filler materials for fabricating Al based hybrid composites [11]. Although little research has been performed on ADC12 alloy –B₄C and RHA reinforced composites, in the present work, MMCs have been prepared by using ADC12 aluminium alloy reinforced with ceramic B₄C particles and Rice husk ash particles. The work was aimed at investigating the effect of 5 wt. % of boron carbide and varying weight percentage of rice husk ash in steps of 3 and 6 wt. % on the wear behavior of ADC12 alloy.

2. EXPERIMENTAL DETAILS
In the present work silicon based ADC12aluminium alloy is used as the matrix material. ADC12 aluminium alloy contains silicon as the major alloying element in the aluminium along with iron and copper. Table 1 is showing the chemical composition of the ADC12 alloy used in the present study.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Wt. Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>12.0</td>
</tr>
<tr>
<td>Fe</td>
<td>1.3</td>
</tr>
<tr>
<td>Cu</td>
<td>2.5</td>
</tr>
</tbody>
</table>
sites were from the melt, the vortex was created in the ADC12 alloy melt by reinforcements. Before adding the B\textsubscript{4}C and RHA particles in the melt, the vortex was created in the ADC12 alloy melt by mechanical stirring at 500 rpm. After the addition of preheated particles stirring was done 5 min continuously for proper mixing of boron carbide and RHA particles in the ADC12 alloy. The molten ADC12 alloy and reinforcement mixture was poured into permanent mould of cast iron having circular cavities of 15 mm diameter and 120 mm in length. The samples were removed from the cast iron mould after gradual cooling. The casted sample of ADC12 alloy-B\textsubscript{4}C-RHA composites are shown in Fig. 1.

Table 2: Chemical composition of Boron Carbide Particles

<table>
<thead>
<tr>
<th>Elements</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt. (%)</td>
<td>63.68</td>
<td>36.32</td>
</tr>
</tbody>
</table>

Rice husk ash (RHA) is one of agricultural waste material and is natural reinforcement material. Huge amount of rice husk is generated across the world every year. This generated amount of waste is an environment nuisance. The current research focused to convert the Rice Husk waste into useful reinforcement material by obtaining Si through Rice husk ash. The chemical composition of prepared RHA is shown in the Table 3. The average particle size of used RHA is 30 µm.

Table 3: Chemical Composition of Rice Husk Ash

<table>
<thead>
<tr>
<th>Elements</th>
<th>Wt. Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si\textsubscript{O\textsubscript{2}}</td>
<td>93.1</td>
</tr>
<tr>
<td>K\textsubscript{2}O</td>
<td>1.28</td>
</tr>
<tr>
<td>CaO</td>
<td>1.1</td>
</tr>
<tr>
<td>MgO</td>
<td>0.56</td>
</tr>
<tr>
<td>Fe\textsubscript{2}O\textsubscript{3}</td>
<td>0.49</td>
</tr>
<tr>
<td>Al\textsubscript{2}O\textsubscript{3}</td>
<td>0.47</td>
</tr>
<tr>
<td>C</td>
<td>0.33</td>
</tr>
<tr>
<td>Na\textsubscript{2}O</td>
<td>0.6</td>
</tr>
<tr>
<td>LOI</td>
<td>2.61</td>
</tr>
</tbody>
</table>

*LOI-Loss of Ignition*

ADC12 alloy, ADC12-5 wt. % B\textsubscript{4}C-3 wt. % RHA and ADC12-5 wt. % B\textsubscript{4}C-6 wt. % RHA hybrid composites were synthesized by liquid phase melt stir casting method. The ADC12 aluminium alloy was melted in graphite crucible using electric resistance furnace. The temperature of the furnace was maintained at 750°C. Before adding the reinforcements particles into the ADC12 alloy the preheating of reinforcement was done in the preheater at a temperature of 300°C. This preheating of B\textsubscript{4}C and RHA particles enhances the wettability of particles and also helps to remove the moisture content. Since, RHA contents Silica which is the combination of Silicon and Oxygen. The improvement in the wettability is very important to have the strong interface bonding between the ADC12 alloy and reinforcements. Before adding the B\textsubscript{4}C and RHA particles in the melt, the vortex was created in the ADC12 alloy melt by mechanical stirring at 500 rpm. After the addition of preheated particles stirring was done 5 min continuously for proper mixing of boron carbide and RHA particles in the ADC12 alloy. The molten ADC12 alloy and reinforcement mixture was poured into permanent mould of cast iron having circular cavities of 15 mm diameter and 120 mm in length. The samples were removed from the cast iron mould after gradual cooling. The casted sample of ADC12 alloy-B\textsubscript{4}C-RHA composites are shown in Fig. 1.

Figure 1: Casted sample

The SEM and EDS characterization of ADC12 alloy and its B\textsubscript{4}C and Rice Husk Ash composites were examined by SEM with EDS attachment at BMS College of Engineering, Bangalore using Vegas made scanning electron microscope. The ADC12 alloy surface morphology and proper dispersion of reinforcement material in composites was observed by SEM analysis. EDS analysis was used to know the elemental analysis of casted ADC12 alloy, ADC12-5 wt. % B\textsubscript{4}C-3 wt. % RHA composites and ADC12-5 wt. % B\textsubscript{4}C-6 wt. % RHA composites. The wear behavior of ADC12 alloy and B\textsubscript{4}C-RHA reinforced composites were analyzed by using pin on disc wear machine. The experiments were conducted as per ASTM G-99 wear testing standard [12] on 10 mm in diameter and 15 mm length circular specimen as shown in Fig. 2. The wear rate was calculated after conducting the dry sliding wear tests at 10 N, 20 N and 30 N varying loads at 750 rpm sliding speed for 1000 m sliding distance in 50 mm diameter wear track. Similarly, one more set of dry sliding wear behavior of ADC12 alloy composites were analyzed at varying sliding speeds of 250 rpm, 500 rpm and 750 rpm at 30 N load and 1000 m sliding distance. The wear loss was noted in terms of weight loss, which further used to calculate the volumetric wear loss of ADC12 alloy and ADC12-B\textsubscript{4}C and RHA reinforced hybrid composites. Finally, the wear of the specimens was expressed in the wear rate. At the time of conducting wear tests using pin on disc wear machine, wear debris were collected and these debris were studied for the various wear mechanisms using SEM micrographs. Further, worn surface morphology also analyzed using scanning electron micrographs to know the various wear behavior involved in the ADC12 alloy and ADC12-5 wt. % B\textsubscript{4}C-3 wt. % RHA and ADC12-5 wt. % B\textsubscript{4}C-6 wt. % RHA hybrid composites.

Figure 2: Wear test specimen
3. RESULTS AND DISCUSSION

3.1. Microstructural Analysis

Figure 3: Scanning electron micrographs of (a) as cast ADC12 alloy (b) ADC12-5 wt. % B$_4$C-3 wt. % RHA (c) ADC12-5 wt. % B$_4$C-6 wt. % RHA composites

Fig. 3 indicates the scanning electron micrographs of as cast ADC12 alloy (Fig. 3a), ADC12 alloy-5 wt. % B$_4$C-3 wt. % RHA composites (Fig. 3b) and ADC12 alloy-5 wt. % B$_4$C-6 wt. % RHA composites. Fig. 3a represents the SEM micrograph of the unreinforced ADC12 alloy sample. The microstructure of ADC12 alloy contains flakes kind structure. Since ADC12 is the one type of silicon based alloy, these flakes represents the presence of silicon content in the alloy. Also, it is visible in the micrograph tiny dark patches, which shows the high weight percentage of Si content in the ADC12 alloy. Further, Fig. 3b and 3c are the SEM micrographs of ADC12 alloy with dual particles reinforced composites. Fig. 3b-c displays fine microstructures with strong interfacial bonding between the ADC12 alloy with B$_4$C and rice husk ash particles. In the hybrid composites B$_4$C and RHA particles are well and evenly distributed and there is no segregation. Fig. 3b indicates B$_4$C and 3 wt. % of RHA particles in the ADC12 alloy along with the Si content. As the weight percentage of RHA increases from 3 to 6 wt. % in the ADC12 alloy along with 5 wt. % of B$_4$C, only RHA and B$_4$C particles are visible in the microstructure as in Fig. 3c.

Figure 4: Energy dispersive spectrum of ADC12-5 wt. % B$_4$C-6 wt. % RHA composites

Fig. 4 is showing the energy dispersive spectrum of ADC12 alloy reinforced with 5 wt. % of B$_4$C and 6 wt. % of rice husk ash reinforced composites. From the spectrum it is evident that Si content is more in the spectrum next to Al, which confirms the presence of more Silicon content in the ADC12 alloy. Further, from the spectrum the presence of B$_4$C particles confirmed in the form of B and C elements.

3.2. Wear Properties

The wear tests are conducted on the ADC12 alloy and micro B$_4$C and rice husk ash reinforced composites at varying loads of 10 N to 30 N in steps of 10 N at 750 rpm constant sliding speed and for a sliding distance of 1000 m. Similarly, experiments were accompanied at varying sliding speeds of 250 rpm to 750 rpm in steps of 250 rpm at constant 30 N loads and 1000 m distance. For all the tests the wear is noted in terms of weight loss, further converted to wear rate using volumetric wear loss.

Effect of Load on Wear Rate
Figure 5: Wear rate of ADC12 alloy and its B₄C and RHA reinforced hybrid composites at varying loads and constant speed

The load is one of the significant parameters which plays an important role in wear loss. Lot of work carried out on the influence of normal load in wear experiments to understand the wear rate of aluminium alloys. Further, to study the effect of load on wear, graphs have been plotted for wear loss in terms of wear rate against different loads of 10 N, 20 N and 30 N at constant distance of 1000 meters and sliding speed of 750 rpm. Fig. 5 is indicating the effect of applied normal load on the wear behavior of ADC12 alloy and ADC12-5 wt. % of B₄C-3 wt. % RHA and ADC12-5 wt. % B₄C-6 wt. % RHA composites. From the graph it is observed that as load increases from 10 N to 30 N, there is an increase in wear for all the composites and base ADC12 alloy. At maximum load of 30 N the temperature of sliding face increases and reaches the critical value. Therefore, as the load increases on the pin there is also increase in the wear loss of the matrix ADC12 alloy, ADC12-5 wt. % of B₄C-3 wt. % RHA and ADC12-5 wt. % B₄C-6 wt. % RHA composites. The wear loss of as cast ADC12 alloy is highest in all the loading conditions and is represented in the Fig. 5. It is seen that the wear loss of the composites decreases with increase in wt. % of RHA in the ADC12 alloy. The increase in wear resistance of the ADC12 alloy with B₄C and RHA reinforced composites may be due to the high hardness of B₄C and RHA particulates which acts as the barrier for the wear loss. It can also be seen that with increase in addition of hard B₄C particles the wear resistance also increases; in present research work increase in wt. % of RHA particles also resulted in the increase in wear resistance, which are similar to the results obtained in present study [13, 14].

Effect of Sliding Speed on Wear Rate
Fig. 6 shows the wear loss with the variation of speed for several test samples with varying compositions. The test is conducted with varying disc speed of 250 rpm, 500 rpm, and 750 rpm by retaining load of 30 N. From the Fig. 6, it is concluded that wear rate increases with the increasing sliding speed. For base ADC12 alloy the effect of sliding speed is more when compared to B₄C and RHA reinforced hybrid composites.

Although at all the sliding speeds, the wear loss of the composites is much lower, when compared with the ADC12 alloy matrix and is much lesser in the case of ADC alloy-5 wt. % B₄C – 6 wt. % RHA particles reinforced hybrid composites. Basically, with increase in RHA particulates the wear losses of the composite decreases in wear loss. The results obtained in present work are similar and are in line with the previous research work carried out by other researchers [15, 16].

(a)

(b)
It's significant to study the worn-out surface morphology of ADC12 alloy, ADC12 alloy-5 wt. % B₄C and 3 wt. % of RHA and ADC12 alloy-5 wt. % B₄C and 6 wt. % of RHA reinforced hybrid composites as it shows the type of wear the materials with different composition have undergone. During sliding the ADC12 alloy matrix is softer than the rubbing disc material & hence shows viscous flow of ADC12 matrix, which is in the form of pin causing plastic deformation of the specimen surface, resulting in very high material loss. The worn surface of ADC12 alloy shows presence of grooves, micro-pits and fractured oxide layer as shown in Fig. 7a, which would have caused the increase of wear loss. Whereas B₄C and RHA particles in ADC12 alloy – 5 wt. % of B₄C, 3 and 6 wt. % of RHA composites restrict the viscous flow of the matrix as shown in Fig. 7b and 7c, it is observed that the grooves or erosion have reduced with addition of B₄C and rice husk ash particles means there is more & more resistance to wear loss [17]. Meanwhile, the stress seems to be transferred on B₄C and RHA particles and strain concentration occurs around these particles and worn surface area shows less and less cracks and grooves with the addition of B₄C and RHA particles.

4. CONCLUSIONS
In this study, ADC12 alloy-B₄C and RHA micro hybrid composites have been manufactured by stir casting technique by taking 5 wt. % of B₄C particles constant and varying Rice husk ash particles in 3 and 6 wt. %. The microstructure and dry sliding wear behaviors of ADC12 alloy hybrid composites were examined. The framework or composite is free from pores and uniform dispersion of micro particles, which is apparent from SEM microphotographs. The EDS examination affirms the nearness of B₄C and RHA particles in the ADC12 alloy matrix. Further, wear resistance of cast alloy ADC12 increased with the presence of B₄C and RHA particles. The applied load and sliding speed affected the wear behavior of ADC12 alloy and its composites. As load and speed increased, the wear rate of ADC12 alloy and its B₄C-RHA particles reinforced hybrid composites also increased. The improved wear resistance is exhibited by the SEM images of worn surface.

REFERENCES