Evaluation of Wear and Corrosion Resistance of A356 Alloy Based Hybrid Composite at Different Aging Conditions

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Abstract

Hybrid metal matrix composites (MMC’s) are significant kind of engineering materials used in automotive, aerospace, marine hardware and other applications because of their lower density, cast ability and better mechanical and wear properties compared to pure aluminum. So, an effort is made to study density, wear and corrosion resistance of A356 alloy based hybrid composites containing RHA and Al\textsubscript{2}O\textsubscript{3} particulates in equal proportions (1wt\%, 2wt\%, 3wt\%, 4wt\% and 5wt\%) are studied with different aging conditions. Stir casting is a type of liquid metallurgy technique was employed in which preheated reinforcements were introduced. A scope of enhancement in both corrosion and wear resistance is observed in Double aged with strain specimens over as-cast, single aged and double aged without strain condition. It was also observed that the density of hybrid composites decreased with increasing particle content. The microstructure of the composites was examined to analyze the dispersion of RHA and Al\textsubscript{2}O\textsubscript{3} particulates in a matrix using optical microscope.

Keywords: Rice Husk Ash (RHA), Hybrid composites, A356, Stir Casting.

INTRODUCTION

The structural material that is composed of two or more combined constituents is known as composite and those combined constituents are mixed at a macroscopic level and are not soluble in each other. One constituent chosen is known as the reinforcing phase and the one in which it is embedded is called the matrix phase. The
reinforcing phase material may be in the form of fibers, particles or flakes. The matrix phase materials are normally continuous. Composite materials are new generation materials developed to meet the demands of rapid development of technological changes of the industry [1].

Ramesh D, et al., [2] examined the wear resistance of frit reinforced aluminium metal matrix composites, revealed improved wear resistance with the increase in frit particle content to aluminium matrix. Ghanashyam et al., [3] have reported the wear behavior of aluminium–Mica/E-glass fiber hybrid composites, exhibited excellent wear resistance under all the test conditions employed. A Comparative study by Honnaiah C, et al., [4] on wear resistance of alumina reinforced Aluminium Metal Matrix composites (AMMC’s) revealed improved wear resistance with the decrease in particle size. Shenoy H et al., [5] have described in their work that the resistance to corrosion of Al 6061-Mica/E-glass fiber can be improved by heat treatment in an effective manner. Dasappa R et al., [6] Studied that the corrosion resistance of the material can be improved by the frit inclusion in Al 6061 matrix.

Metal matrix composites (MMC’s) progressively adapt as an appealing material for advanced Aerospace, Automotive and Marine hardware applications. The properties of MMC’s can be modified by adding the preferred reinforcement. The parameters of micro-structural reinforcement are the size and shape of material, weight fractions of reinforcements and as well as orientation and distribution. Thus, the elastic properties of the MMC’s are greatly determined by its micro-structural parameters of the reinforcement [7].

Various light metals such as Aluminium, Magnesium and many more are being used as matrices, among these light metals, especially aluminium and alloys of aluminium are being used much extensively in manufacturing of MMC’s as matrices. The Aluminium metal matrix composites show numerous exceptional mechanical and superior wear resistance characteristics in comparison with the matrix alloy. Due to this factor the current investing applications are considering MMC’s which are based on aluminium alloy and these MMC’s are being proposed as aspirant materials [8].

A huge number of researchers analyzed that production of discontinuous reinforced metal matrix composites can be made economical by adopting the melting and casting techniques. The related works on metal matrix composites demonstrated that there is no much published data available on production techniques of A356/RHA/ Al₂O₃ hybrid metal matrix composites with wear resistance and corrosion behavior.

**AIM OF THE PRESENT WORK**

In the present work an attempt is made to develop an A356 Alloy based hybrid composites with the use of RHA and Al₂O₃ particulates of equal proportions (1wt%, 2wt%, 3wt%, 4wt% and 5wt %) with an end application in marine filed. This hybrid composite is used to manufacture the external portion of the ship that is immersed continuously in a sea water always. The immersed part should be hard, should be resistant to corrosion and wear.
MATERIAL SELECTION
Khanna O.P (2007) published that, while selecting a suitable material for experimental process several factors needs to be considered, such as service, fabrication, and economic requirements. The materials such as i) A356 ii) RHA iii) Al$_2$O$_3$ has been selected based on the comprehensive survey done in literature. RHA and Al$_2$O$_3$ are reinforcements whereas A356 is a matrix material.

Al$_2$O$_3$
The Al$_2$O$_3$ supplied by Vasa Scientific Co, in the form of a powder of average particle size 100μm. The density of Al$_2$O$_3$ used is 3.69 g/cc.

Aluminium356
M. Abdulwahab et al. (2012) have noted that A356 possess high strength, superior casting properties, heat treatment capability. Due to these properties and its wide applications, A356 was chosen as a matrix material which is available in the form of ingots. The A356 chemical composition applied in the present experimental study is represented in the Table 1. The density of A356 used is 2.67 g/cc.

Table 1: A356 Chemical composition

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>6.6</td>
</tr>
<tr>
<td>Mg</td>
<td>0.45</td>
</tr>
<tr>
<td>Fe</td>
<td>0.10</td>
</tr>
<tr>
<td>Ti</td>
<td>0.10</td>
</tr>
<tr>
<td>Cu</td>
<td>0.05</td>
</tr>
<tr>
<td>Mn</td>
<td>0.055</td>
</tr>
<tr>
<td>Zn</td>
<td>0.005</td>
</tr>
<tr>
<td>Ni</td>
<td>0.005</td>
</tr>
<tr>
<td>Al</td>
<td>Balance</td>
</tr>
</tbody>
</table>

RHA (Rice Husk Ash)
Siva Prasad et al. [9] concluded that most economical and low density material is rice husk ash (RHA). The RHA is available as a byproduct in huge quantities as a reinforcement material. Rice husk obtained as a byproduct after rice milling procedure and this is agriculture debris. Rice husk consists of 20% inorganic substances and rest is the organic substances. After rice milling the 50kg of rice, it is approximated that, rice husk of 10Kg can be obtained. When we burn the rice husk, the RHA is acquired. To enhance the mechanical properties as well as to lower the material density, here RHA, which is of less weight and available in surplus, is being used as reinforcement in MMC’s. The chemical composition of RHA used is as presented in Table 2. An average granular size of RHA is 75μm. The mass density of RHA used is 2.1 g/cc.
Table 2: The RHA chemical composition

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica</td>
<td>90.23</td>
</tr>
<tr>
<td>Graphite</td>
<td>4.77</td>
</tr>
<tr>
<td>Calcium oxide</td>
<td>1.58</td>
</tr>
<tr>
<td>Magnesium Oxide</td>
<td>0.53</td>
</tr>
<tr>
<td>Potassium oxide</td>
<td>0.39</td>
</tr>
<tr>
<td>Ferric Oxide</td>
<td>0.21</td>
</tr>
</tbody>
</table>

EXPERIMENTAL WORK

The rice husk was burned and the ash obtained was intensively cleaned with H₂O to discard fine particles and dehydrated at normal room temperature for 1 day. Cleaned rice husk ash was then heated at 200°C for 60 min in order to eliminate the organic matter and wateriness. The resulted material is then kept for heating at 600°C for about 12 hr. This process removes the carbonaceous material [10]. After this process, the color of the material changes to grayish white from its original color of black. Thus, in the preparation of composites, the reinforcement material used is a silica-rich ash obtained from the above process.

The stir casting is a type of liquid metallurgy technique method. The stir casting method has advantages like production cost is less; control of material is an easy and discontinuous reinforcement of casting ingots uses this method. There are various other techniques like liquid metallurgy technique, Powder metallurgy, and spray deposition, etc., were feasible to formulate the MMC’s. However, Stir casting is advantageous over the all available techniques. The mechanical properties of the resulting composite materials after the reinforcement of RHA and Al₂O₃ can be studied by carrying out several experiments and results can be analyzed to discover the reinforcement effects.

A356 aluminium alloy was charged in the electric furnace and superheated to a temperature of 800°C. The stir casting technique was used to fabricate specimens and after applying this method, the melt of the matrix alloy creates the vortex. The stainless steel stirrer puts into the melt and stirred at the speed of 500 RPM slowly to mix the molten metal. The reinforcement particles, RHA and Al₂O₃ were preheated to 450°C for 1 h. After preheating, particles are consolidated it into the melt to exclude moisture. To reduce the porosity, the addition of the degassing tablet has been done once after the metal is completed melted. To enrich the wettability, meantime 1% by weight of magnesium was included in the melt. This addition of magnesium improves the wettability between the matrix alloy and the reinforcement. The preheated particles of RHA and Al₂O₃ were included during constantly stirring of molten metal. Even after the accomplishment of particle feeding, the stirring was preceded for another 5-10 min. After this stage, the molten mixture was drained into the mould. To accomplish the uniform solidification of the molten metal the mould was preheated to
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200°C for 30min. Thus, particle strengthened hybrid composite materials are formed by adapting the stir casting process and 1%, 2%, 3%, 4% and 5% by equal weight proportions of RHA and Al₂O₃ are thus used.

Heat Treatment Procedure
The following steps are involved in the heat treatment procedure:
- Solutionizing
- Quenching
- Stretching/straining
- Aging
  - Aging with low temperature (Single aging)
  - Aging at higher temperature (Double aging)

- Solutionizing and Quenching: The solution treatment is done for two hours, first soaking temperature of 540°C was maintained succeeded by water quench at room temperature was carried out.
- Stretching/straining: This is a particular condition where, instantaneously after the heat treatment and quenching, before precipitation starts and the hybrid composite material become harder. An external force is applied (before 5Hrs) to permanently deform the one set of prepared samples by 8% to 10%.
- Single aging: After quenching single aging is at the temperature of 140°C for about 12hrs of period is carried out.
- Double aging: The Second step of aging procedure also done for the 12hrs of time and at a temperature of 190°C.

RESULTS AND DISCUSSION
The samples were machined as per the ASTM specifications and were exposed to solution heat treatment. Density, Corrosion resistance and Wear resistance of formed hybrid composites have been analyzed.

Microstructure Analysis:
The alloy matrix was subjected to the microstructure examination following Fig.1 to Fig.4 are the micro structures obtained in our experiment.
The microstructure examination confirms the presence of the reinforcements inside the composites. Once the casting is ready, a cross section sample was collected from the castings. These castings are carrying through grinding at the beginning and then emery paper was used to polish the ground one, at last, engraved using Keller’s solution and was examined through an optical microscope.
The optical microscope has been used to investigate the A356 alloy based hybrid composite material. The Aluminium composites which are reinforced with RHA and Al₂O₃ particulate and microstructure obtained from optical microscope are shown from Fig.1 to Fig. 4.
**Figure 1:** Microstructure of As-cast A356 Hybrid composite (4% RHA and 4% Al$_2$O$_3$)

**Figure 2:** Microstructure of Single aged A356 Hybrid composite (4%RHA and 4% Al$_2$O$_3$)
Figure 3: Microstructure of Double aged without strain A356 Hybrid composite (4% RHA and 4% Al₂O₃).

Figure 4: Microstructure of Double aged with strain A356 Hybrid composite (4% RHA and 4% Al₂O₃).
The optical micrographs demonstrate the uniform distribution of RHA and Al$_2$O$_3$ reinforcement particles in the matrix. And it is evident that there are no void and discontinuities in the A356 alloy composite material. Thus, we can say that the good interfacial bonding among the reinforcement particles and matrix material.

**Density Measurement:**

![Density Measurement Graph](image)

**Figure 5:** Density of A356 alloy hybrid composite by Archimedes Principle

Archimedes Principle can be used to measure the density. From Fig. 5 we can observe that density of A356 Alloy Hybrid composite material reduces when the percentage of reinforcement RHA and Al$_2$O$_3$ increases. The presence of voids in matrix, low interface bonding between reinforcement and matrix and development of fracture of reinforcement leads to lower density with increase in reinforcement. The presence of higher porosity may be due to solidification nature and due to the agglomeration of Al$_2$O$_3$ [11]. The Archimedes Principle can be applied here and the succeeding expression can be derived for the density of the composites.

$$\rho_{\text{comp}} = \frac{m}{m - m_1} \rho_w$$

(1)

Where m is the mass of the composite specimen in air, m$_1$ is the mass of the same composite specimen in distilled water and $\rho_w$ is the density of distilled water. The density of distilled water at 20°C is 998Kg/m$^3$. 
Wear Resistance:
The wear rate of as-cast and various aged samples can be studied by conducting the dry sliding wear tests. The pin-on-disc test apparatus has been used in the investigation. An ASTM has certain standards specified for composites; thus the aim of the investigation is to find the dry sliding wear characteristics of aluminium alloy and its composites. Test samples were taken from the castings, machined to pins of size 10mm diameter and 30mm height, polished and subjected to wear tests. The counterpart disc was made of high carbon EN32 steel having a hardness of HRC62 and the radius of the sliding track on the disc surface was 57mm. All the wear tests were conducted at room temperature for 20 minutes with a load of 1Kg and at 600RPM. The wear rates of the composite specimens were analyzed as a function of the volume worn out (Volume loss method), sliding distance and applied load. The wear rate is estimated from the following equation.

\[
\text{Wear Rate} = \frac{\text{Volume of the material removed}}{\text{Normal load} \times \text{Sliding distance}}
\]

(2)

Figure 6: Evaluation of wear rate for specimens with different RHA and Al₂O₃ particulates and Aging conditions.

Due to the drastic enhancement in hardness and great bonding among the matrix and the reinforcement it is evident from the above Fig. 6, which with the increase of reinforcement decreases the wear rate of the composites. The wear loss is greatly reduced with aging and the lowest wear rate was noticed in double aging with strain specimens which can be associated with higher hardness.

Corrosion Test
Various solutions were prepared and stored in vessels; by dipping the samples in these vessels corrosion test was performed. The solution is prepared using 5% NaCl, Sea
Water and 0.1 normal HCL and the samples were soaked in to it for a period of 96 hours. After this the specimens are cleaned with H2O and rinsed with acetone and weight is checked in an electronic weighing machine. Following formula can be used to calculate the percentage of corrosion rate.

\[
\% \text{ Corrosion Rate} = \frac{W_i - W_a}{W_i} \times 100
\]

Where, \(W_i\) is the initial weight before corrosion and \(W_a\) is the final weight after corrosion.

**Figure 7:** Evaluation of corrosion rate for specimens with different RHA and Al\(_2\)O\(_3\) particulates with Aging conditions in 0.1 normal HCL

**Figure 8:** Evaluation of corrosion rate for specimens with different RHA and Al\(_2\)O\(_3\) particulates with Aging conditions in 5% NaCl
Figure 9: Evaluation of corrosion rate for specimens with different RHA and Al$_2$O$_3$ particulates with Aging conditions in Sea water.

From the Fig. 7, 8 and 9, it is noticeable that the corrosion rate of the A356 hybrid composite material is much lower when compared to that of its parent metal. With the increases in wt% of RHA and Al$_2$O$_3$ content the corrosion resistance has improved. This is due to the inclusion of reinforcement makes the A356 alloy into stronger and resistant to corrosion. And stabilized material has been resulted from the heat treatment and aging and hence there is an appreciable reduction in corrosion resistance. It is also evidence that the corrosion rate in NaCl and sea water is lesser than HCL.

CONCLUSION
This study, conducted on A356 based hybrid composites materials with RHA and Al$_2$O$_3$ particulates as reinforcement materials with as-cast and various aging conditions the preceding conclusions can be made.

- To fabricate the hybrid composite material of the A356 alloy matrix we can use the stir casting method and the particles of RHA and Al$_2$O$_3$ can be effectively added to the A356.
- When there is an increase in RHA and Al$_2$O$_3$ particulates percentage in the alloy matrix, then the density of A356 alloy based hybrid composites decreases.
- It is evidenced that corrosion loss decreased with increase in RHA and Al$_2$O$_3$ particles in the matrix alloy under different test conditions. Thus the corrosion resistance of the hybrid composites is highly influenced by the heat treatment.
• It has been evidenced that the wear loss decreased with increase in RHA and Al<sub>2</sub>O<sub>3</sub> particles content in the matrix alloy. Thus wear behavior of the hybrid composites is highly influenced by the heat treatment.
• The outcomes captured evidently demonstrate that the double aged with strain specimens shown improved Wear resistance and corrosion resistance in comparison with the single aging and as cast specimens.
• It is clearly demonstrated that composites with 4% of RHA and Al<sub>2</sub>O<sub>3</sub> particles have shown improved Wear resistance and corrosion resistance in comparison with the other combinations.
• Further increase in reinforcement did not show significant improvement because of reinforcement floating on the metal and removed as dross.

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REFERENCES


