Abstract

The present study has been focused on the feasibility and viability of developing low cost - high performance Al matrix hybrid composites with the use of Rice Husk Ash (RHA), Copper (Cu) and Magnesium (Mg) as reinforcements. The three-weight concentration % (wt. %) of Cu particulates added with 6, 8 and 10wt.% RHA were utilized to prepare the reinforcing phase with Al 6061 alloy as matrix using stir casting method. The 1wt.% of Mg was added to improve the wettability between the Al matrix and reinforcements. The presence of Silicon Dioxide (Silica) is confirmed by X-ray diffraction pattern and EDS spectrum. The effect of reinforcement composition is studied by varying the RHA concentration between 6wt% and 10wt%. It is reported that the tensile strength and hardness of the hybrid composites increased with increasing wt.% of the reinforcing phase (RHA + Cu) while the %Elongation and impact strength decreased with increasing wt.% of RHA in the reinforcing phase. This is because reinforcements are comparatively harder and less ductile than matrix.

Keywords: Al 6061, Copper, Magnesium, Rice Husk Ash, Hybrid Composites, Stir Casting, Mechanical Properties.

I. INTRODUCTION

Researchers in the area of materials science are continuously developing materials having higher strength, hardness, toughness and other tribological properties. Metal Matrix Composites (MMCs) have emerged as a class of materials suitable for structural, aerospace, automotive, electronic, thermal, and wear applications owing to their advantages over the conventional materials [1-2]. The incorporation of different reinforcements into a matrix has led to the development of hybrid composites. Hybrid composites are becoming better substitutes for the conventional alloys because of characteristics like high stiffness, high strength and low density. Aluminium hybrid composites are a new generation of metal matrix composites that have the potentials of satisfying the recent demands of advanced engineering applications. These demands are met due to improved mechanical properties, amenability to conventional processing technique and possibility of reducing production cost of aluminium hybrid composites. The performance of these materials is mostly dependent on selecting the right combination of reinforcing materials since some of the processing parameters are associated with the reinforcing particulates. The different reinforcing materials used in the development of Aluminium matrix hybrid composites are synthetic ceramic particulates, industrial wastes and agro waste derivatives. It has been also observed that increasing number of reinforcements in MMCs can improve some mechanical properties, depends upon the nature of reinforcement or sometimes it reduces cost without altering the properties significantly [3]. The different countries have target to get composites by consideration the industrial and agro wastes as reinforcement material and subsequently reducing the cost and improvement in performance level. On the other side, the reinforcement materials such as Silicon Carbide and alumina have relatively high cost due to its procurement from abroad. Fly ash, silica, and graphite are a few examples of industrial/inorganic materials that have been used as reinforcement in Aluminium hybrid composites. Rice husk ash, bagasse ash, and coconut shell ash are few agro waste products which have also been tested as potential reinforcing material [4-8]. Though literatures on the potentials of agro waste ashes are still limited compared to the synthetic reinforcement, the available results show that Al based composites reinforced with synthetic ceramics such as silicon carbide and alumina have superior properties in comparison to the agro waste ash reinforced grades. An approach which will seek to harness the clearly superior strength levels of the synthetic reinforcements and the lower cost and density advantages of the agro wastes have not received much attention in literature. This research work is motivated by the prospect of developing high performance Al matrix hybrid composites using silicon carbide and bamboo leaf ash as complementing reinforcements. Bamboo trees are found in large quantities in Nigeria and likewise so many other parts of the world; and the leaves often litter the environments where they are found [9]. Pydi P. et al. [10] reported that the RHA is an important source of silica and it can be added in Aluminium metal. The author further observed that by successful addition of rice husk ash in molten metal the mechanical properties of composites can be
improved. Alaneme et al. [11] investigated the fabrication characteristics and mechanical behaviour of Al-Mg-Si alloy matrix composites reinforced with alumina (Al2O3) and RHA. This was aimed of developing high performance Al matrix composites at reduced cost. The results shown that the less dense Al-Mg-Si/RHA/Al2O3 hybrid composites have estimated percent porosity levels as low as the single Al2O3 reinforced grade (<2.3% porosity). The hardness of the hybrid composites decreased slightly with increase in RHA content with a maximum reduction of less than 11% observed for the composites decreased slightly with increase in RHA content with a maximum reduction of less than 11% observed for the composites without graphite. However, the wear resistance up to 50% RHA was observed to be higher than that of the composites containing 0.5 wt.% graphite and of graphite on the hardness became less significant. The results showed that the less dense Al/RHA/SiC hybrid composites have estimated percent porosity levels as low as <2.86% porosity. Vijaya Kumar Raju P. et al. [18] investigated the tribological behaviour of an Al–5-wt.% Cu alloy, Al–10-wt.% Cu alloy (hypoeutectic alloy), and an innovative composite combination of an Al–5–wt.% Cu alloy as the matrix and a 5-wt.% Cu powder as the reinforcer fabricated using stir casting method. The wear and frictional properties of the metal matrix composites was studied by performing dry sliding wear test using a pin-on-disc wear tester and Taguchi’s L9 Orthogonal array was selected for analysis of the data. Wear rate of the composite was found lower when compared to both the alloys.

Management of most agro wastes could be overwhelming and the best approach remains to explore more recycling techniques; and then applications where recycled wastes can be productively utilized. This work is part of current efforts aimed at considering the potentials of a wide range of agro waste ashes for the development of low cost- high performance Aluminium based hybrid composites. These low cost hybrid composites could have potentials for use in stress bearing and wear applications among others. RHA is silica enriched agricultural waste. The objective of the present work is to develop low cost and high performance Al 6061 matrix hybrid composites with the use of RHA and Cu as reinforcements and mg as a coupling agent. Microstructural characteristics of RHA and mechanical properties of fabricated Al matrix hybrid composites were investigated.

II. EXPERIMENTAL DETAILS

A. FABRICATION OF COMPOSITES

In the present study, rice husk was thoroughly washed with water to remove the dust and other unnecessary substances and dried at room temperature. The rice husk was further taken into graphite crucible and heated up to 200°C for one hour to remove moisture and organic matter. During this heating operation, the colour of the rice husk changed from grey to black due to presence of organic matter. After heating rice husk at 200°C, the rice husk ash was again heated up to 600°C±30°C for 6 hours. In this operation, the rice husk was completely burnt in the presence of oxygen. For obtaining desired properties the ash was further heated in the electrical furnace at 750°C for 12 hours. After finalized this operation and cooling at room temperature the ash’s color was completely changed from black to grey or slightly greyish-white. In this work, Al 6061 was used as matrix material and 6, 8 and 10 wt.% RHA, 3wt.% Copper (Cu) and 1wt.% Magnesium (Mg) were
used as reinforcements. Table 1 shows the sample wt.% composition used for investigation.

The composites were prepared using two step stir casting method. The RHA and copper particles are initially preheated separately at a temperature of 250 °C to remove moisture and to improve wettability with molten Al alloy. The Al alloy was charged in graphite crucible and was melted to a temperature of about 750 °C using electrical furnace. The liquid alloy was cooled in the furnace to a semi solid state at a temperature of about 630°C. The preheated RHA and copper particles were charged into the semi-solid melt at this temperature (about 630°C) and stirred manually for 20 min. 1wt% of magnesium was added to improve the wettability between the matrix and reinforcements. The semi-solid hybrid composite mixture was heated to temperature of about 900 °C and stirred using an automated mechanical stirrer at 300 for 10 min. Finally, the molten composite mixtures were poured into the mould cavity for the casting purpose.

<table>
<thead>
<tr>
<th>Sample Designation</th>
<th>Composition (wt.%) of Hybrid Composites Materials</th>
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<tbody>
<tr>
<td>A0</td>
<td>100%Al6061</td>
</tr>
<tr>
<td>A1</td>
<td>93%Al6061+6%RHA+1%Mg</td>
</tr>
<tr>
<td>A2</td>
<td>90%Al6061+6%RHA+3%Cu+1%Mg</td>
</tr>
<tr>
<td>A3</td>
<td>88%Al6061+8%RHA+3%Cu+1%Mg</td>
</tr>
<tr>
<td>A4</td>
<td>86%Al6061+10%RHA+3%Cu+1%Mg</td>
</tr>
</tbody>
</table>

B. XRD and microstructural characterization of RHA

X-ray diffraction of prepared RHA powder was taken using an X'PERT PRO X-ray diffractometer with Cu anode, K α radiation and Ni filter. The XRD analysis was carried out at a voltage 45kV and current intensity 40mA. Microstructural characterization of the RHA powder was also conducted by scanning electron microscopy (SEM) to analyse the microstructure. Energy dispersive X-ray analysis (EDX) was done in conjunction with SEM to study the composition of the RHA powder in terms of the percentages of carbon(C), oxygen (O), aluminium (Al), silicon (Si), potassium (K) etc.

C. MECHANICAL TESTING

Composite specimens were prepared on lathe machine as per the standards and tensile, hardness and impact tests were performed. Hardness test of the prepared samples was conducted using Rockwell hardness testing machine on standard test condition of B scale. Prior to this hardness testing, the samples were machined and polished to obtain a smooth plane surface. Five readings were taken for each sample to obtain conformal results and average value was taken as a measure of the hardness of the specimen. The tensile tests were performed on the samples prepared from as-cast composites in accordance with ASTM standard using universal testing machine. A total of 4 samples of each composite composition at room temperature were tested for reliability of data generated and average values were taken for further analysis. The tensile properties measured and evaluated from the test data were ultimate tensile strength and % elongation. Impact strength (toughness) of the composites was determined by Charpy impact test technique using impact testing machine. The composites samples for Charpy impact test arrangement were prepared according to ASTM standards (10×10×55 mm³). The tests were carried out for the 4 notched samples of each composite composition at room temperature for reliability of data generated and average values were taken for further analysis.

III. RESULTS AND DISCUSSIONS

A. XRD AND MICROSTRUCTURAL CHARACTERIZATION OF RHA

The X-ray diffraction patterns of RHA powder shown in Fig.1 confirmed the presence of Silica.

![Fig. 1: XRD pattern of RHA](image)
B. Mechanical Properties

The mechanical properties of the unreinforced, single and hybrid composites are presented in Fig. 3, 4 & 5 using bar chart. It is evident that the hardness and ultimate tensile strength of the hybrid composites are observed to increases slightly with the increase in wt. % of RHA content. It is also observed from the sample series A1 and A2 that copper affects additionally on hardness by 7.35% (Fig. 3) and ultimate tensile strength by 4.04 % (Fig. 4). Hardness and ultimate tensile strength of hybrid composite increases significantly with increase in RHA content from 0wt. % to 8wt. % but becomes less significant with further increase from 8wt. % to 10wt. %. This indicates that the addition of RHA and Cu in Al 6061 with certain wt.% leads the improvements in hardness and tensile strength. From Fig. 5, it can be noted that the impact strength of composite material decreases with the addition of 6 wt. % of RHA but, it slightly improves with the addition of 3 wt. %Cu and it further decreases with the increase in wt. % of RHA.

![Graph showing hardness (HRB) of unreinforced Al 6061 alloy and Al matrix hybrid composites with different wt. % of RHA](image)

Fig. 3: Hardness (HRB) of unreinforced Al 6061 alloy and Al matrix hybrid composites with different wt. % of RHA.

Fig. 2: (a) SEM micrograph (b) EDS spectrum at slot1 of RHA particles (c) EDS spectrum at slot2 of RHA particles (d) EDS spectrum at slot3 of RHA particles
It is observed that % elongation of hybrid composite decreases with increase in wt. % of reinforcements (Table 2). Higher the reinforcements content, lower the % elongation, this is because reinforcements are comparatively harder and brittle and less ductile than Al alloy. It is further noted that hybrid composite particularly grade containing 10 wt.% RHA, 3 wt.% Cu and 1 wt.% Mg has lower % elongation compared to unreinforced Al alloy.

| Table 2: %Elongation of unreinforced Al 6061 alloy and Al matrix hybrid composites |
|----------------------|------|------|------|------|------|
| Sample               | A0   | A1   | A2   | A3   | A4   |
| Tensile strength(MPa)| 85   | 91.5 | 95.2 | 97.1 | 98.4 |
| Initial length (mm)  | 80   | 80   | 80   | 80   | 80   |
| Final length (mm)    | 87.8 | 85.6 | 86.2 | 85.1 | 84.3 |
| Net change in length(mm) | 7.8   | 5.6   | 6.2   | 5.1   | 4.3   |
| Elongation %         | 9.75 | 7    | 7.75 | 6.37 | 5.37 |
IV. CONCLUSION

Based on the experimental results and analysis, the following conclusions have been drawn which clearly indicated that there is a possibility of a significant improvement in the mechanical properties of Al matrix hybrid composites with the use of rice husk ash (RHA), copper (Cu) and magnesium (Mg) as reinforcements

- The X-ray diffraction patterns of rice husk ash powder confirmed the presence of silicon dioxide (silica). It is evident from the SEM micrograph and EDS profiles that the Silica (SiO2) is major constituent derived from RHA.
- Hardness of the hybrid composites increases with increase in reinforcements content with the maximum increment of 35.11% for the Al-10wt.%RHA-3wt.%Cu -1wt.% Mg composition in comparison with increment of 17.20% for Al-6wt.%RHA -1wt.% Mg.
- Ultimate tensile strength of the hybrid composites increases with increase in reinforcements content with the maximum increment of 15.76% for the Al-10wt.%RHA-3wt.%Cu -1wt.% Mg composition in comparison with increment of 7.64% for Al-6wt.%RHA -1wt.% Mg.
- Impact strength and % Elongation of hybrid composite decreases with increase in wt. % of RHA.
- RHA can serve as a complementing reinforcement for the development of low cost and high performance Al hybrid composites.

REFERENCES


