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# Processing and Mechanical Properties of $Al_2O_3$ and Red Mud Particle Reinforced AA6061 Hybrid Composites

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## Abstract

**Aluminum 6061 alloy metal matrix composites (MMCs) reinforced with four different weight fractions of ($Al_2O_3$ + red mud) particles up to 10 wt% were fabricated by a vortex method. The effects of reinforcement content on the mechanical properties of the composites such as hardness and tensile strength were investigated. The density measurements showed that the samples contained little porosity, and the amount of porosity in the composites increased with increasing weight fraction of particles. Scanning electron microscopic observations of the microstructures revealed that the dispersion of the particles was uniform with small clusters at some places and porosity. The results showed that the hardness and the tensile strength of the composites increased with increasing weight fraction of particles.**

## Keywords

**MMCs, $Al_2O_3$, Red Mud, AA6061, Compocasting**

## 1. Introduction

In the recent years, usage of ceramic particle-reinforced metal matrix composites (MMCs) is steadily increasing. Aluminum matrix composites (AMCs) have gained wide acceptance in the past three decades due to their high specific strength and stiffness and superior wear resistance [1]-[4]. A number of processing routes have been developed for the manufacture of particle/whisker/short fibre-reinforced composites. Melt stirring or the stir

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casting technique is currently one of the simplest and most economical fabrication routes employed to manufacture particle-reinforced composites. The process involves melting the matrix alloy and stirring in the particulate reinforcement to create the composite which is then cast either into a useable form or to provide ingot material for subsequent deformation processing. An advantage of this production route is the potentially large size of ingots which can be made. Thus, there is the potential for low cost, high volume production of these materials. However, process variables must be controlled in the melt stirring technique to achieve a high degree of microstructural integrity. Use of non-optimal parameters could lead to porosity, particle clusters, oxide inclusions and interfacial reactions, which will in turn lead to poor mechanical properties [5].

In this study, these problems have been overcome by stirring the melt in semisolid state and by preheating the ceramic reinforcement particles to improve the wettability before incorporation into the metal matrix alloy. In terms of both processing and properties, the main concern that must be investigated is that of obtaining uniform dispersion of the ceramic particles in MMCs [6]. $Al_2O_3$ and SiC fibres and particles are the most commonly used reinforcements in MMCs, and the addition of these reinforcements to aluminum alloys has been the subject of a considerable amount of research work [1] [7]. The application of $Al_2O_3$ or SiC reinforced aluminum alloy matrix composites in the automotive and aircraft industries is gradually increasing for pistons, cylinder heads, etc., where the tribological properties of the material are very important [8]-[13]. Therefore, the development of aluminum matrix composites is receiving considerable emphasis in meeting the requirements of various industries. Incorporation of hard second phase particles in the alloy matrix to produce MMCs has also been reported to be more beneficial and economical [14]-[16]. While the reinforcement induces superior strength and tribological properties, the reinforcement particles also bring about difficulties in characterization [17].

The purpose of the present work, therefore, was to: a) produce the particle reinforced metal matrix composites by a two step vortex method; b) investigate the effect of reinforcement content on the porosity and the mechanical properties of ($Al_2O_3$ + red mud) particulates reinforced 6061 aluminum alloy composites. Considerable work has been done on $Al_2O_3$ as reinforcement but data on red mud is scarce. Red mud is a residue of alumina processing and is available for free with major constituents as $Al_2O_3$ and $Fe_2O_3$. Successful addition of red mud will reduce the reinforcement cost.

## 2. Experimental Procedure

### 2.1. Material Selection

The aluminum alloy used as matrix material in the present study is 6061 Mg-Si alloy (AA6061) whose composition is given in **Table 1**. $Al_2O_3$ (alumina) and red mud particles used as reinforcement have densities of 3.9gm/cc and 3.05 gm/cc respectively. The chemical composition of $Al_2O_3$ and red mud particles used in this study are presented in **Table 2** and **Table 3**, respectively. For manufacturing of the MMCs, 2.5, 5.0, 7.5, and 10 wt% of reinforcement consisting of $Al_2O_3$ and red mud particles mixed in equal quantities were used.

### 2.2. Processing

The liquid metallurgy technique with optimum care was taken and standard procedure was followed to obtain the cast composites. The matrix alloy was melted in a graphite crucible. Preheated reinforcement particles were added through the periphery of the vortex, which was created by stirring the melt with a mechanical impeller at 450 RPM. Composites contain 2.5, 5.0, 7.5 and 10.0 wt% $Al_2O_3$. Red mud particles were cast into ingots. The cast ingots were hot extruded at 540˚C on a 50 ton extrusion press with an extrusion ratio of 20:1. Specimens for microstructural characterization and mechanical testing were made from the extruded rod. Tests were carried out as per ASTM standards. The density of material, that is ratio of weight to volume, was obtained by accurately measuring the weight and the volume of the composites. FTM make Rockwell hardness tester served the purpose of measurement of hardness. Carefully polished and mirror finished specimens were examined under SEM to obtain microphotographs. The mechanical properties were evaluated using model UTE40 universal testing

**Table 1.** Chemical Composition of AA6061 Aluminum Alloy.

| Element | Mg | Si | Fe | Cu | Ti | Cr | Zn | Mn | Al |
|---|---|---|---|---|---|---|---|---|---|
| wt% | 0.85 | 0.69 | 0.14 | 0.24 | 0.02 | 0.02 | 0.004 | 0.03 | Bal |

**Table 2.** Properties of $Al_2O_3$ Particles.

| | |
|---|---|
| Melting Point | 2072˚C |
| Density | 3.95 gm/cm$^3$ |
| Hardness (VH) | 2600 kg/mm/mm |
| Young's Modulus | 530 GPa |
| Compressive Strength | 2000 - 4000 MPa |

**Table 3.** Chemical Composition of Red Mud.

| Constituents | % | Constituents | % |
|---|---|---|---|
| $Al_2O_3$ | 14.41 | MgO | 0.049 |
| $Fe_2O_3$ | 48.50 | ZnO | 0.027 |
| $TiO_2$ | 5.42 | CaO | 3.96 |
| $SiO_2$ | 11.53 | $V_2O_5$ | 0.116 |
| $Na_2O$ | 7.50 | $P_2O_5$ | 0.297 |
| MnO | 0.17 | Others | Balance |

machine of 40 ton capacity.

### 2.3. Density Measurement and Porosity

The experimental densities of the composites were obtained by the Archimedian method of weighing small pieces cut from the composite rods first in air and then in water, while the theoretical density was calculated using the rule of mixtures according to the weight fraction of the combined reinforcement particles. The porosities of the produced composites were evaluated from the difference between the expected and the observed density of each sample.

### 2.4. Hardness and Tensile Strength Tests

The hardness of the composites and matrix alloy were measured after polishing to a 1 µm finish. The Rockwell hardness values of the samples were measured using Rockwell hardness tester. Tensile tests were used to assess the mechanical behavior of the composites and matrix alloy. The composite and matrix alloy rods were machined to tensile specimens with a diameter of 8 mm and gauge length of 40 mm. The tensile strength was tested on UTE40 Universal testing machine at a cross-head speed of 0.5 mms$^{-1}$.

### 2.5. Microstructure

The composite were polished with 400, 600, 800 and 1000 grit sandpapers, respectively. Finally, the polishing was performed on cloth using diamond paste of 6 and 1 µm. Polished samples were etched using Keller's solution. Unreinforced 6061 Al matrix alloy was also polished in the same way. Microscopic examinations of the composites and matrix alloy were carried out using a scanning electron microscope (SEM).

## 3. Results and Discussion

### 3.1. Production of Composites

In the present work, 6061 Al alloy MMCs reinforced with varying weight fraction (2.5, 5.0, 7.5, and 10 wt%). ($Al_2O_3$ + Red mud) reinforcement particles have been successfully produced using stir casting. The optimum process parameters were found to be as follows—temperature for mixing 610˚C pouring temperature: 710˚C, stirring speed: 450 rpm, stirring time: 5 min after the completion of particle feeding. Hot extrusion was performed at 540˚C and extrusion ratio 20:1. Optimum process conditions given above and hot extrusion have resulted in uniform distribution of reinforcement in the matrix.

### 3.2. Density and Porosity

The graphs of theoretical and experimental densities and porosities of the composites according to the weight fractions of red mud and $Al_2O_3$ particles are shown in **Figure 1** and **Figure 2**, respectively. **Figure 1** shows that the theoretical density values of the composites increase linearly (as expected from the rule of mixtures). Although a linear increase was seen in the experimental densities, the values are lower than that of the theoretical densities. The density measurements showed that the composites contained some porosity, and as shown in **Figure 2**, the amount of porosity and density in the composites increased with increasing weight fraction of the particles. These results have been observed in previous investigations [1] [18] [19]. During the production process of the MMCs, some porosity is normal, because of the long particle feeding duration and the increase in surface area in contact with air caused by decreasing the particle size [18] [19].

### 3.3. Microstructures

SEM micrographs of the various wt% of particle-reinforced composites, fabricated under the optimum production conditions, are shown below. The most important factor in the fabrication of MMCs is the uniform dispersion of the reinforcements. As shown in **Figure 3**. Uniform dispersion of the 2.5% reinforcement particles was achieved in the composites with some agglomerations. **Figure 4** and **Figure 5** present the SEM micrographs of the 5.0 wt% and 7.5 wt% $Al_2O_3$ red mud particle-reinforced composites in which the particle clustering and agglomeration are clearly shown. Also, **Figure 6** shows the SEM micrograph of the 10 wt% $Al_2O_3$ red mud particle-reinforced composite which shows a uniform distribution of reinforcement particles.

As a result, SEM observations of the microstructures revealed that the dispersion of the coarser sizes was more uniform while the finer particles led to agglomeration and segregation of the particles, and porosity. The

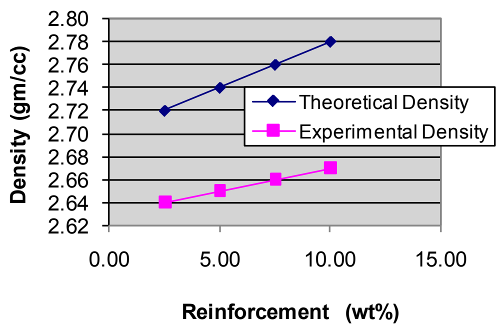


**Figure 1.** The variation of theoretical and experimental density with $Al_2O_3$ red mud particle content.

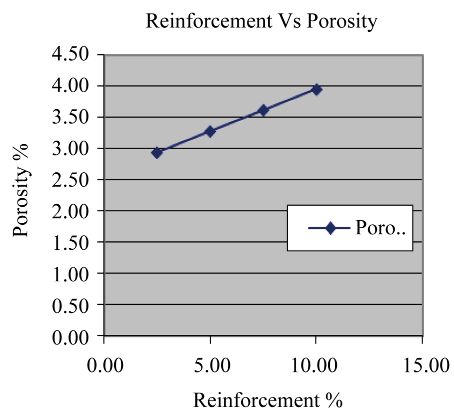


**Figure 2.** The variation of porosity with $Al_2O_3$ red mud particle content.

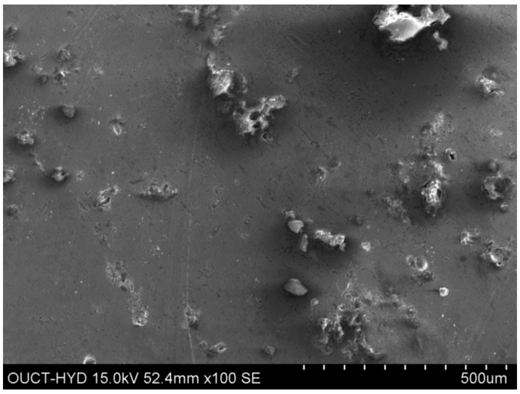


**Figure 3.** SEM micrograph of 2.5 wt% $Al_2O_3$ red mud particle-reinforced composite.

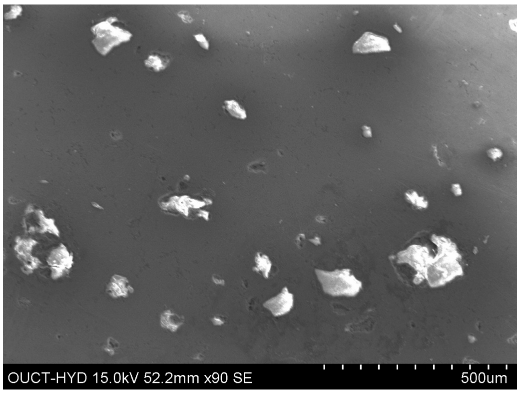


**Figure 4.** SEM micrograph of 5.0 wt% $Al_2O_3$ red mud particle-reinforced composite.

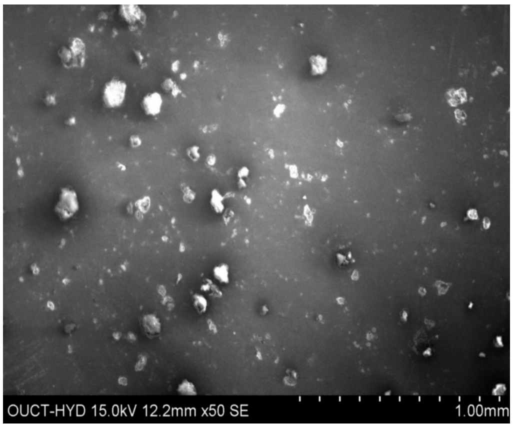


**Figure 5.** SEM micrograph of 7.5 wt% $Al_2O_3$ red mud particle- reinforced composite.

reason for the particle segregation is proposed as follows: the Al dendrites solidify first during solidification of the composite, and the particles are rejected by the solid-liquid interface, and hence, are segregated to the inter-dendritic region. This event occurred more easily with the finer particles [20].

### 3.4. Hardness and Tensile Strength

Hardness tests were performed on a rock well hardness tester and the results of the tests are shown in **Figure 7**.

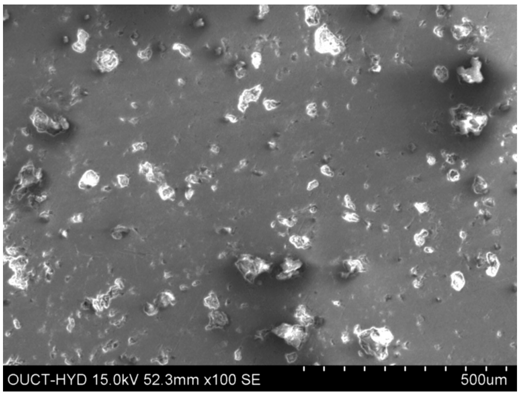


**Figure 6.** SEM micrograph of 10 wt% $Al_2O_3$ red mud particle-reinforced composite.

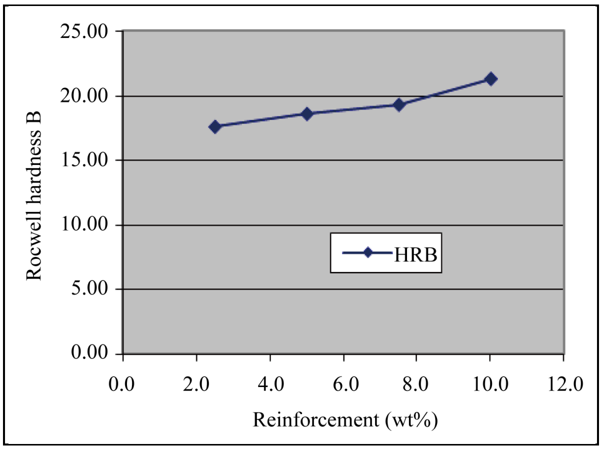


**Figure 7.** The variation of hardness (HRB) with $Al_2O_3$ red mud particle content.

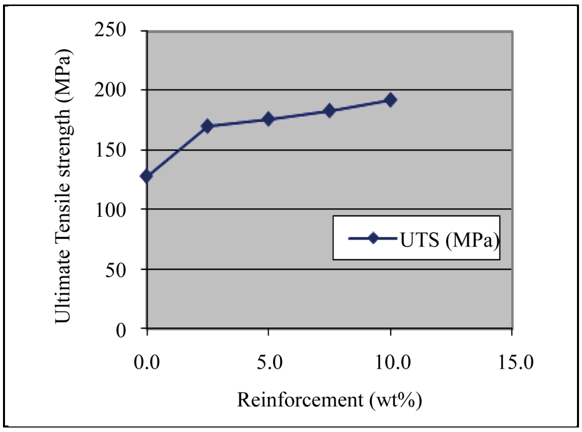


**Figure 8.** The variation of tensile strength with $Al_2O_3$ particle content.

As shown, hardness increases with the amount of reinforcement particles present.

The results of the tensile strength tests are given in **Figure 8**. Which shows the variation of tensile strength with the weight fraction of reinforcing particles? As shown here, the tensile strength of the MMCs increased with increasing amount of particles like the hardness. Among all of the MMCs, the composites reinforced with 10% $Al_2O_3$ particles have the maximum hardness and tensile strength. Compared with the 6061 Al matrix alloy, the tensile strength and hardness of the MMCs are greater, and the addition of (red mud + $Al_2O_3$) particles has increased the tensile strength and hardness of the Al alloy. The increase in filler content contributes to the increase in tensile strength. The reason for the increase in tensile strength in spite of increase in porosity is the thermal mismatch between metal matrix and the reinforcement. This is a major mechanism for increasing the dislocation density of the matrix and therefore increasing the composite strength.

## 4. Conclusions

The optimum process conditions for production of $Al_2O_3$ red mud particle-reinforced aluminum alloy composites by the vortex method and subsequently extruded are found in the present work. SEM microstructures, density and porosity, and the tensile strength and hardness of MMCs were investigated. The following conclusions have been drawn.

1) AA6061 MMCs reinforced with different weight percentages of ($Al_2O_3$ + red mud) particles (up to 10 wt%) have been successfully fabricated by compocasting. The optimum conditions of the production process were that the pouring temperature was 710˚C; stirring speed was 450 RPM, and the stirring time after the completion of particle feeding was 5 min.

2) SEM observations of the microstructures showed that the coarser particles were dispersed more uniformly, while the finer particles led to agglomeration and segregation of particles and porosity.

3) The density and porosity of the composites increased with increasing weight percentage of reinforcement.

4) The tensile strength and hardness of MMCs increased, with increasing weight percentage of the reinforcement.

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