

# Mechanical Behavior of Red mud reinforced Al-5Mg Alloy MMC Material Processed by ECAP

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**Abstract:** The metal matrix composite with Aluminium -5wt%Magnesium (Al-5Mg) alloy matrix and the industrial waste of micro sized Red mud particles were used as reinforcement material with different proportions (5, 10 and 15wt.%) and prepared by stir casting technique followed by Equal Channel Angular Pressing (ECAP). It was noticed that there is a significant improvement of mechanical properties with an increase in the proportion of reinforcement of red mud up to certain extent in the Al-5Mg matrix composite. Casted billets of composite material are subjected to an annealing treatment of 225<sup>o</sup>C for 30 minutes so as to homogenize the microstructure of the material. The specimens were prepared from these composites for Equal channel angular pressing (ECAP) operation. The effect of ECAP on the microstructure and mechanical properties of Al-5Mg Red mud composite were evaluated for various weight fractions of red mud. The distribution of reinforcement particles, porosity and grain growth was observed from the optical microscope. The mechanical properties of Al-5Mg base material such as hardness and density were compared with the as-cast Al-5Mg Red mud and ECAPed composites.

**Keywords:** Al-5Mg metal matrix composite, Red mud, ECAP

## 1. INTRODUCTION

Metal matrix composites (MMCs) offer considerable promise to help engineers in meeting the challenges of current and future demands. MMCs consist mainly of a metallic matrix reinforced by ceramics. MMCs exhibit excellent mechanical properties while reinforcing with ceramic particles to impart high strength and load-bearing capacity. These materials that meet definite requirements, such as low density, improved hardness, ultimate tensile strength, and can deliver overall improved mechanical properties. Depending on the product requirements, a wide range of composite materials with different combinations of matrix materials and reinforcements can be prepared. Preliminary investigations were carried out with the process design using various types of reinforcement materials. Metal matrix composites reinforced with ceramics are widely used due to their high specific modulus, strength and wear resistance. Bauxite residues, also known as red clay or red mud, are a very alkaline waste product consisting mainly of iron oxide created in the industrial production of alumina is used for manufacturing metallic aluminium, as well as widely used in the manufacture of ceramics materials. Red mud can be used to produce ceramics, acting as a raw material for bricks and tiles due to its high iron oxide, alumina, and silica content. In terms of metal production, the ratio of aluminium to red mud is 1:2. This waste material has been accumulating at an increasing rate throughout the world. Research and development work on red mud utilization in India is of much interest for engineering applications. In this current investigation, the stir casting technique was employed to fabricate the Al-5Mg and Red mud reinforced composite material

Several investigations are carried out on Aluminum alloy metal matrix composite material processed by commercial pure stir casting technology. The cast Al-SiCp composite shows a uniform distribution of particles, Particle distribution after ECAP was found that, ECAP improves the particle size of the matrix material. In Al-5 vol.% SiCp composite, particle size decreased from 45  $\mu$ m to 8  $\mu$ m after 2 ECAP passes. The compression test was performed at room temperature to evaluate the mechanical properties Composite. Both composites show improved mechanical properties after ECAP (Ramu@2009).

In another study, aluminium metal matrix composite with Al6061 matrix and graphite particles (5-20 $\mu$ m), a composition varying between (2-8wt.%) of graphite particles was prepared by a stir casting technique. Significantly improved tensile strength and ductility have been observed. The results are compared with Al6061 base materials and as Al6061-Gr castings. There is a significant improvement in the stiffness and ultimate tensile strength of the processed ECAP compounds (Lokesh T, U S Mallikb@2016)

In the research work carried out by M.S. Arab(2014) on Aluminum-silicon carbide (Al-SiCp), improved mechanical properties and corrosion resistance were observed by addition of SiCp particles to aluminium matrix. Equal channel angular pressing (ECAP) was applied to the casting compound at room temperature to investigate the effect of the ECAP pathway on SiCp size and distribution. A maximum of 12 passes were performed on Al-5% (10%) samples of SiC. After the application of ECAP, the distribution of SiC-reinforced particles was also improved. Compressive strength and rigidity are more than 3 times higher than that of Al-5% SiC. In addition, composite ductility remains same after the ECAP process.

## 2. EXPERIMENTAL STUDIESEXPERIMENTAL STUDIES

### 2.1 Stir casting for the preparation of MMCs:

Stir-casting equipment shown in Figure 1 is currently the simplest and most commercially viable method for production of MMCs. This technique involves the mechanical mixing of the preheated micro sized red mud reinforcement particulates into a molten metal bath of 95wt%Aluminum and 5wt%Magnesium alloy material and further transferred the mixture directly to a shaped mould prior for complete solidification. In this process, the crucial thing is to create good wetting between the particulate reinforcement and the molten metal.



**Figure 1:** Stir casting equipment

Microstructural inhomogeneity can cause notable particle agglomeration and sedimentation in the melt subsequently during solidification. Inhomogeneity in reinforcement distribution in these cast composites could also be a problem as a result of interaction between suspended ceramic particles and moving solid-liquid interface during solidification has a major advantage of reduced inhomogeneity.

The term stirring is the process of mixing molten metal to uniformly mix alloying element magnesium and red mud reinforcement particles by continuous stirring the molten metal in the stir casting furnace. In the case of stirring, particles often tend to form clumps. Here the stir casting method has been adopted to prepare the metal matrix composites with vortex technology which can provide a high strength homogeneous Aluminum alloy composite material. Pure aluminium along with 5 wt% Magnesium were taken into a graphite crucible and charged into electric resistance furnace and the temperature was raised up to 750 °C. To remove the moisture content from Red mud particles of the three proportions, they were kept at 400°C for 30 minutes. Preheated Redmud micro particles are uniformly added to Al-5Mg molten metal at 750°C and stirring operation has been carried out at 200rpm for 5 minutes. At last the crucible was taken carefully out of the furnace and liquid state metal was poured into a mold (figure 2) having dimensions of 20mm diameter 150mm length and was left cool at room temperature (RM) for 2 hours. These casted sample billets (figure 3) are further considered for ECAP operation and material characterization.



Figure 2: Casting mould    Figure 3: Casted billets

## 2.2 Sample Preparation:

After the casting process, finishing operations were carried out to remove the excess material on the casted billets as shown in the figure 3. Due to the geometry of round billets that are obtained from casting moulds, they are machined to the dimensions of 16\*16\*150 mm by using CNC milling machine as the ECAP die is having the square cross sectional mould shape.

Before doing the ECAP process the samples should undergo the heat treatment process to homogenize the microstructure of samples. The temperature of annealing of the samples depends on the materials that are undergoing the ECAP process and generally for aluminium alloy the annealing temperature is performed at 350 to 400°C. For aluminium composites it is lower than the aluminium alloy i.e., 200 to 300°C. In this present study, before doing ECAP the samples were annealed at a temperature of 230°C for 30 minutes to homogenize the microstructure of the samples.

## 2.3 Equal Channel Angular Pressing

Severe plastic deformation (SPD) characteristics are seen to be beneficial as the strengthening pure metals and alloys and refining of grains by introducing a larger deformation of plastic as the true strain value is greater than 1. SPD is performed under high pressures and at relatively low temperatures; it is often less than ideal  $0.4T_m$ , where  $T_m$  is the highest temperature in Kelvin. Among the different SPD techniques, equal -channel angular extrusion/pressing (ECAE/P) process is considered because the cross-section of the sample remains consistent throughout the process, the industrial coatings on the materials does not undergo the dimensional changes, damage, or removal often associated with typical severe plastic deformation (SPD) methods.

The angle of the channel is the most important experimental factor that affects the refinement of the grain because it forces the total tension imposed on each pass. Most experimental works reported to date used channel angle values of 90° to 120°, and there was little or no attempt to compare the results obtained when using die with different channel angles. Despite the efficiency of the ECAP process, it is empirically easier to press billets when using dies with angles that are larger than 90° for very hard materials or for materials with low ductility. It is claimed that it is difficult to compress commercially pure tungsten. However, excellent results were achieved at the same pressing temperature when the angle of the channel was increased to 110° to 120°.

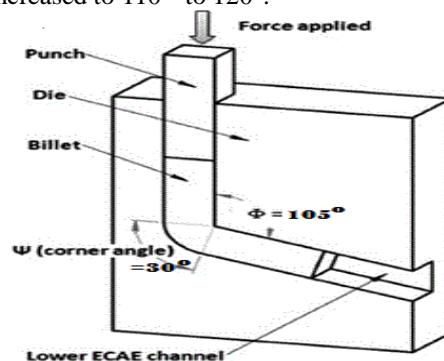


Figure 4: ECAP Die with channel angle of 105° and outer channel angle 30°,

## 2.4 Extrusion process:

In this present investigation, the extrusion process of ECAP has been carried out by Universal testing machine (UTM) with required loads for all the combinations of composite material that is 5, 10 and 15wt%. High carbon and high chromium punch is used. Lubricant (Molybdenum disulphide (MoS<sub>2</sub>)) is applied to the die channels and cross-sections of the samples in order to reduce the friction between the samples and walls of the die.

## 3 Mechanical Characterization Of Composite Specimens

### 3.1 Vickers hardness test:

This Vickers hardness test is used on the feature of miniatures which cannot be tested in other ways. While using a test load of 1 kg or less, similar to Brinell hardness test, Vickers hardness test is performed by applying force to the indenter in a designated format over a period of time.

The accurate impression measurement is performed and is used in conjunction with the load test to calculate the value on the scale. A microhardness test is a method for determining the hardness or resistance to penetration of a material when the test samples are too small or thin, or when measuring small areas in the composite sample or coating. It can provide accurate and detailed information about the surface features of materials with fine, multi-stage structure, heterogeneous or prone to cracking.

### 3.2 Optical microscopy:

The function of creating a magnified image of a sample consists of three basic functions: "get a clear and sharp image", "change the magnification", and "focus in focus." The optical system to carry out these functions is referred to as an optical control system.

At the same time, the sample illumination function consists of three basic functions: "light supply", "light aggregation" and "light intensity change". The optical system to perform these functions is referred to as the optical lighting system. In other words, the optical monitoring system displays a sample through an optical system, moreover, driving a projection image to the eyes or a capture device such as a CCD.

### 3.3 Density Test Based on Sample Mass and Volume:

Density is a measure of the "compactness" of matter within a substance and is defined by the equation:

$$\text{Density} = \frac{\text{Mass } kg}{\text{Volume } m^3}$$

The standard metric units in use for mass and volume respectively are grams and milliliters or cubic centimeters. Thus, density has the unit grams/milliliter (g/ml) or grams/cubic centimeters (g/cc). Density may be calculated from a separate mass and volume measurement, or, in the case of liquids, may be determined directly by the use of an instrument called hydrometer. The volume of any solid object, irregular or regularly shaped, can be measured by displacement

For less defined shapes, volume can be determined by water displacement. Volumes of liquids such as water can be readily measured in a graduated cylinder. To use the water displacement method, an object (in this case, a small metal cylinder) is inserted into a graduated cylinder partially filled with water. The object's volume occupies space, displacing liquid and raising the water level. The difference between the two volumes, before and after the object was inserted, is the object's volume.

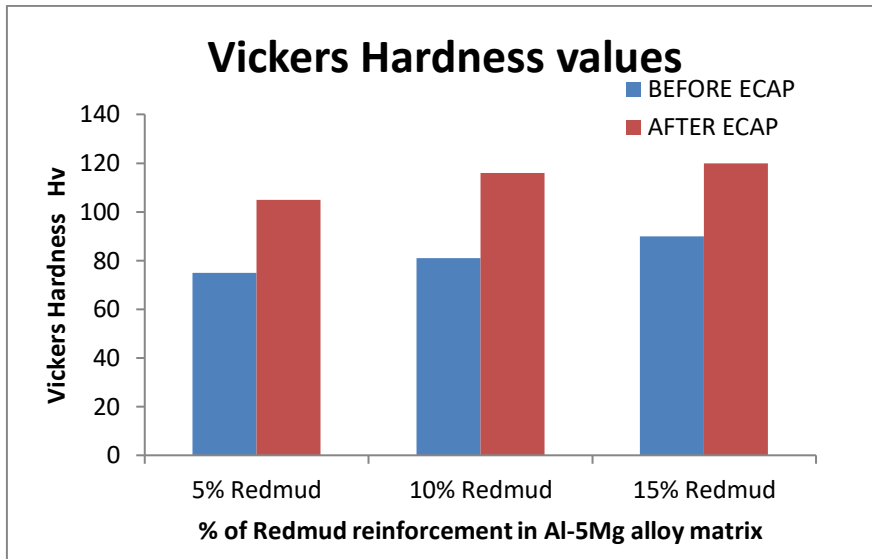
$$\text{Change in Volume} = V_{\text{final}} - V_{\text{initial}}$$

$$\text{Density} = \text{Mass (grams)} / \text{Volume (ml)} * 1000 \text{ Kg/m}^3$$

## 4. Results and Discussion

### 4.1 Hardness Tests:

The Vickers hardness tests are evaluated before and after ECAP for the six samples of Al-5Mg Red mud composite is shown in graph 1. The values of the composite before ECAP are observed that the incremental order as 74, 77, and 85 H.V for 5%, 10% and 15wt% of Red mud.



Graph 1: Hardness of the samples before and after ECAP by increasing Red mud percentage

The hardness values of the composite specimens are higher than that of Al-5Mg alloy in the as-cast condition of Red mud particles reinforcement in three percentages into Al-5Mg alloy. After ECAP process, the hardness of the composite samples is observed to be increased with values 105, 115, and 118 H.V for 5%, 10% and 15wt% of Red mud respectively. The hardness is increased after ECAP by 28% for 5wt% red mud, 33% for 10wt% and 27% for 15wt% as compared to the specimens before ECAP. By observing the hardness of the composite before and after ECAP, it is concluded that the hardness of the ECAPed samples is highly increased. This is due to the fine grains of the metal matrix composite in ECAP process and also material become strain hardened due to ECAP.

**4.2 Density Tests:**

The density values of the Al-5Mg and Red mud composite material is shown in Table 1. The density and porosity of as casted (before ECAP) is observed that the addition of red mud particles into Al-5Mg alloy leads to a decrease in density and increase in porosity. After one pass of Equal channel angular pressing (ECAP), it is observed as increment in density compare to as casted composite and porosity is decreased. By observing the results, it is concluded that the addition of red mud particles caused a decrease in density due to more porosity and after ECAP process the material under severe plastic deformation, led to a decrease in the porosity and a gradual increment in density of composite material is observed. Density values of before and after ECAP samples are furnished in the below table 1

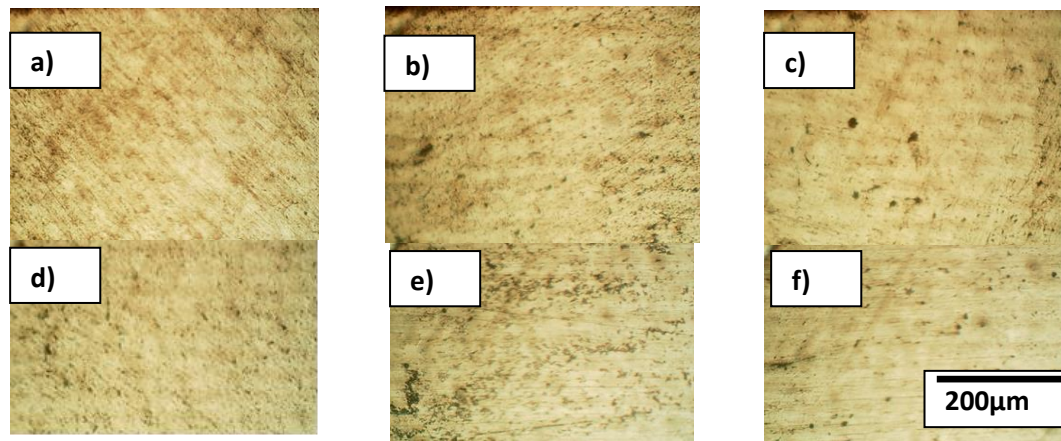
Al-5Mg - Redmud composite			
% of Red mud	5%	10%	15%
Density (Kg/m <sup>3</sup> ) Before ECAP	2525	2495	2310
Density (Kg/m <sup>3</sup> ) After ECAP	2620	2555	2358

It is also concluded that the density of composite before ECAP was decreased by 4.71%, 5.84% and 12.83% compare to Al-5Mg alloy and also, after the ECAP process 1.13%, 3.58%, and 11.02% of decrease is observed. There is an increased density observed after subjecting to the ECAP deformation than the as-casted composite specimens of three incremental proportions by 3.62%, 2.34%, and 2.03%. From all the results it is concluded that due to the porosity affect during the casting process of composite, density is decreased and after the ECAP process, the density is increased due to porosity decrement in the ECAP process.

**4.3 Microstructural studies of composite before and after ECAP process:**

Every composite material property is depending on its microstructural characteristics and interface characteristics between reinforcement and matrix. The optical microstructures of Al-5Mg and Red mud composite of three weight percentages are shown in figure 5. The microstructures are shown in figures 6 a, b, and c is captured before the ECAP process and figures d, e, and f are captured after the ECAP process. These microstructures are

interpreted over a fine polished surface of the specimens and found the Red mud deposition. It is concluded that the distribution of red mud for 5wt% shows not much difference due to low content compared to 10 and 15wt%. Also after the ECAP process, the distribution is closer compare to as casted composite because of the severe plastic deformation of samples with increased density.



**Figure 5:** Optical microscope of (a) 5% red mud, (b) 10% red mud, (c) 15% red mud before ECAP. (d) 5% red mud, (e) 10% red mud, (f) 15% red mud after ECAP.

## 5. CONCLUSION

The conclusions drawn from the present investigation are as follows:

1. The stir casting technique was successfully employed to prepare Al-5Mg matrix composite material reinforced with red mud particle reinforced composites and the microstructures reveals that the distribution of red mud particle in the matrix are uniform.
2. The effect of red mud reinforcement (5, 10, and 15wt %) on Al-5Mg matrix led to an increase in hardness, and after ECAP on the casted billets the hardness further increase with peak hardness at 15% red mud sample.
3. After equal channel angular pressing (ECAP) there is no effect of distribution of reinforcement particles. But it is found that there a considerable reduction in grain size after the ECAP process with the 5wt % of red mud.
4. The porosity of the Al-5Mg alloy matrix reinforced with red mud particle composite specimens is reduced after ECAP and as a result the density of the composite was increased after performing the ECAP operation.

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