# Analysis of Al6061-Fe2O3 Metal Matrix Composites via Multiple Passes of Equal Channel Angle Pressing Subjected to Severe Plastic Deformation

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ABSTRACT: Aluminum-metal matrix composites have been widely used in engineering and non-engineering applications for 30 years due to their versatile properties. The properties of composite materials can be improved by subjecting the composite to severe plastic deformation (SPD). ECAP (Equal Channel Angular Pressing) is one of the most commonly used SPD methods to create ultrafine particles within structures. In this study, AMC was fabricated using HeAl6061 alloy as the matrix material and hematite (Fe2O3) as the reinforcement material. Stir casting technology was used to fabricate composites with compositions varying from 0% to 4% in 1% increments. The sample passed through his ECAP twice. The strain on the sample deformation increased with increasing reinforcement rate and from the first pass to his second pass. The performance of composite materials before and after SPD was studied by evaluating various properties, and an improvement in properties was observed.

Keywords: Metal Matrix Composites, Hematite, Severe Plastic Deformation, Equal Channel Angular Pressing, Ultra-fine grains, Scanning Electron Microscope.

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## INTRODUCTION

Composite materials are created by combining a matrix and a reinforcing material (1). In MMC, the matrix material is a metal of iron, copper, aluminum, or magnesium, and the reinforcement can be ceramic or metal added in the form of particles, whiskers, or fibers (2-3). Composite materials have superior mechanical properties compared to monolithic materials, including high strength-to-weight ratios, high stiffness and wear resistance, and increased resistance to thermal expansion and corrosion (4-5). Adding reinforcement to a matrix material improves one property at the expense of the other. For example, harder materials decrease ductility and increase hardness (4-7).

## SEVEREPLASTICDEFORMATION

The properties of MMC can be improved by performing secondary processing such as extrusion, drawing, forging, rolling, and heat treatment. The ductility and yield strength of a material are affected by grain size. Ultrafine grain sizes are obtained by applying large plastic deformations through severe plastic deformation (SPD) techniques (8-9). Super particle structures on the order of 100 nm can be created by SPD technology (10). Structural parameters such as grain size and shape, grain and grain boundary dislocation density, microstructural homogeneity, and phase composition changes can be refined by SPD. The yield strength is affected by the grain size and is calculated using the Hall-Petch equation (8-10).

$$\sigma f=\sigma o+\lambda d^{-1/2}$$

Where, $\sigma_f$= flow stress of material, d=average grain size and $\sigma_o$ &$\lambda$ are material parameters which are strain& temperature dependent.

### Grain Refinement Mechanism

In SPD technology, grain refinement is performed in a multistep process. First, dislocations within the grain rearrange to form dislocation cells. As deformation progresses, the dislocation cells form partial grains, which are further reduced in size by grain size (11).

### Equal Channel Angular Processing

Particulate composite materials can have increased strength and hardness and improved ductility under severe plastic deformation. Various SPD techniques include equal channel angular pressing (ECAP), high pressure torsion (HPT), twisted extrusion (TE), simple shear extrusion (SSE), and repetitive corrugation straightening (RCS) (8-12). The ECAP technique (conformal channel machining) is the most commonly used technique and is achieved by cold working without reducing the cross-sectional area of the deformed sample. The ECAP matrix is shown in Figure 1. and the angle "Φ" between the intersecting channels typically varies between 90° and 135° (13-14). Friction has a significant effect on deformation behavior. As the corner angle approaches zero, the friction within the die increases during the deformation process and the tensioned material remains attached to the outer surface of the channel. This creates dead metal zones and uneven stress distribution. By increasing the corner angle, the effects of friction can be minimized, which results in a more uniform stress distribution. The flow of material can be increased by providing grooves in the internal channel surface connections (10)

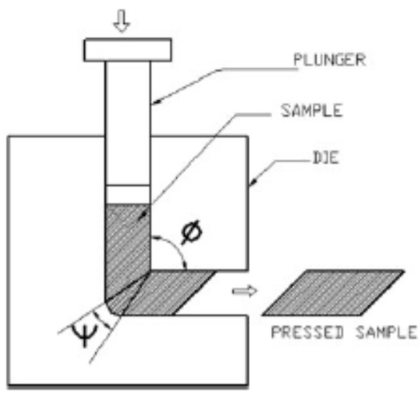


**Figure1** Equal Channel Angular Pressing Die

**Strain Path for different Routes**

At the intersection of these channels, the sample undergoes deformation by simple shear [11]. (Φ/2). For Φ=90°[15], a maximum strain rate of 1.15 per pass can be achieved. $\varepsilon$ eq=1/√3[2cot(ψ/2+φ/2)+ψ cosec(ψ/2+φ/2)]. Ψ = corner radius angle, $\varepsilon$ eq = equivalent elongation, Φ = intersection angle of two channels. Higher strains can be achieved by subjecting the sample to multiple passes by changing the strain path between successive passes. The path is modified by rotating the sample around its longitudinal axis through an angle of 0° for route A, 90° for root band, and 180° for route C. The approximate shear stress experienced by the material is given by the equation ε=2/√3cot

## FABRICATION OF ALUMINUM-HEMATITE METAL MATRIX COMPOSITE MATERIAL

In experimental studies, hematite is used as reinforcement with Al6061 matrix materials, as it is the most widely used commercial form of aluminum (12, 14-15, 16-19). The chemical composition of Al6061 is shown in Table 1. The mechanical properties are shown in Table 2. Magnesium and silicon added as ingredients to the Al6061 series enhance the fluidity and fluidity of the metal during the casting process (17). Hematite (iron oxide) occurs naturally in powder form and is harder and more brittle in nature (20). The properties of hematite are shown in Table 3. In this study, LR grade 40-45 micron thick hematite ($Fe_2O_3$) was reinforced with various weight percentages of aluminum 6061 to produce superior wear-resistant composites.

**Table 1** Chemical composition of Al6061

| Constituent | Si | Fe | Cu | Mn | Mg | Ni | Ti | Zn | Sn | Cr | Pb | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| %by weight | 0.43 | 0.43 | 0.24 | 0.139 | 0.802 | 0.05 | 0.022 | 0.006 | 0.001 | 0.184 | 0.204 | Bal |

**Table 2** Properties of Al & Al 6061

| Material | Ultimate Tensile Strength (MPa) | Yield Strength (MPa) | Hardness (BHN) | Density (gm/cc) |
|---|---|---|---|---|
| Aluminum | 40–50 | 15–20 | 15 | 2.6 |
| Al 6061 | 110-115 | 45-55 | 30 | 2.7 |

**Table 3** Properties of Hematite

| Tensile Strength (MPa) | Elastic Modulus (GPa) | Poisson's ratio | Melting point | Density (gm/cc) |
|---|---|---|---|---|
| 350 | 211 | 0.35 | 1595 $^{o}$C | 5.26 |

Aluminum–hematite composites are fabricated using standard stir-casting techniques to ensure uniform mixing of reinforcement and matrix materials (21, 22). The various proportions of Al6061 and hematite composites are shown in Table 4. The samples were successfully prepared and various mechanical characterizations were performed.

**Table 4** Compositions of Al6061 and Hematite for different specimens

| | Sample1 | Sample2 | Sample3 | Sample4 | Sample5 |
|---|---|---|---|---|---|
| Weight of Al6061 Added | 2000grams | 1980grams | 1960grams | 1940grams | 1820grams |
| % of Hematite | 0% | 1% | 2% | 3% | 4% |
| Weight of Hematite added | 0.0grams | 20grams | 40grams | 60grams | 80grams |

**ECAP Process**

The ECAP die and punch are shown in the figure. Two are made of EN-31 material and hardened. EN-31 is a high carbon alloy steel with high compressive strength and wear resistance. The loads required for the deformation process were applied using a universal testing machine TUE-CN-400 and are shown in Figure 3. The samples obtained through the ECAP process are shown in Figure 4**.**

**Figure 2** ECAPDie

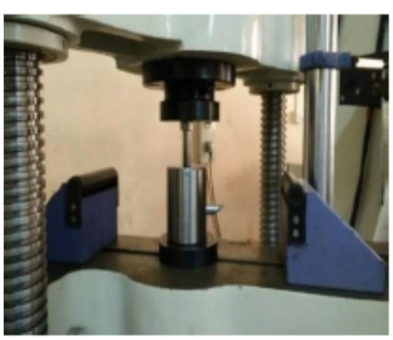

**Figure 3**ECAPProcess

**Figure 4** Specimen after ECAP process

## EXPERIMENTATION, RESULTS & DISCUSSION

**Density Test**

The theoretical density of the sample was determined by the mixing law, and the density was also measured experimentally using the direct method. The densities of the various samples are shown in Table 5 and graphically shown in Figure 5. From the results, the density of the composite increases as the reinforcement rate increases. Due to the small proportion of added reinforcement, no significant variation in the measured density was observed, even though the density of the reinforcement was higher than that of the matrix material. There is some variation in the theoretical and experimentally measured composite densities, probably due to casting defects.

**Table 5** Densityv/s% Reinforcement

| Weight% of Reinforcement | | 0% | 1% | 2% | 3% | 4% |
|---|---|---|---|---|---|---|
| Theoretical Density in gm/cc | | 2.70 | 2.71 | 2.72 | 2.73 | 2.75 |
| Experimental Density in gm/cc | Before ECAP | 2.69 | 2.71 | 2.69 | 2.72 | 2.73 |
| | After ECAP (2 Passes) | 2.70 | 2.73 | 2.75 | 2.78 | 2.81 |

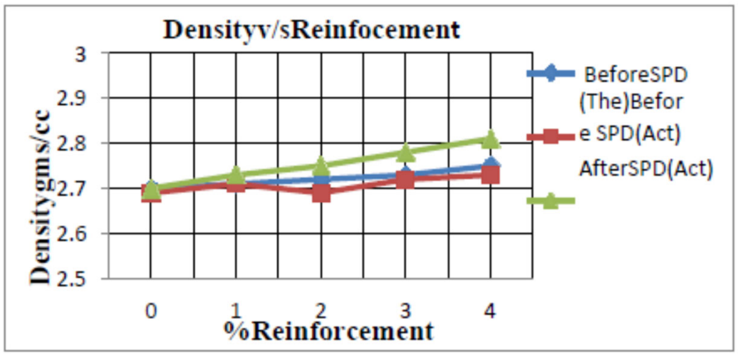


**Figure5** Densityv/s% Reinforcement

The deformation loads for the ECAP process were applied using a 40-ton capacity universal testing machine. The "Route B" method was used to deform the samples. The sample was passed twice. The maximum loads applied to the deformation process for each pass for different compositions are listed in Table 6 and graphically shown in Figure 6. From the above results, it can be seen that the stress increases as the reinforcement ratio increases from 0% to 4%. This is because the hardness increases with increasing reinforcement percentage. Additionally, the deformation load increases by 2.5 times from the first pass to the second pass. This is due to work hardening of the sample. When the sample was subjected to compressive loading, the voids in the structure were minimized and super particles were formed due to the 90° angle between the channels of the die.

**Table 6** Deformation Loadv/s %Reinforcement &Number of passes

| % of Reinforcement | 0% | 1% | 2% | 3% | 4% |
|---|---|---|---|---|---|
| First Pass (Load in kN) | 40 | 55 | 63 | 72 | 80 |
| Second Pass (Load in kN) | 110 | 140 | 162 | 170 | 198 |

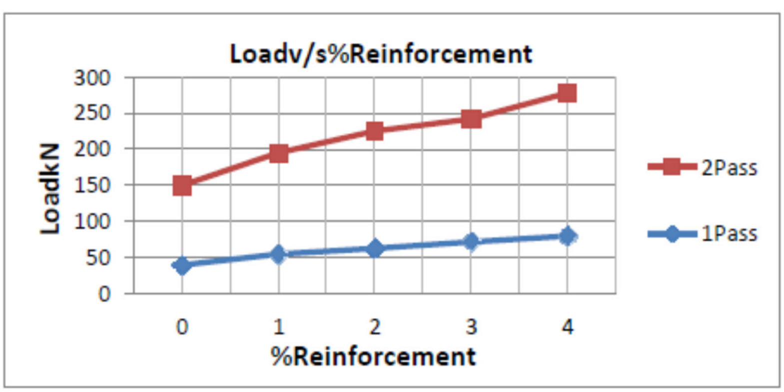


**Figure 6** Deformation Load v/s %Reinforcement & Number of passes

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**Hardness Test**

The particle size of the sample affects its hardness. A Brinell hardness tester TKB 3000 was used to measure the hardness. Tests were performed using a 5 mm diameter hardened steel indenter with a load of 250 kg. The hardness was calculated using the formula BHN =$2F/ [\pi D*(D-\sqrt{(D2-d2)})]$. where F = applied load (kgf), D = indenter diameter (mm), d = indenter diameter (mm). The hardness of samples with different compositions before and after the ECAP process is shown in Table 7 and graphically shown in Figure 8. The results show that the hardness increases as the reinforcement rate increases, and it is clear that the reinforcement of hematite particles is inherently harder. As observed, as the number of passes increased, the hardness also increased. This may be due to the higher work hardening during the deformation process, which minimizes voids and cracks. It is clear that the super grain structure minimizes voids and increases hardness.

**Table7** Hardnessv/s% Reinforcement &Number of passes

| % of Reinforcement | 0% | 1% | 2% | 3% | 4% |
|---|---|---|---|---|---|
| 0 Pass (Hardness) | 35 | 39 | 42 | 40 | 44 |
| 1 Pass (Hardness) | 44 | 49 | 52 | 59 | 61 |
| 2 Pass (Hardness) | 68 | 70 | 67 | 72 | 76 |

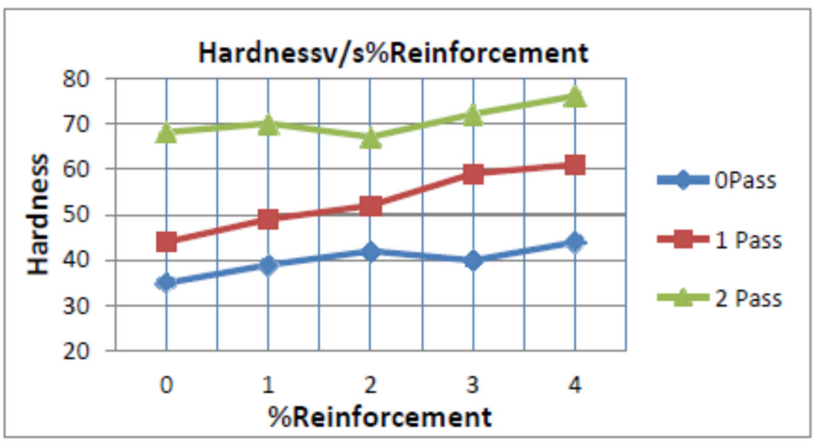


**Figure 8** Hardnessv/s% Reinforcement & Number of passes

## CONCLUSIONS

The following conclusions are drawn from the study of highly plastically deformed Al6061-Fe2O3 composites of different compositions.

• The density of Al6061-Fe2O3 composite increased slightly with increasing reinforcement. For the actual density of the composite, a maximum deviation of only 4% was observed.

• During manufacturing, uniform distribution of reinforcing particles is achieved using stir casting technology.

•The results clearly show that the deformation strain increased significantly from his 0% reinforcement to 4% reinforcement of hematite.

• This result also shows that the deformation load in the second pass almost increases. 2.5 times the load consumed in the first pass. This is because the ECAP method results in larger plastic deformation and higher work hardening.

• It is clear that the deformation load increases with hyper grain refinement of the composite due to the larger plastic deformation, indicating an increase in the strength of the composite.

• Hardness values increased when the reinforcement rate increased from 20 to 30%. The results also show that as the number of passes increases (60–70%), the hardness increases significantly.

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