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Improvement of mechanical properties of FCC & HCP structured materials processed by Equal Channel Angular Pressing

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Abstract-- Equal channel angular pressing (ECAP) is a simple technique used to refine the grain size to nanometer size of materials. In the current work is to study the evaluation of microstructure in order to improve mechanical properties of pure aluminum (Al) and AZ31 alloy through ECAP up to two passes. The average grain diameter was significantly reduced to 5µm for aluminum at room temperature and for AZ31 alloy is reduced to 2.8µm at 360^{0}C. The mechanical properties of these materials were significantly improved with decreasing the grain size diameter as increasing the number of passes. In addition, percentage elongation of aluminum was decreased but in AZ31 alloy it was increased around 7.3% after two passes. The hardness of Al and AZ31 alloy has been found to be increased as 10.6% and 41.2% respectively by increasing number of passes.

Keyword: ECAP, AZ31 alloy, pure aluminum, Grain refinement, and properties.

1 INTRODUCTION

AMONG all severe plastic deformation (SPD) [1] techniques, equal channel angular pressing (ECAP) [2] is an extensively used to impose the large plastic strain in metals and their alloys. It has been used to refine the grains into nanometer size from coarse grains, in order to enhance properties of the materials. Since few decades, the major research work has been done in ECAP with aluminum (Al) [3], magnesium (Mg) and its alloys [4] than other materials [5], [6], [7] due to its advantages. They are strength to weight ratio, ductility and light weight though they have different crystal structures [2], [3]. In such a way, that these materials have been used in many of the following structural applications as automotive, aerospace, electronic devices and nuclear industries [3], [8]. In addition to many advantages, some of the limitations have been involved to condense the importance of these materials [2], [3]. Further, many papers have been published to the evidence of improvement in all fields by minimizing the limitations as a result of the process [3], [9].

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Nevertheless, as reported in [10], there was a little data on comparison of various materials other than aluminum with different die angles using ECAP process for the grain refinement. Literally, it gave the possibility to compare the mechanical properties of Al and Mg alloy (AZ31 alloy) through ECAP. The main aim of this study is to compare the superior mechanical properties of Al and AZ31 alloy by refine the grains during ECAP process. Optical microscope was used to capture the microstructures of the specimens to evaluate the grain diameter.

1.1 Ecap Layout

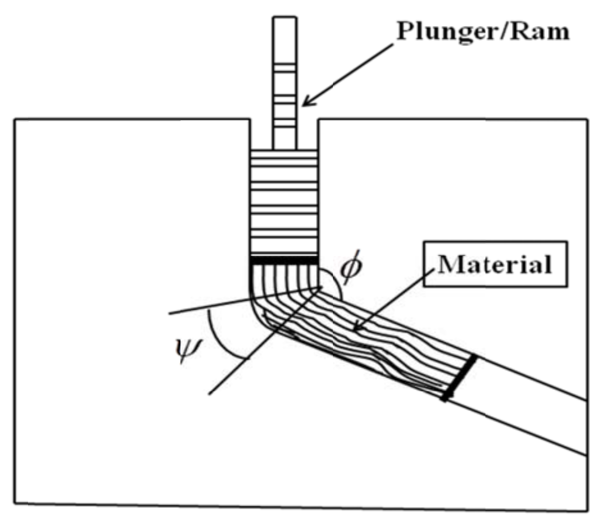

Fig.1 ECAP set up

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The principle of ECAP technique is illustrated in Fig.1. It consists of two equal channels intersect a particular angle called die angle (ϕ) and the arc of curvature (ψ) subtended at the point of channel intersection. Sample was pressed through die channel using plunger or ram to impose large plastic strain with the same cross-sectional area by neglecting the end effects into the sample [11]. The total strain of the material has been calculated by using the equation (1). After 'n' number of passes the accumulated strain becomes n×ε [10].

$$\varepsilon = \frac{1}{\sqrt{3}}\left\{2\cot\left(\frac{\phi}{2}+\frac{\psi}{2}\right)+\psi\ \mathrm{cosec}\left(\frac{\phi}{2}+\frac{\psi}{2}\right)\right\} \quad \ldots\ldots\ldots.. (1)$$

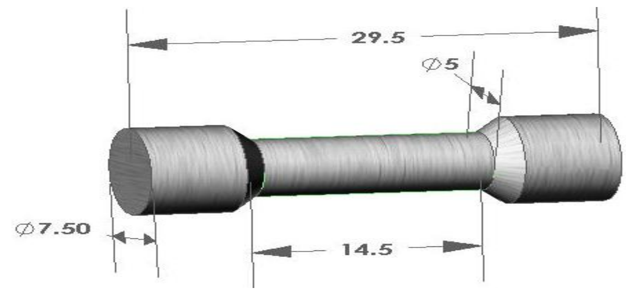
Where ε is total strain, ϕ is die angle, ψ is outer arc curvature.

On other hand, four basic fundamental routes involved while processing the ECAP. They are route A, route Ba, route Bc, and route C [1]. There is no specimen rotation in route A, the specimen is rotated 90^0 between consecutive passes in route Ba, the specimen is rotated 90^0 counterclockwise direction in consecutive passes in route Bc, and the specimen is rotated 180^0 between each pass in route C.

2 Experimental Procedure

ECAP experiment was performed using die angle of 120^0 and the arc of curvature of 30^0 to reduce the dead zone of the materials. The present configuration of die was designed to give an approximate strain of 0.7 on each pressing. Specimens were prepared from as-received materials into required circular shape with a diameter of 16mm and a length of 80mm. Then these specimens were pressed through the channel at different working conditions as at room temperature and 360^0C for Al and AZ31 alloy respectively. Graphite has been used as a lubricant in order to prevent the friction between the specimens and die channel using procedure route Bc in between consecutive passes. The preparation of sample for testing involved mechanical polishing using different SiC papers in addition, the colloidal Al_2O_3 and diamond past have been used to get mirror finish samples. Polished samples were subsequently etched by using Keller's [12] for Al and Picral [12] for AZ31 alloy. The tensile test and hardness test were carried out to evaluate the mechanical properties of Al and AZ31 alloy.

Fig.2 shows the tensile test specimen with a gauge length and a diameter of 14.5mm and 5mm prepared as per ASTM E-8 standards and tested using Hounsfield Tensometer test rig. Hardness test was carried out using Vickers microhardness test rig by applying a load of 100g with dwell time of 13s for AZ31 alloy and for Al the dwell time is 5s with the same load.



All dimensions are in mm

Fig.2 Dimensions of tensile test specimen

3 Results & Discussion

3.1 Tensile Properties

Engineering stress verses engineering strain curves of Al and AZ31 alloy have been measured and drawn from force vs. distance graph for two passes as illustrated in Fig.3 and Fig.4. The measured values of ultimate tensile strength (UTS), Yield strength (YS) and the percentage elongation of these materials have been tabulated for better understand of variations among them in Table 1.

TABLE 1
Mechanical Properties of Pure Al and AZ31 Mg alloy Before and After ECAP Process.

	UTS (MPa)	YS (0.2%) (MPa)	Elonga-tion (%)	Hard-ness (HV)
unECAPed Al	237	194	35.4	75
First passed Al	282	237	21.9	80
Two passed Al	285	243	27.9	83
unECAPed AZ31	232	105	20.4	51
First passed AZ31	242	165	13.6	69
Two passed AZ31	227	122	21.9	72

The UTS and YS of Al have been increased greatly as 20% and 25% respectively and the elongation was decreased to around 26.9% with decreasing in grain diameter after second pass (Fig.3). In AZ31 alloy, YS and percentage elongation of AZ31 alloy have been found to be increased to 16% and 7.3% respectively with decreasing in grain diameter (Fig.4). The variations among curves in Al have found to be large, where as in AZ31 alloy, it was observed to be small because of plastic anisotropy. In both the materials, YS had a good relationship with hardness by increasing the number of passes. The elongation of the Al material has been decreased, while AZ31 alloy it was increased with increasing number of passes because of processing temperature.

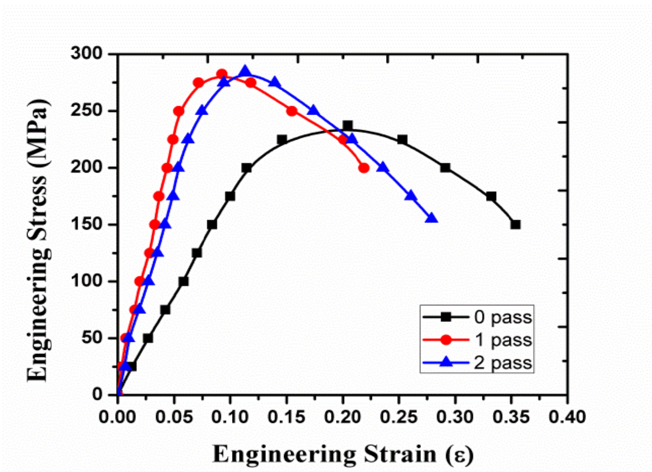


Fig.3 Engineering stress – Engineering strain curve for pure Al processed by ECAP up to two passes at room temperature.

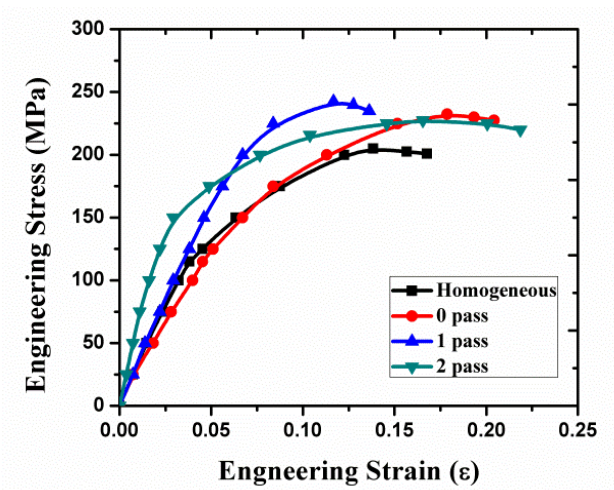


Fig.4 Engineering stress – Engineering strain curve for AZ31 alloy processed by ECAP up to two passes at 360^{0}C temperature

3.2 Microstructure Characterizations

Fig.5 and Fig.6 show the microstructures, observed from image analyzer of as-received and second pass of Al and AZ31 alloy individually. The average grain size of Al has been found to be reduced to 5µm from 125µm processed at room temperature. For AZ31 alloy it was reduced to 2.8µm from 22.5µm processed at 360^{0}C. Earlier, the grain were distributed large in size with inhomogeneous structure of as-received Al, whereas after second pass, the grains were deformed significantly smaller in size at room temperature for route Bc. It would be because of number of ECAPed passes and slip planes posses more than five in the Fcc structure.

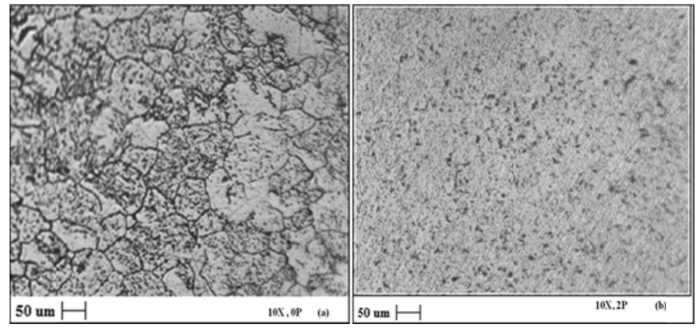


Fig.5 Optical microscope micrographs of pure Al for (a) as-received (b) two passed ECAP specimen

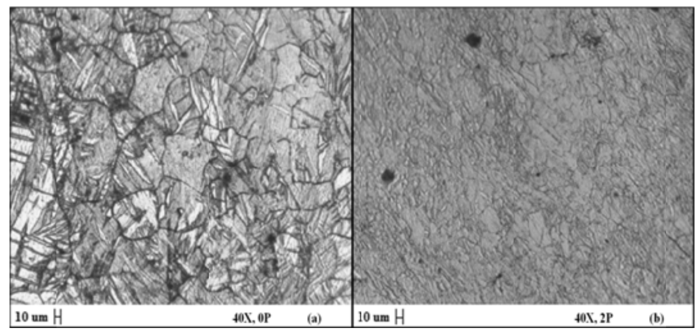


Fig.6 Optical microscope micrographs of AZ31 Mg alloy for (a) as-received (b) two passed ECAP specimen

The distribution of grains in as-received AZ31 alloy was similar to FCC structured material, but in addition, twins occur on grains because of rolled sheet in the presence of yield asymmetry. Hence, the shear deformation occur in only one direction [13], because of Hcp structured material has less than five slip system planes and it was difficult to deform at room temperature [12] as compared to Fcc structured material. The grains have been significantly refined from coarse to fine after shear deformation for second pass at 360^{0}C as shown (Fig.6 (b)). It was found to be the fine grains were bounded with large coarse grains indicating the heterogeneous distribution of grains as explained by Feng Kang et al. [14]. It representing the beginning of dynamic recrystallization [15] of material from second pass and it may further increase with increase number of passes.

3.3 Hardness

The Vickers micro-hardness verses number of passes of Al and AZ31 alloy was drawn in Fig.7. The average hardnesses of as-received and after processed specimens of Al and AZ31 alloy have been measured and tabulated in (table 1).

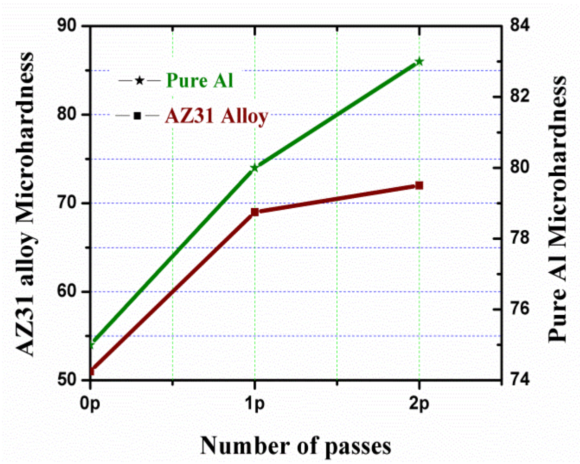


Fig.7 Variations of micro hardness with ECAP passes

The percentage increase in hardness of Al and AZ31 alloy have been found to be 10.7% and 41.1% respectively. In here, the Hcp structured material was increased greatly at elevated temperature of 360^{0}C as compared to Fcc structured material processed at room temperature, because of reduction in grain diameter. Hence, the temperature and variation in grain diameter have been observed the factors influenced to improve the hardness of the material.

4 CONCLUSIONS

Fcc and Hcp structured material mechanical properties have been calculated and discussed by evaluating microstructures observed from image analyzer at different working conditions. In the current work, following determinations can be drawn from experimental observations:

- The average grain size of Al and AZ31 alloy was found to be reduced to 5µm and 2.8µm respectively, though they have done at different working conditions with large die angle.
- Yield strength for both materials has been improved by refining grain diameter with increasing number of passes.
- Even though materials have different structures, the processing temperature was influenced to varying percentage of elongation by increasing in number of passes.
- Hardness of Al and AZ31 alloy has been increased with reduction of grain diameter at different working conditions to route Bc.

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