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High-strength aluminum alloy of ultrafine grained by consolidation-ECAP

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Abstract. Technology of Severe Plastic Deformation (SPD) has emerged as a widely known procedure for the fabrication of ultrafine grained metals and alloys. Equal Channel Angular Pressing (ECAP) are one of methods of SPD has been developed for many applications; military devices, aerospace and automotive components. This paper examines recent developments related to the use powder of Aluminum alloys processed by consolidation-ECAP, for grain refinement; Al-5Mg, were compared by another type of Aluminum, which has also been researched. Characterization by mechanical, physical and microstructured. In the current study powder of material wrapped in copper capsule to be compressed and heated at a temperature of 400°C in hot press under the pressure of 450-500 MPa. Afterward the powder in solid condition was cooled in the air. The sample results of Aluminum by ECAP process then followed heat treatment with type Annealed, for heating at a temperature of 346°C for 1,5 continuing 415°C during 2 hours followed by heating at a temperature of 205-230°C for 4 hours. This paper describes the effect of heat treatment on the characteristics of the powder material on Al-5Mg are based on changes in the mechanical properties and microstructures.

1. Introduction

The latest development of metal processing technology is Severe Plastic Deformation (SPD), It has updating conventional metal processing technology. For conventional metal forming processes, the imposed plastic strain is generally less than about 2.0. When the pressing forces are carried out up to a plastic strain of greater than 2.0, the thickness and the diameter become very thin and are not suitable to be used for structural parts. In order to impose an extremely large strain on the bulk metal without changing the shape, then SPD are compatible for that processes [1-2]. There are many SPD processes already developed. Various SPD processes such as; Equal Channel Angular Pressing (ECAP) [3], High Pressure Torsion (HPT) [4], Accumulative Roll Bonding (ARB) [5], are a development for the manufacture of metallic materials to achieve superior nature. At this moment, ECAP has emerged as a widely recognized procedure for the manufacture of ultrafine-grained metals and alloys. To grain refinement including modifying of conventional-ECAP in order of improve process in efficiency and techniques on increasing the scale of procedures so that very difficult processing can be smoothly to pressed. All of basic and experimental parameters with alternate functions in microstructure during operations of pressing processes. Significant progress has been made in ECAP development in recent years, so it shows there are excellent prospects for future successful merge of the process. Among SPD technologies, ECAP has advantages for several reasons; First, it can be applied to billets large enough so that there is potential to produce materials that can be used in a wide range of structural applications. Secondly, it is a relatively simple procedure that is easy to do on various alloys and, except for development of dies only, processing by ECAP uses the equipment available in most laboratories. Thirdly, ECAP can be developed and applied to materials with different crystal structures and materials



for many ranges from alloy tensile hardening to intermetallics and metallic-matrix composites. Fourth, reasonable homogeneity is achieved through most of the as-pressed billets providing the pressing that keeps the strain high enough. Fifthly, the process may scale-up to suppress relatively large samples and, there is potential for developing ECAP for use in commercial metal-processing procedures [1,3,6]. ECAP is one kind of SPD processes by combining pressing and tensile stress in the mold. ECAP is manufacturing process for the metal that has ability to introducing significant grains refinement into large bulk samples, can produce fine grain structures and combined with oxide inclusion from high- strength particle surface [7-9]. The processing scheme for ECAP Consolidation is shown in Figure 1.

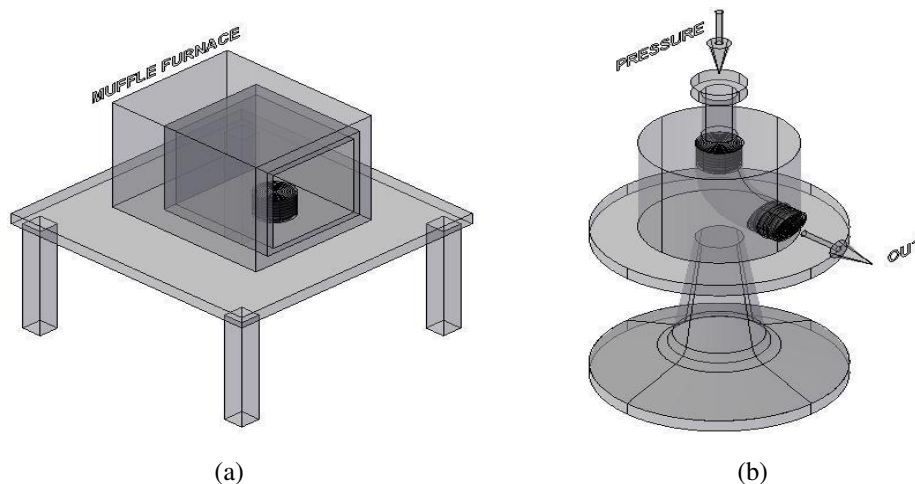


Figure 1. Schematic processes of Consolidation ECAP: (a) Pre-heating Al-5Mg on the muffle furnace; (b) Pressing Al-5Mg inside in the dies on ECAP Consolidation.

Aluminum Alloys type Al-Mg has good mechanical properties, high corrosion resistance and weldability, it was different processing Al-Mg subject to dynamic loading such as impact or collision with other objects. Therefore, the mechanical properties and constitutive behavior of these alloys at both low and high levels of deformation need to be investigated properly [10]. ECAP combines compressive and tensile stress in the mold to generate products with severe deformation. It has the ability to introducing significant grain refinement into large bulk samples. Typically, it reduces the grain size into the sub-micrometer level, The resulting grain reaching 1-10 μm , on the size of a grain that was ultrafine grained (UFG) and thereby produces materials which are capable to give unusual physical and mechanical properties [3,9]. Although the mechanical and physical properties of all crystalline materials are determined by several factors, the average grain size of the material generally plays a very significant, and often a dominant, role. Thus, the strength of all polycrystalline materials is related to the grain size, d , through the Hall-Petch equation which states that the yield stress, σ_y , is given by :

$$\sigma_y = \sigma_0 + k_y \cdot d^{-1/2} \quad (1)$$

where σ_0 is termed the friction stress and k_y is a constant of yielding. It follows from equation (1) that the strength increases with a reduction in the grain size and this has led to an ever-increasing interest in fabricating materials with extremely small grain sizes [3].

This study investigates the relationship microstructure on mechanical properties of the ECAP Consolidation process with heat treatment of Al-5Mg and characterization of hardness and compressive strength to get the relationship between the mechanical properties to microstructures.

2. Experimental Methods

Starting material by Al-5Mg powder, average particle size: $\pm 70\mu\text{m}$. The Materials come from Aluminum Powder Company Ltd, ALPOCO. The powder was wrapped in the copper sheet and heated in a resistance furnace at 400-500°C with holding time of 1 hour. The samples were transported to the non-heated ECAP die during 3 – 4 seconds and pressed at the rate of 5 mm/s through the angle of 90° for one pass. For each sample front stopper as back-pressure was used. The pressure for compacting 16×16 mm square specimens was in the range of 300-550 MPa. For improve the properties of Al-5Mg, heat treatment was performed after ECAP Consolidation. Annealing was conducted by heating the sample up to 345°C and holding for 1,5 hours. ECAP consolidation process series of Aluminum Alloys

and heat treatment as shown in Fig. 2



Figure 2. The preparation process of aluminum-based nano powder ECAP Consolidation

3. Characterization of Aluminum Alloys (Al-Mg)

Characterization of mechanical properties was traced by Vickers hardness (HV10) and compressive strength test. All of samples measured on specimens with diameter ± 5 mm and height of 8mm. Scanning Electron Microscope (SEM) JEOL JSM-6510LA was used to determine the grain morphology and precipitate distribution. To obtain the results achieved in Al-5Mg, then pure Aluminum is used as a comparison.

4. Result Discussion

4.1. Micros-structured

The microstructure shown fine grains in the matrix phase Al has been spread evenly among Mg_5Al as black color a precipitates, which is randomly dispersed as flat shape precipitates (Figure 3(a)). After the annealed process occurs grain boundary grain growth followed by reduction of aluminum as a matrix size, but Mg_5Al precipitate grain size has magnification as shown in figure 3(b). Annealing at high temperatures, the precipitated particles are embedded and greatly interact with the remaining grain boundaries. As long as the annealing density of the dislocation is reduced due to the effects of the recovery by increasing the ductility [7].

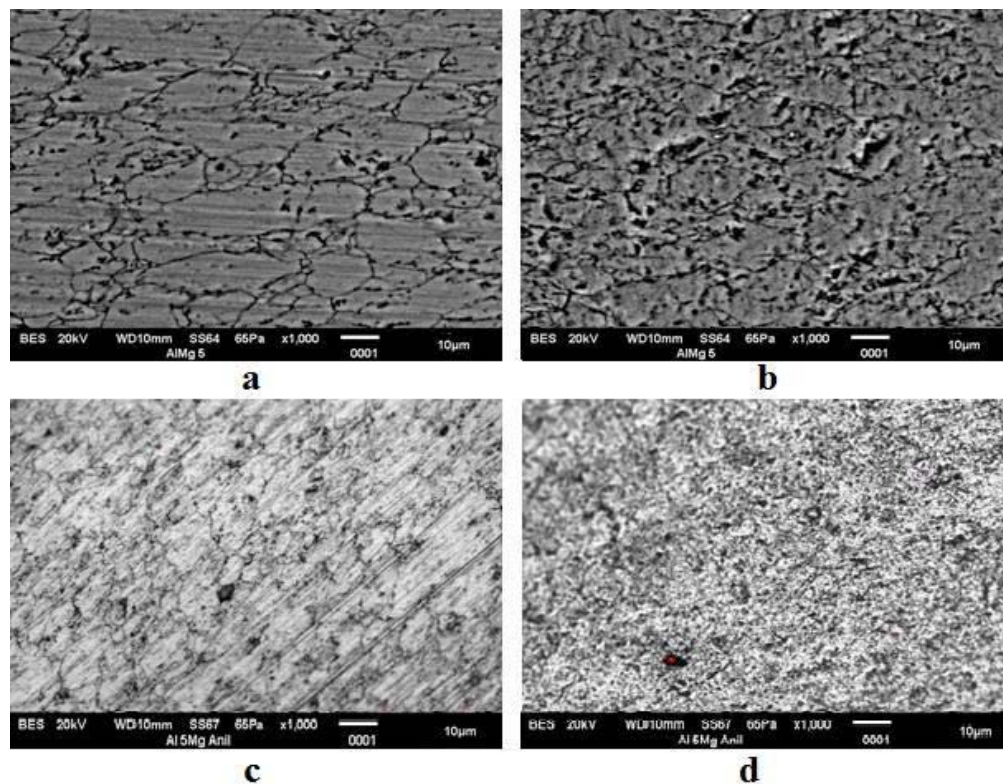


Figure 3. The microstructure of Al-5Mg by ECAP consolidates a). Al-5Mg as received ECAP-Consolidation b). Al-5Mg anneal process c). Calculation of Image-J Al-5Mg as received d). Calculation of image-J Al-5Mg result of anneal

The grain calculations used Image-J, result an average grain size of $9.6\mu\text{m}$ on the consolidated ECAP shown figure 3(c). After annealing process, the grain changes become $9.2\mu\text{m}$, this grain change is not to significant. In figure 3, seen in the annealing process there are Mg_5Al that visible precipitates evenly distributed between the aluminum grain boundaries. This condition cause of uniformly distributed hardness and increases mechanical properties. Morphological grains of Al-5Mg by ECAP becomes oval grains with a grain morphological pressure line. The oval grains of ECAP resulted are due to grain shifts from the high force by ECAP pressure process, between the compressive and tensile stresses which make the grains shift into ovals, after receiving an annealing treatment (figure 3(d)) Mg as precipitates spread over several aluminum grain boundaries, the aluminum grain becomes large while the precipitate is spread evenly.

4.2. Mechanical Properties Characterization

Mechanical properties measurements by hardness vicker (HV10) and compressive strength (MPa). Measurement of mechanical properties to get information of homogeneity of strength Al-5Mg as received by ECAP consolidation and annealing process. UFG capable to increase the strength with great reinforcement on ECAP consolidation, associated with considerable improvements during intensive plastic deformation [8-9]. The Result of Al-5Mg by ECAP consolidated samples was presented in tables 1. Hardness values of Al-5Mg are 148 HV, after annealing, the hardness decreases down to 102 HV. The decline in hardness on the annealing process caused by grain growth in the heating stages, that resulting in coarse grains. This will be followed by an increase of ductility. Increase in ductility cause by the grains growth of equiaxed shaped, resulted in the loss of the dislocation network as well.

Compressive strength in figure 4 shown directly proportional of strength value Al-5Mg by ECAP-Consolidation 450 MPa, higher than compressive strength of annealed process 200 MPa. The compressive strength value will be proportional to the hardness, but after heating of annealing type, then the value of compressive strength and hardness will decrease, this decrease is due to the Al-5Mg as precipitate which is less evenly distributed in the aluminum matrix, so the hardness and strength will tend to decrease, but the annealing will cause the grain coarsening that increases on ductility.

Table 1. Mechanical Properties of Al-5Mg by ECAP-Consolidation.

Materials	Hardness (HV10)	Compressive Strength (MPa)	Ductility (%)
Al-5Mg as it is	148	450	15
Al-5Mg Anneal	102	200	35
AA6061	141	250	30
AA7075	121	395	2.5

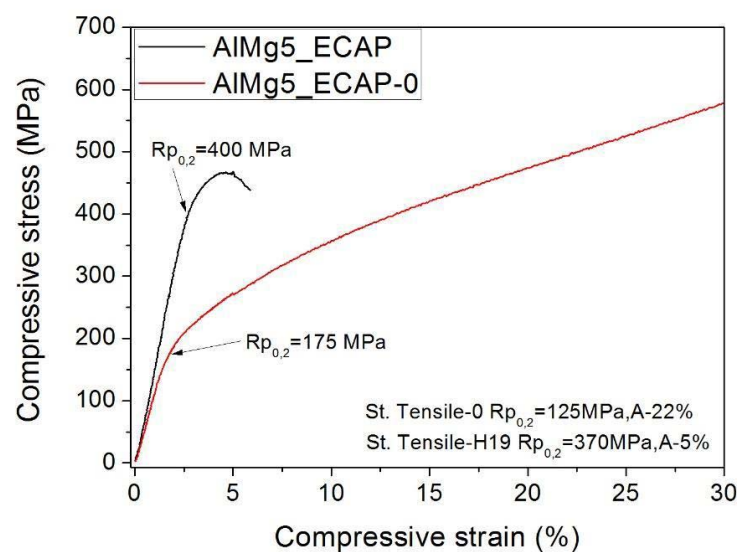


Figure 4. Compressive strength of Al-5Mg by ECAP-Consolidation.

4.3. Comparative results of the aluminum process by ECAP Consolidation.

Aluminum alloys have elements that act as precipitates, Mg_2Si on AA6061 series acts as precipitates [7], $MgZn_2$ inside AA7075 acts as precipitate [8]. Al-5Mg compounds act as precipitates as well. High-strength aluminum alloys containing Mg_2Si , $MgZn_2$ and Al-5Mg, which are easily reached, but for formability processes is not sufficient to be applied. Therefore, much research has focused on increasing the formability of these alloys through heat treatment. High strength aluminum alloy, such as alloy AA7075, which combines the power of high-density ratio with excellent mechanical properties, is widely used for aviation applications, superplastic forming into high-volume fabrication of components in the automotive. Consumer products industry is currently limited because of the relatively low strain rate. AA6061 are some of the alloys materials, mostly used currently covering the whole range of industry. Applications of AA6061 easier to process than AA7075 because of properties the material

elasticity, AA7075 tend to form internal cracks as a result of micro-segregation. That way heat treatment is required to improve the properties of the material when it is processed by ECAP [11]. At Al-5Mg the most superior character is compressive strength, compared with: AA6061 and AA7075. To increase ductility applied heat treatment of annealing type. The heating process is needed as a step for the application of component manufacturing processes. But compared to other kind of aluminum, AA7075 was lower on formability, this is seen in low ductility. In figure 5 it has been proven that research with AA7075 will tend to form cracks during the process. Workability of AA7075 usually constrained by the microstructure of the material, deposit of precipitates such as $MgZn_2$ element typically forming a micro-segregation, which lead to cracking when processed materials [12]. Based on plastic strains of structure of the alloys was determined, Fig 5 represents the results of the failure of sample formation process due to limited ductility AA7075 due to micro-segregation of produce cracks [11-12].

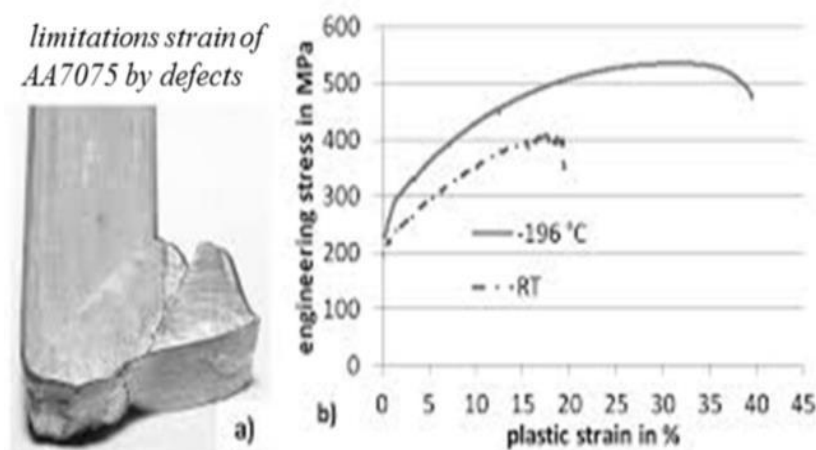


Figure 5. Limitations due to the formation of cracks AA7075 by ECAP process [12].

4. Conclusions

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