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Experimental Investigations on Microstructure of Equal Channel Angular Pressed Aluminum Alloys at Different Die Angles

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Abstract: Equal channel angular Pressing (ECAP) is at present one of the most promising technique to produce bulk nanostructured or ultra fine-grained materials .ECAP is a severe plastic deformation process where a material is extruded through a channel that intersect at an angle. As the material crosses the channel's intersection, the material is deformed by simple shear and the billet accumulates deformation. The channel of the die are manufactured with approximately the same cross-section. As the cross-section at the entrance and exit is equal, the billet dimension does not change when the part is extruded.In the present work, AA7075 aluminum alloys are processed through ECAP dies with various channel angles at room temperature. After deformation, all the pressed samples are subjected to microstructure test. The results showed improved grain orientation of the ultra-fine grained aluminum alloy that is developed. The results are compared with the microstructure of pure aluminium billet . This research provides an opportunity to examine the significance of the ECAP process for aluminum alloys on microstructure.
Keywords: ECAP, AA7075, Microstructure.

INTRODUCTION

Light metals with high strength are the immediate and future requirements for aerospace as well as automotive industries. Grain refinement is one of the techniques, which provides finer grains and hence ultra high strength and ductility combination demanded for ambient and cryogenic temperature applications.The manufacturing and processing of these ultra-fine grained and nanocrystalline materials have attracted growing scientific and industrial interests in the last decade as a result of attractive properties of these materials[1]. Polycrystalline materials can be classified as nanocrystalline if their grain size is within the range 1 nm – 100 nm, as ultra-fine grained if an average grain size is in the range 100 nm – 500 nm, as fine grained if grain size is in the range 0.5 μm – 10 μm, and coarse grained if grain size is greater than 10 μm[2]. These ultra-fine grained and nanocrystalline materials have mechanical properties that include extraordinarily high yield strength, high hardness, improved toughness and ductility with increasing strain rate.These materials have been found to exhibit very different microstructures and mechanical behaviors from their conventional coarse grained polycrystalline counterparts, namely ultra-fine grained materials have enhanced superplasticity deformation at low and high strain rate[3].Severe Plastic Deformation (SPD) is an innovative process capable of producing uniform plastic deformation under superimposed hydrostatic pressure in a variety of materials, without causing significant change in geometric shape or cross section. SPD involves simple shear deformation leading to exceptional grain refinement of the material that is achieved by passing the work piece through a die containing two channels of equal cross section that meet at a predetermined angle[4-6].The development of the principles underlying severe plastic deformation techniques is attributed to the pioneering work of P.W. Bridgman at Harvard University, which took place in the 1930s.The main objective of a severe plastic deformation process is to produce very strong and lightweight parts that are useful in everyday situations.The two most commonly used severe plastic deformation methods – high pressure torsion and equal channel angular pressing – were developed to fabricate and process ultra-fine grained material to better understand the properties of materials in order to design a material with superior performance. The equal channel angular pressing (ECAP) technique is the more attractive technique because it offers the potential for high strain rate superplasticity by effective grain refinement from macrograined structures to the level of the submicron or nanoscale through a special die. Their objective, when designing the process at that time, was to develop a metal forming process with a high strain rate. Since then, the process has undergone much modification and modernization in the design of the die, the processing routes and the use of other experimental parameters. Many researchers around the world are continually developing a range of nanostructured materials with exceptionally favourable properties. [7,8]. The processing of materials by ECAP has undergone active development in several areas. These areas include the development of many different nanoscale metals and alloys and the commercial production of semi-finished products within ultra-fine grained structures using a wide range of metals and alloys. The application of the ECAP procedure is currently under investigation for many different materials ranging from aluminium, copper, magnesium and nickel alloys to eutectic and eutectoid alloys and intermetallic materials.The aim of this study was to produce an ultra-fine grained material using the ECAP technique, and to examine the microstructural properties of the material produced. We have also summarised recent review articles and new trends in the design of the ECAP die and processing parameters. The applications of the ECAP technique in the manufacturing industry are also discussed[9 - 11].

In thiswork investigation on material properties has been carried out below recrystallization temperature of alluminium alloy (220^{o}C) i.e.,at roomtemperaturefor two dies with angles 120^{o}and 150^{o}.This study is madebecause two to three passes followed by the low temperature annealing can be useful to break down an initial coarse structure, refine the grain size and increase the strength of the material. Complex micro structures and textures can be developed by changing the orientation of the billet between successive extrusions.

EXPERIMENTAL PROCEDURE

The ECAP die is composed of two channels with identical rectangular cross sections connected through the intersection at a specific angle. The cross section can also be circular or square. The work piece is machined to fit within the channel and extruded through two intersecting channels with the same cross section using a plunger (Figure 1). During the ECAP process, adequate lubrication is essential because of frictional influences, tool wear and the loads necessary for plastic deformation. One important advantage of the ECAP process is that it can be repeated several times without changing the dimensions of the workpiece, and the applied strain can be increased to any level; these advantages mean that the severe strains that can be applied and a simple shear deformation mode contribute to the strong and unusual properties of the material produced.

Die Design

The ECAP die used in all experiments had to be constructed from scratch as there was very limited knowledge about ECAP at NTNU at the start of this work. Many parameters had to be taken into consideration regarding sample shape, sample size, working temperature, and maximum work load. We decided to use die with rectangular channel of 20mm x 20mm cross section and sample length of 70mm which should be capable of a maximum workload of 600kN. In addition we wanted the possibility of heating the die to a maximum of 500^{o}C.The dies were made up of EN 24 steel. Each die consists of two plates mated together using double pins and two rectangular clamps. Each plate is machined to the dimensions 150 x 150 x 40mm^{3}. The channel was made on each plate on CNC machine using knife edge tool, and the channel on one plate is the mirror image to the other, so that when they mate together forms the perfect die. The channel surfaces were finished and diamond polished to decrease mating friction between billet and the channel and for increased wear resistance.

EN 24 Steel Properties

EN24 steel is a high tensile alloy steel renowned for its wear resistance properties and also where high strength properties are required. EN 24 steel is a popular grade of through hardening alloy steel due to its excellent machinability. EN24 is used in components subject to high stress and with a large cross section. This can include aircraft, automotive and general engineering applications for example propeller or gear shafts, connecting rods, aircraft landing gear component and its hardness is in the range of 248/302 HB and can be further surface-hardened to create components with enhanced wear resistance.

Name	C	Si	Cr	S	P	Density kg/m^3	Meltin g point
Comp ositio n	0.52	0.22	1.3	0.05	0.05	7810	1540

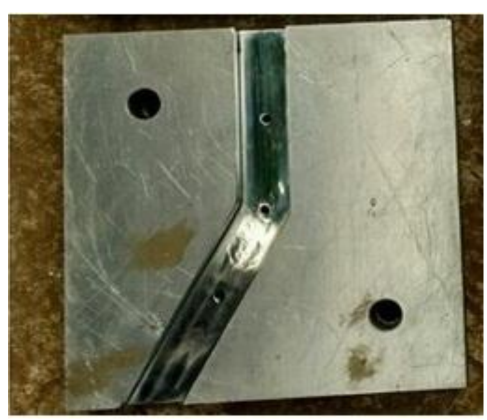
Table.1 EN24 Steel Mechanical Properties

Size Mm	Tensile Strength N/mm^2	Yield Stress N/mm^2	Elong ation	Impact Izod J	Impa ct KC V J	Hardness HB
63 to 150	850-1000	680 min	13%	54	50	248/302

Die Channel Making

Channels on the dies are made using CNCcentering machine.Dimensions of channel: 20×20mm^2 equal channel with angles 120^{o}, 150^{o} at the junction.3Holes of diameter 3mm are drilled in the channel for one plate of each die using drilling machine and holes of diameter 12 mm are made on each plate to insert double pins for perfect alignment of the dies.

Angle 120^{o}



Angle 150^{o}

Fig.2 Dies with different angles

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Design of clamps

The clamps are made up of EN 31 steel which can withhold the maximum workload of 500KN slightly less than that of the die. The rectangular clamps are machined to the dimensions 200 x 40 x 40 mm^3. Holes are made to the clamps at both the ends with diameter20mm. These clamps were fixed to the die using 100mm length bolts and 20 mm diameter nuts.

Table.2 Chemical composition (% weight)

Size mm	Tensile Strength N/mm^2	Yield Stress N/mm^2	Elongation	Impact Izod J	Impact KCV J	Hardness HRC
63 to 150	750	450	30%	54	50	63

Design of Plunger

The Plunger is made from the same steel quality as the die, e.g. EN 24 steel. Two plungers have been used for the process to avoid the bending of the longer plunger at high pressures. The longer plunger has the cross section of required dimensions 20 x 20 x100 mm^3, and the smaller plunger has the dimensions 20 x 20 x 60 mm^3. The molybdenum disulphate (MoS_2) aerosol is sprayed to avoid sticking friction along the whole plunger length..

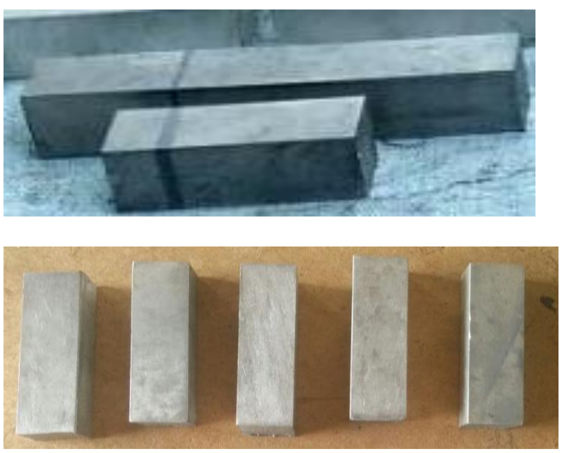

Fig.3 Plunger and Workpiece

Pressing speed

The ECAP technique is always conducted using high-capacity hydraulic presses that operate with relatively high ram speeds. The influence of pressing speed was investigated using samples of pure aluminum and a range of pressing speeds from 10^{-2} mm/s to 10 mm/s. The results showed that the speed of pressing had no significant influence on the equilibrium grain size, at least over the range used in these experiments, and that the nature of the microstructure was dependent on the pressing speed, because recovery occurred more easily at slower speeds, resulting in more equilibrated microstructures. There was also indirect evidence for the advent of frictional effects when the cross-sectional dimensions of the samples were 5 mm or less.

Aluminium **ingots** at room temperature are extruded in the dies for 3 passes, they are polished and etched with kellars reagent to study microstructure.

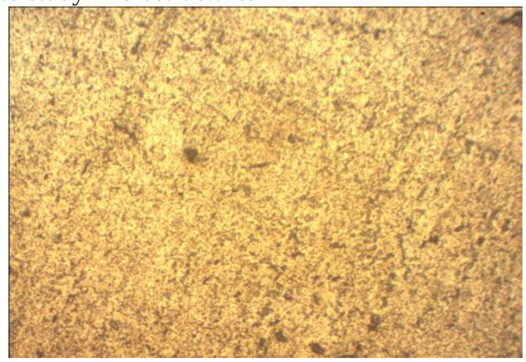

Fig.Original specimen

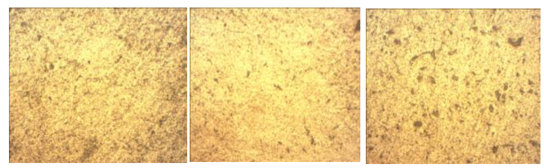

Fig : Die angle 120^0 Room temperature in 3 pases

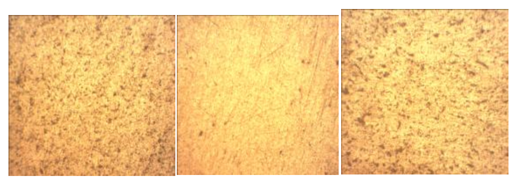

Fig : Die angle 150^0 Room temperature in 3 pases

Conclusions

ECAP is an effective tool for attaining significant ultrafine grain sizes in bulk materials to produce unique properties . An important advantage of this technique over conventional metal working processes,such as extrusion and rolling,is that very high strains may be attained without any concomitant change in the cross sectional dimensionsof the sample.The technique is also used as a basic principle for microstructural refinement. In this study a considerable change in microstructure after every successive pass is observed and there is a partial grain orientation in the resultant microstructures. Based on the grain structures it can be predicted that Hardness of 120 ^{o} die angle samples to be very large when compared to 150 ^{o} die angle samples. While comparing microstructures of different passes III pass is found to be the best one where there is complete grain orientation and remodification .There are several factors that influence the workability and the microstructure characteristics of equal channel angular pressed materials; these factors are associated directly with the experimental ECAP facility which include the angles within the die between the two parts of the channel and the outer arc of curvature where the channels intercept. Experimental factors like the speed and temperature of pressing influence the grain refinement and the homogeneity of the microstructures of the resultant samples. The total number of passes and the processing route that the sample undergoes also affect the grain refinement.

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