EXPERIMENTAL INVESTIGATIONS ON MICROHARDNESS OF EQUAL CHANNEL ANGULAR PRESSED ALUMINUM ALLOYS AT DIFFERENT TEMPERATURES

S.V.Narsimha Rao[*] J.Kandasamy[*] M.Manzoor Hussain[$] S.Rajesham[#]
* MVSR Engineering College, Nadergul – 501510
[$]JNTUH CES, Sultanpur, Medak.
TKR Engineering College, Medbowli, Hyderabad.

Abstract
Equal channel angular pressing (ECAP) is a severe plastic deformation technique for producing ultra fine grain structures in submicron level by introducing a large amount of shear strain into the materials without changing the billet shape or dimensions. In the present work, AA7075 aluminum alloys are processed through ECAP dies with various channel angles at different temperatures. After deformation, all the pressed samples are subjected to Vickers micro hardness test. The results showed improved surface behavior of the ultra-fine grained aluminum alloy that is developed. The results are compared with the already existing results available on pure aluminium. This research provides an opportunity to examine the significance of the ECAP process for aluminum alloys on surface hardness.
Keywords: ECAP, AA7075, Micro hardness.

INTRODUCTION

The manufacturing and processing of ultra-fine grained and Nano crystalline 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 Nano crystalline 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 Nano crystalline 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 super plasticity deformation at low and high strain rate[3].

Severe plastic deformation is a generic term describing a group of metalworking techniques that involve using extreme plastic straining to produce materials by imposing very high shear deformations on the material under superimposed hydrostatic pressure. Severe plastic deformation leads to exceptional grain refinement of the material without introducing any significant changes in the overall dimensions of the specimen or work piece[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 super plasticity by effective grain refinement from macro grained structures to the level of the submicron or Nano scale 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 favorable 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 aluminum, 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, mechanical and hardness 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 this work investigation on material properties has been carried out below recrystallization temperature of alluminium alloy (220^{o}C) at four different temperatures (i.e., 150^{o}C, 180^{o}C, 200^{o}C, room temperature) for four dies with angles 90^o, 120^o, 135^o and 150^o.This study is made because 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. By changing the orientation of the billet between successive extrusions, complex micro structures and textures can be developed.

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 workpiece 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

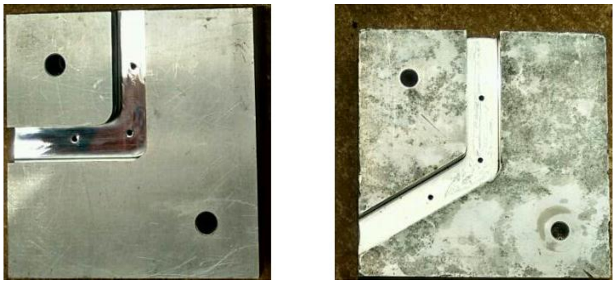
EN24 is usually with a tensile strength of 850/1000 N/mm^2. EN 24 steel is a popular grade of through hardening alloy steel due to its excellent machinability. EN24 is used in components such as gears, shafts, studs and bolts, its hardness is in the range of 248/302 HB. EN24 can be further surface-hardened to create components with enhanced wear resistance.

Table.1 **EN24 Steel Mechanical Properties**

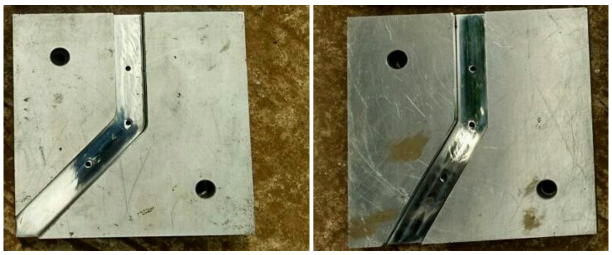
Size mm	Tensile Strength N/mm^2	Yield Stress N/mm^2	Elongation	Impact Izod J	Impact KCV J	Hardness HB
63 to 150	850-1000	680 min	13%	54	50	248/302

Die Channel Making

Channels on the dies are made using CNC centering machine. Dimensions of channel: 20×20 mm^2 equal channel with angles 90^0, 120^o, 135^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 90°
Angle 120°



Angle 135°
Angle150°

Fig.2 Dies with different angles

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 diameter 20mm. These clamps were fixed to the die using 100mm length bolts and 20 mm diameter nuts.

Table.2 Chemical composition (% by weight)

Name	C	Si	Cr	S	P	Density kg/m^3	Melting point
Composition	0.52	0.22	1.3	0.05	0.05	7810	1540

Table.3. EN31 steel mechanical properties

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 and Heater

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. In the experimental procedure J type thermocouples are preferred to determine the temperature of the aluminium ingot undergoing extrusion at 3 points in the channel. These thermocouples are connected to the digital reader to track the temperature during the process. Heater with capacity of 600°C is designed to heat the aluminum ingots at different temperatures before inserting billets into the dies.

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 aluminium 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.

Aluminum **ingots** are heated in the heater at temperatures 150°C, 180oC, 200oC including room temperature and are extruded in all the dies for 3 passes. Hardness is tested for the obtained billets.

Fig.4 Pressed Specimen

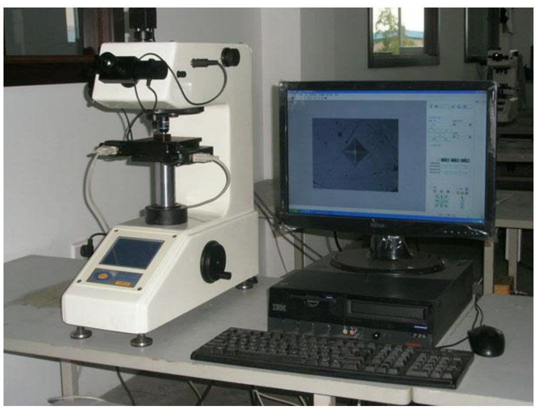


Fig.5 Vickers Hardness Testing Machine

Equipment used: Vickers cum Brinell Hardness Tester, Method of Testing: As per IS: 1501-1984

Table.2 Vickers Hardness HV5 Test Results

Angle	Temperature	Route A	Route B	RouteC
	Room	85.8	88.3	85.1
	150°C	71.4	82.4	75.8
	180°C	69.5	78.3	89.0
120°	200°C	76.6	82.0	77.6
	Room	40.3	80.2	74.1
	150°C	41.6	72.3	61.2
	180°C	89.5	73.4	66.5
135°	200°C	46.5	68.9	78.2
	Room	67.7	79.9	72.8
	150°C	58.0	78.4	64.7
150°	180°C	59.2	67.8	62.2
	200°C	58.0	74.1	67.6
90°	Room	93.8	94.5	92.7

Conclusions

The ECAP technique is now recognized for achieving very significant grain refinement of ultra-fine grained materials which, at present, have unique mechanical properties. The technique is also used as a basic principle for microstructural refinement. Several factors influence the workability and the hardness characteristics of equal channel angular pressed materials; these factors are associated directly with the experimental ECAP facility and 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 and micro hardness of the pressed material. Other factors that affect grain refinement are the processing route and the total number of passes that the sample undergoes.

References

1. Gleiter H. Nanostructured materials: Basic concepts and microstructure. Acta Mater. 2001;48:29.
2. Valiev RZ. Paradoxes of severe plastic deformation. Adv Eng Mater. 2003;5(5):296–300. http://dx.doi.org/10.1002/adem.200310089
3. Kumar KS, Swygenhoven H, Suresh S. Mechanical behaviour of nanocrystalline metals and alloys. Acta Mater. 2003;51:5743–5774. http://dx.doi.org/10.1016/j.actamat.2003.08.032
4. Langdon TG. Processing by severe plastic deformation: Historical developments and current impact. Materials Science Forum. 2011;667– 669:9–14. http://dx.doi.org/10.4028/www.scientific.net/MSF.667-669.9
5. Azushima A, Kopp R, Korhonen A, et el. Severe plastic deformation (SPD) processes for metals. CIRP Annals – Manufacturing Technology. 2008;57:716–735.
6. Valiev RZ, Langdon TG. Principles of Equal Channel Angular Pressing as a processing tool for grain refinement. Prog. Mater. Sci. 2006;51:881–981. http://dx.doi.org/10.1016/j.pmatsci.2006.02.003
7. Iwahashi Y, Horita Z, Nemoto M, Langdon TG. The process of grain refinement in equal-channel angular pressing. Acta Mater. 1998;A382(1- 2):30–34.
8. Nakashima K, Horita Z, Nemoto M, Langdon TG. Development of a multi-pass facility for equal-channel angular pressing to high total strains. Mater Sci Eng A. 2001;281(1–2):82–87. http://dx.doi.org/10.1016/S0921- 5093(99)00744-3

9. Furukawa M, Horita Z, Nemoto M, Langdon TG. The use of severe plastic deformation for microstructural control. Mater Sci Eng A. 2002;324:82–89. http://dx.doi.org/10.1016/S0921-5093(01)01288-6

10. Ma E. Eight routes to improve the tensile ductility of bulk nanostructured metals and alloys. J Miner Metall Mater Soc. 2006;58:49–53. http://dx.doi.org/10.1007/s11837-006-0215-5

11. Rosochowski A, Olejnik L. Numerical and physical modelling of plastic deformation in 2-turn equal channel angular extrusion. J Mater Proc Tech. 2002;125–126:209–316.