International Journal of Advancements in Mechanical and Aeronautical Engineering– IJAMAE
Volume 1: Issue 2 *[ISSN 2372 – 4153]*
Publication Date : 25 June 2014

Evaluation of Mechanical Properties of Commercially Pure Aluminium Deformed by Equal Channel Angular Extrusion

[1]Arkanti Krishnaiah, [2]Padavala Anand and [3]Maloth Ramulu

Abstract-Equal channel angular extrusion (ECAE) is a processing method for introducing an ultrafine grain size into a material. In the present study, a severe plastic deformation process was used to produce ultrafine grained Al with significantly enhanced mechanical properties. This paper reports the mechanical properties and microstructures of the Al specimens processed by ECAE at room temperature.

Keywords-Equal Channel Angular Extrusuion, Aluminium, Mechanical properties, Microstructure.

I. Introduction

Equal channel angular extrusion (ECAE) is a severe plastic deformation (SPD) that has become very promising technique over the last decade because of the potential for achieving considerable grain refinement, typically to the submicrometer or nanometer level [1,2] in a wide range of metals and alloys [3-9], composites and intermetallics [10,11]. Several methods of SPD processing are currently available but the most versatile, and potentially the most useful in industrial applications, appears to be equal channel angular extrusion (ECAE). In the equal channel angular extrusion (ECAE) process, the die consists of two channels of equal cross sectional area intersecting at an angle 2φ (which is usually between 90^o and 135^o) [12, 13]. Typically, samples are pressed for several consecutive passes through the die so that very high strains are imparted. Processing by ECAE was first developed in the former Soviet Union over 20 years ago [14] and subsequently there were reports documenting the use of ECAE in producing materials with exceptionally small grain sizes that were significantly finer than those generally achieved using conventional thermo mechanical processing [15–17].

[1]Dr. Arkanti Krishnaiah, Professor of Mechanical Engineering
University College of Engineering (Autonomous)
Osmania University, Hyderabad, India

[2]Padavala Anand, Senior Lecturer
Govt. Institute of Printing Technology
Secunderabad, India

[3]Maloth Ramulu, Senior Scientist
Indian Institute of Chemical Technology
Hyderabad, India

Different routes may be employed in order to process the material; Route A: in which the orientation of specimen remains unchanged in successive passes; Route B_A: specimen is rotated ± 90^o about its longitudinal axis alternatively; Route B_C: specimen is rotated 90^o about its longitudinal axis in the same direction. Route C: in which the specimen is rotated 180° about its longitudinal axis. Depending on the processing route, microstructural characteristics will also differ. The theoretical analysis of Segal [1] states that for billets large enough and assuming idealized frictionless conditions, the material experiences simple shear producing a stationary plastic flow in the shear plane. The total equivalent plastic strain after *'N'* passes through a die with a channel angle of 2ϕ is given by equation (1):

$$\varepsilon = \frac{2N}{\sqrt{3}} \cot \phi \qquad \ldots\ldots\ldots\ldots\ldots\ldots.. (1)$$

In the present study, the commercially pure aluminium specimens were processed by ECAE to 3 passes using Route Bc with a die angle of $2\phi = 120^o$ to reduce the grain size and increase the mechanical properties.

II. Experimental Procedure

The chemical composition of the commercial purity Al used is (in wt.%) 0.335 Fe, 0.429 Si, 0.026 Cu, 0.024 Mn, 0.495 Mg, 0.072 Zn and balance aluminium. The samples were solutionized at 450°C in a muffle furnace for 4 hours. At the end of solutionizing, the specimens/billets were quenched in water at room temperature. It is well known that solutionizing results in decreased hardness. The solutionized billets after machining to required size are used for the process of ECAE. The die was designed and fabricated with $2\phi=120^o$. The specimens were 120 mm in length with a diameter of 20 mm. A 45º taper was also given at front end of the specimen to facilitate the easy start of ECAE. The ECAE process was performed on well lubricated (MoS_2) aluminium specimens at a speed of approximately 50 mm/min at room temperature. The

ECAE is done for twelve samples, to get specimens, for tensile strength, hardness and micro-structure for each pass. The process of ECAE is started only after ensuring the assembly is properly done and dies are aligned correctly. The experiments were conducted up to 3 passes using route Bc, rotating the specimen for 90° after each pass in counter clockwise direction between consecutive passes. Afterwards, specimens were cut in the extrusion axis direction (longitudinal) and transverse directions and microhardness was measured. Figure 1 shows the schematic diagram of equal channel angular extrusion.

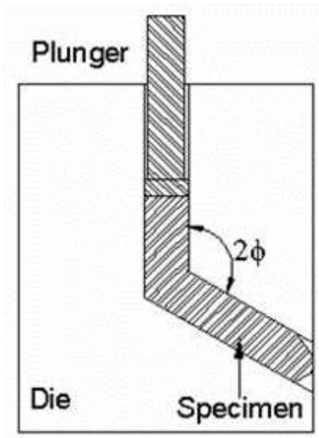

Fig. 1 Schematic diagram of equal channel angular extrusion process.

Vickers microhardness measurements were carried out on longitudinal direction (LD) and transverse direction (TD) using a 250 g load applied for 15 sec. Reported values of Vickers hardness represent the average of ten measurements for each condition.

Tensile testing was carried out on a 50 kN DAK, universal testing machine (UTM). In this test, the specimens were prepared suitable for gripping into the jaws of the testing machine that will be used. The specimen used is approximately uniform over a gauge length (the length within which elongation measurements are done). Three specimens were prepared for each pass. The major parameters that describe the stress-strain curve obtained during the tension test are the ultimate tensile strength (UTS), yield strength (YS), percent elongation (EL). These values are averaged for each pass and the values against the number of passes are plotted. Tensile specimens were made as per the ASTM E-8M from all the specimens processed by ECAE. The tensile specimens had gauge diameter of 4 mm, gauge length of 20 mm and 56 ± 2 mm as total length.

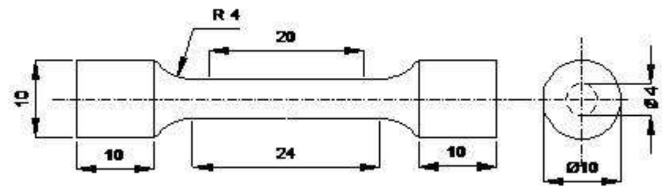

Fig. 2 Schematic and dimensions of tensile test specimen.

Fig. 3 Photograph of ECAE samples before and after extrusion

III. Results and Discussion

A. Mechanical properties after ECAP

The variation of the microhardness of the ECAE samples along the longitudinal (LD) and transverse directions (TD) is shown in Figure 4. It is seen clearly that microhardness increases noticeably after pass one and changes significantly during subsequent passes.

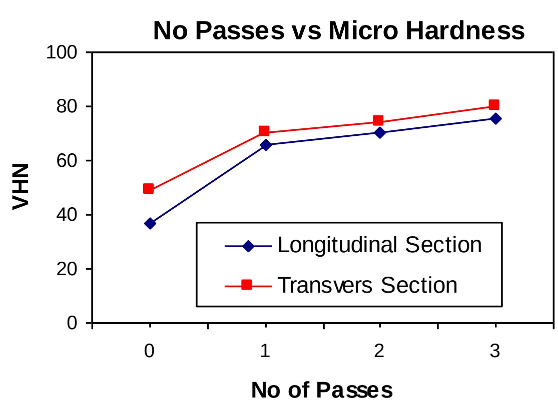

Fig. 4 Vickers hardness dependence with number of passes.

B. Tensile strength and % Elongation at Fracture

The UTS and percent elongations to failure are summarized in Table 1 for various passes. The UTS in the as annealed condition was 100.81 MPa. The UTS gradually increased from pass 1 to pass 3. The increase in strength was due to the ultrafine grains and strain hardening developed in the Al specimens. At the maximum level of strain, ε = 2 (investigated in the current study) highest strength of 200 MPa was obtained for specimens subjected to pass 3 without a significant drop in the ductility. The % elongation to failure was found to be 33% for the initial annealed sample and decreased to 25% after 3 passes for the processing by ECAE.

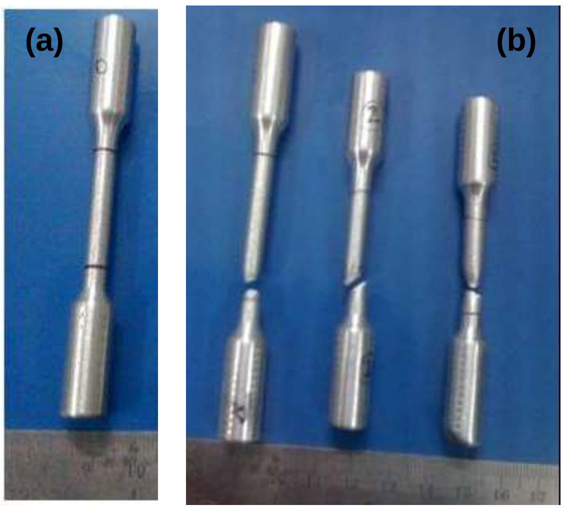

Fig. 5 Photograph of tensile samples (a) before and (b) after fracture

Table1. Mechanical properties of commercial pure Al after ECAE

No of Passes	UTS (MPa)	YS (MPa)	% Elongation
0	100.81	73.59	32.65
1	172.88	124.02	26.13
2	197.90	131.85	25.97
3	200.03	145.07	25.52

C. Microstructure

The samples are prepared in the same manner described for hardness specimens, for each of the ECAP pass and solutionized samples. These samples are again polished using alumina powder on a rotating disc, and again by diamond paste, to ensure mirror finishing of the samples. The mirror finish of the samples is necessary so that no scratches should be present on the sample, before mounting it on the optical microscope (OM). The prepared samples are wrapped in soft cotton, to ensure scratch free samples.

The specimens after adequate polishing are wiped off using the prepared etchant, and mounted on the optical microscope. And the micro graphs are taken at the magnifications of 10x. Before etching micro-structures are taken to check that there are no scratches. Then etching is done for one and half a minute for each sample and the samples are again mounted on the OM, and the micro graphs are taken. The micro structures for different passes and at different magnifications are obtained using OM.

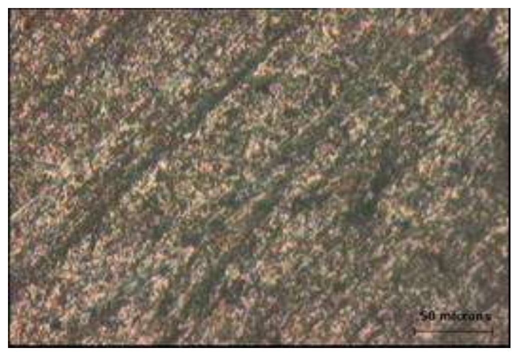

Fig. 6 Optical micrograph of CP Aluminium

Figure 7 and 8 shows the stress-strain curves after pass one and pass three.

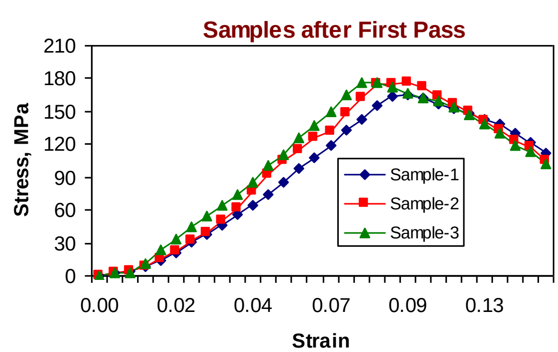

Fig. 7 Stress-strain plots of Al during ECAE, after pass one.

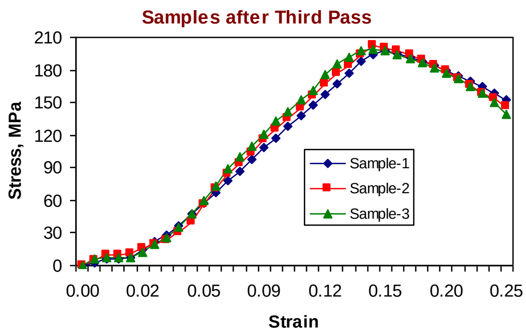

Fig. 8 Stress-strain plots of Al during ECAE, after pass three.

IV. CONCLUSIONS

Equal channel angular extrusion of Al through processing Route B_C leads to an optimum combination of strength and ductility. The ultimate tensile strength and the yield strength of the material have been increased significantly after first and second passes of ECAP. UTS is increased from 100.81 MPa to172.88 MPa in the first pass and then to 197.90 MPa in the second pass. YS is increased from 73.59 MPa to 124.02 MPa in the first pass and then to 131.85 MPa in the second pass. The results reveal that the ultimate tensile strength of material is reaching towards saturation point after the third pass (200.03 MPa). There is a significant reduction in percentage of elongation after the first pass of ECAP (32.65% to 26.13%), but lesser reduction in percentage of elongation after the second (25.97%) and third (25.52%) passes. The microhardness of the material has been increased significantly after first pass of ECAE both in transverse (from 36.7 VHN to 65.5 VHN) as well as longitudinal (49.3 VHN to 70.1 VHN) sections. Almost there is a constant increase in microhardness after the second and third passes of ECAE in both the sections (65.5 VHN to 70.4 VHN and then to 75.8 VHN in transverse section and 70.1 VHN to 74.1 VHN and then to 79.7 VHN in longitudinal section).

Acknowledgements

This work was carried out as part of a research project sponsored by AICTE, New Delhi, Government of India and this assistance is gratefully acknowledged.

References

[1] Y. Iwahashi, Z. Horita, M. Nemoto and T.G. Langdon: Acta Mater. 45 (1997), p. 4733.

[2] Y. T. Zhu, Terry C. Lowe and Terence G. Langdon: Scripta Mater. 51 (2004), p. 825.

[3] V.V. Stolyarov, Y.T. Zhu, I.V. Alexandrov, T.C. Lowe and R.Z. Valiev: Mater. Sci. Eng. A 299 (2001), p. 59.

[4] R.Z. Valiev, N.A. Krasilnikov and N.K. Tsenev: Mater. Sci. Eng. A 137 (1991), p. 35.

[5] Y. H. Zhao, X. Z. Liao, Z. Jin, R. Z. Valiev and Y. T. Zhu: Acta Mater. 52 (2004), p.4589.

[6] Y. Iwahashi, Z. Horita, M. Nemoto and T.G. Langdon: Acta Mater. 46 (1998), p. 3317.

[7] K. Oh-Ishi, Z. Horita, M. Furukawa, M. Nemoto and T.G. Langdon: Metall. Mater. Trans.29A (1998), p. 2011

[8] K. Nakashima, Z. Horita, M. Nemoto and T.G. Langdon: Acta Mater. 46 (1998), p. 1589.

[9] Y. Iwahashi, Z. Horita, M. Nemoto and T.G. Langdon: Metall. Mater. Trans. 29A (1998), p. 2503.

[10] R. Z. Valiev and A. K. Mukherjee: Srcipta. Mater.44 (2001), p. 1747.

[11] S.X. McFadden, R.Z. Valiev and A.K. Mukherjee: Mater.Sc.Eng. A319 (2001), p.849.

[12] R. Z. Valiev, R. K. Islamgaliev and I. V. Alexandrov: Prog. Materials Science. 45 (2000), p. 103.

[13] M. Furukawa, Z. Horita, M. Nemoto, T.G. Langdon: J. Mater. Sci. 36 (2001), p. 2835.

[14] V.M. Segal: Mater. Sci. Eng A197 (1995), p. 157.

[15] R.Z. Valiev, N.A. Krasilnikov, N.K. Tsenev: Mater. Sci. Eng. A137 (1991), p. 35.

[16] N.A. Akhmadeev, N.P. Kobelev, R.R. Mulyukov, Ya.M. Soifer and R.Z. Valiev: Acta Metall. Mater. 41 (1993) 1041.

[17] J. Wang, M. Furukawa, Z. Hotita, M. Nemoto, R.Z. Valiev and T.G. Langdon: Mater. Sci. Eng. A216 (1996), p. 41.

[18] M. Furukawa, Zenji Horita and Terence G. Langdon: Mater.Sc.Eng. A332 (2002), p. 97

[19] V.M. Segal: Mater.Sc.Eng. A386 (2004), p. 269. Annealing.

Dr. Arkanti Krishnaiah, Ph.D (I.I.T Madras) Post Doc. (South Korea) Professor, Dept. of Mech. Engg., University College of Engineering Osmania University, Hyderabad. He is working in the area of Materials Forming and Processing of bulk Nanomaterials.