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TENSILE BEHAVIOR OF A6063 ALUMINIUM ALLOY PROCESSED BY ECAP AT ROOM TEMPERATURE

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ABSTRACT

Nanostructured materials are capable of superplastic elongation at strain rates twice bigger than the ones in the commercial processes. Equal Channel Angular Pressing (ECAP) is currently one of the most well-known methods used for processing UFG (ultra-fine grain) materials. Commercial A6063 aluminium alloy was processed up to 4 passes by ECAP at room temperature using a channel angle of 90^o. This paper analyses the tensile behaviour of the aluminium alloy before and after the plastic deformation by ECAP. The aluminium surface was optically observed after the ECAP deformation.

KEYWORDS: Equal Channel Angular Pressing (ECAP), Plastic deformation mechanisms, Mechanical properties

1. INTRODUCTION

Nanostructured materials have certain unique physical and mechanical properties, and an increased performance due to very small grains. Equal Channel Angular Pressing (ECAP) is a well-established process that allows the accumulation of very high stresses (difficult to obtain by any other conventional deformation) because there are no significant changes in sample size work. This process was originally proposed by Segal [10] and then developed by Valiev [11] and other research groups [4-9]. In the past 20 years it has been recorded a very important progress in designing molds and fundamental knowledge of the phenomena occurring during deformation by ECAP. Currently, ECAP is one of the most popular methods of severe plastic deformation (SPD) used for grain refinement and obtaining materials with ultrafine grains (UFG). UFG materials show excellent mechanical properties due to the mechanism of grain boundaries strengthening.

Microstructure evolution in the ECAP process with several passes is very thoroughly described in the literature, especially for simple materials such as pure aluminium. After the process deformation by ECAP with a single pass, in the sample some elongated deformation bands appear, which, in a smaller scale, are divided by dislocation cellular structures. Depending on the microstructure of the original and the size of grain, some grain boundary with large angles (HAGBs) are already present but due to cell structures in deformation bands grain boundaries with small angles (SAGBs) dominate the misorientation distribution angles and the extra deformation. From the fourth ECAP pass, dislocations cells reach smaller sizes, around or below 1 micron for pure aluminium, and additional deformation leads to growth of angles, misorientation of the grain, and subgrain boundaries. For a strain rate higher than 4 it is possible to continue refining the grain but this occurs very slowly until a level of saturation is reached.

Recent studies by electron backscatter diffraction (EBSD) on the grain misorientation showed that an efficient grain refinement (in the sense of obtaining new HAGBs formations) occurs without rotation of the sample in the mold (route A), due to lack of redundant strain, which leads to new subgrains formation and a significant increase in misorientation angles while forming.

One of the major advantages of ECAP processing is the ability to produce material capable of stretching superplastic strain rates by about two orders of magnitude faster than those currently used in commercial processes.

2. EXPERIMENTAL SECTION

Commercial pure aluminium A6063 samples were used in this study and the chemical composition is shown in Table 1. The samples for the ECAP process were aluminium bars with 10x10 mm square profile and 47 m length. The ECAP was processed with a number of 4 passes at room temperature, all the crossings being taken on route A. The mould was made of hot steel work, with the angle between the two channels 90º and 25º angle of die corner. Based on Iwahashi’s equation, an equivalent strain approximately equal to 1.05 for each pass can apply for these angles. In Figure 1 there are aluminium samples after ECAP with 4 passes on route A.

Table 1. *Chemical composition of commercially pure aluminium A6063 (mass fraction, %)*

Si	Fe	Cu	Mn	
0.2÷0.6	0.0÷0.35	0.0÷0.1	0.0÷0.1	
Mg	**Zn**	**Ti**	**Cr**	**Al**
0.45÷0.9	0.0÷0.1	0.0÷0.1	0.1 max	97.5÷99.4

Fig. 1. *ECAP samples after 1(a), 2(b), 3(c), and 4(d) passes*

3. RESULTS AND DISCUSSION

3.1. Tensile test for the as-cast aluminium samples

Tensile tests were conducted for commercial aluminium A6063 before and after severe plastic deformation by ECAP with 4 passes. The ‘unECAPed’ A6063 aluminium bars were prepared for the tensile test, as shown in Figure 2.

The samples had a diameter of 10 mm and a total length of 100 mm, the gauge length being 5mm. The tensile tests for unstrained aluminium were done on three identical samples. For the 3 samples of unstrained aluminium on the tensile test, the tensile modulus ranged between 17.7 and 17.9 MPa, a tensile load at maximum stress of 5.13 kN, with a maximum tensile stress value of 208.3 Mpa. Figure 3 shows the tensile stress-strain curves for the as cast 3 aluminium A6063 specimens. Tensile test properties for commercial aluminium A6063, for the three specimens are shown in Table 2. The tensile tests were performed at room temperature using an INSTRON 5587 machine.

Fig. 2. *Shape of the specimen before and after the tensile test, for commercially pure A6063*

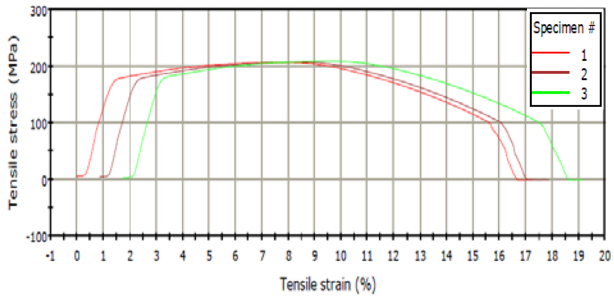

Fig. 3. *Tensile-stress-strain curves of the ‘unECAPed’ aluminium A6063*

Table 2. *Tensile properties of A6063 before ECAP*

	Modulus (E-modulus) (Mpa)	Tensile stress at Yield (Offset 0.2 %) (Mpa)	Maximum Tensile stress (Mpa)	Tensile strain at Maximum Tensile stress (%)	Load at Maximum Tensile stress (kN)
.	17,985.07538	174.55702	206.26402	7.66651	5.08030
.	17,967.28363	175.94793	206.89197	7.49984	5.09577
.	17,764.63013	179.29131	208.39804	7.70823	5.13286

3.2. Tensile test for ECAP with 4 passes samples

The samples processed by ECAP with 4 passes were prepared for tensile testing after the dimensions shown in Figure 4. The gauge length of the samples was 10mm and the diameter 6mm. The tensile test was performed at room temperature on a INSTRON 5587 testing machine.

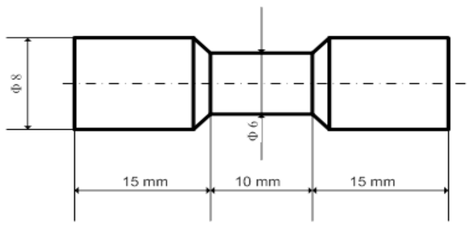

Fig. 4. *Shape and dimensions of the sub-sized specimen for tensile-test, after ECAP with 4 passes*

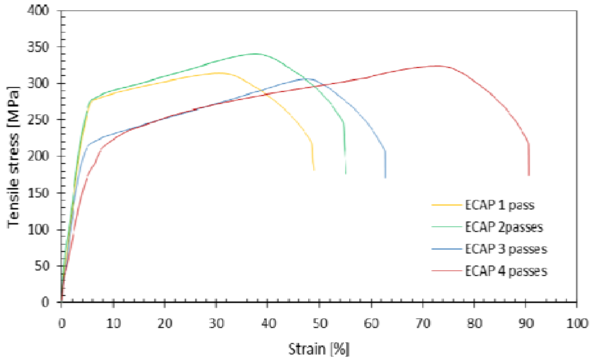

Fig. 5. *Tensile stress-strain curves for each ECAP pass sample*

Figure 5 shows the tensile stress–strain curves for all 4 samples ECAP deformed. It can be seen that for a single pass test the maximum tensile stress values are about 310 Mpa; for 2 passes test – up to 340 Mpa; for 3 passes test – Mpa, and for 4 passes – up to 325 Mpa. As can be noted, sample 4 passes shows a good ductility. The large surface area under this curve indicates increased toughness. Exact data obtained from the flow curves i.e. yield stress (YS) and ultimate tensile stress (UTS) and the amount of elongation to failure of the specimens are presented in Table 3. The severity of the deformations and the great changes in microstructure, especially increase of the dislocation density during ECAP, leads to yield stress variation.

Table 3. *Tensile properties of A6063 after ECAP*

No. of passes	Modulus (E-modulus) (Mpa)	Tensile stress at Yield (Offset 0.2 %) (Mpa)	Tensile strain at Yield (Offset 0.2 %) (%)	Maximum Tensile stress (Mpa)	Tensile strain at Maximum Tensile stress (%)	Load at Maximum Tensile stress (kN)	Extension at Maximum Tensile stress (mm)
1.	5,493.42232	4.01729	221.46871	309.26648	35.50053	8.74430	3.55005
2.	8,191.28113	1.09677	87.72919	340.70322	46.00039	9.63316	4.60004
3.	5,330.35812	3.24727	170.39000	305.86899	60.66541	8.64824	6.06654
4.	4,865.61012	2.78889	162.82942	324.18668	43.27778	9.16616	4.32778

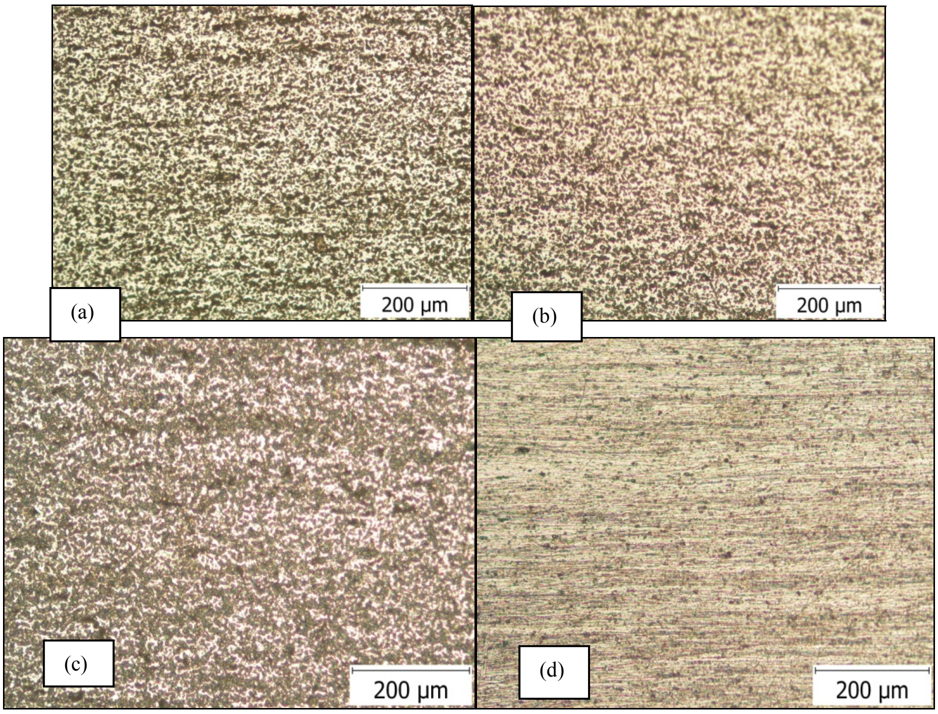

Fig. 6. *Optical microscopy images of the aluminium surface after ECAP processing (200x) for: (a) 1 pass, (b) 2 passes, (c) 3 passes, (d) 4 passes*

Optical microscopy was used to study A6063 aluminium sample surface after ECAP 4 with passes deformation. The samples were polished on a Buehler grinding machine with grinding paper with size 800 and 1000. Figure 6 presents optical microscope images of the ECAP deformed samples. In fig. 6 (d) the appearance of the shear bands after severe plastic deformation can be noted.

4. CONCLUSIONS

Severe plastic deformation of A6063 aluminium alloy with 4 passes of ECAP at room temperature generated short shear bands within the microstructure.

Significant increases in yield stress of the deformed material can be attributed to the increase in dislocation density and their interaction with one another.

The increase of the ECAP number of passes up to 4 passes increases the yield stress and the yield strain.

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