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THE EFFECT OF DEFORMATION ROUTE IN EQUAL CHANNEL ANGULAR PRESSING ON MECHANICAL PROPERTIES OF ALUMINUM ALLOY 1050

WPŁYW DROGI ODKSZTAŁCENIA PLASTYCZNEGO W PROCESIE ECAP (EQUAL CHANNEL ANGULAR PRESSING) NA WŁAŚCIWOŚCI MECHANICZNE STOPU ALUMINIUM Z SERII 1050

A b s t r a c t

Annealed samples of commercial purity aluminium (1050) were processed by Equal Channel Angular Pressing (ECAP) at room temperature for up to eight passes. ECAP was conducted by using three processing routes (schemes). Tensile tests and micro hardness were conducted to evaluate variation of mechanical properties after each pass. Analysis of fractography was carried out due to investigate a fracture of the samples. The results showed that all the schemes had similar micro hardness values – around 50 HV. The tensile test results showed that the highest yield strength was achieved in the second scheme after eight passes – 186 MPa – while elongation maintained at the level of 17.4%. The value of yield strength achieved increased more than six times in proportion to annealed condition.

Keywords: aluminium, severe plastic deformation, equal channel angular pressing, mechanical properties

S t r e s z c z e n i e

Wyżarzone próbki, wykonane ze stopu aluminium AA1050, poddano procesowi przeciskania przez kanał kątowy (Equal Channel Angular Pressing – ECAP) w temperaturze pokojowej. Próbki przeciskano w ośmiu cyklach według trzech dróg odkształcania. W celu oceny zmian właściwości mechanicznych przeprowadzono statyczną próbę rozciągania oraz pomiar mikrotwardości. Wykonano również analizę fraktograficzną w celu obserwacji przełomów próbek. Otrzymane wyniki mikrotwardości we wszystkich schematach wykazywały zbliżone wartości – na poziomie 50 HV. Statyczna próba rozciągania wykazała, że najwyższa granica plastyczności $R_{p0,2}$ została osiągnięta dla próbki przeciskanej według II drogi odkształcenia po ósmym cyklu i wyniosła 186 MPa przy wydłużeniu równym 17,4%. Uzyskana wartość granicy plastyczności wykazuje ponad sześciokrotny wzrost w stosunku do stanu wyżarzonego.

Słowa kluczowe: aluminium, techniki intensywnych odkształceń plastycznych, przeciskanie przez kanał kątowy, właściwości mechaniczne

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1. Introduction

The dynamic development of industry leads to an increased demand for new types of materials, which are characterized by high strength properties while maintaining relatively good plastic properties. According to the dependence of Hall-Petch, the refinement of microstructure is the only known mechanism to achieve high strength and good ductility [1, 2]. Traditional techniques refinement of microstructures such as thermomechanical processes allow a grain size of about 2, 3 μm to be obtained. However, intensive plastic deformation techniques (Severe Plastic Deformation – SPD) are methods for obtaining submicron or nano-size [3, 4]. In these methods plastic deformation is used in order to create a cell dislocation substructure [5, 6]. A major advantage in SPD is that the material cross section is unchanged during pressing. There are wide severe plastic deformation techniques. The most popular include: Equal Channel Angular Pressing (ECAP), High Press Torsion (HPT), Accumulative Roll Bonding (ARB), and Cyclic Extrusion Compression (CEC) [7–12]. ECAP is processing. ECAP is a technique whereby an intense plastic strain is imposed by pressing a sample in a special die. The die consists of two channels with a square or circular cross-section and bend radius usually of 90°.

The aim of this study is to analyse the influence of road plastic deformation in the ECAP process on the mechanical properties of aluminium alloy of series AA1050.

2. Experimental procedure

Commercial purity aluminium (AA 1050) was used in this study. The chemical composition of the alloy was performed on a Bruker Q4TASMAN spectrometer and the result is shown in table 2.1. The content of the elements correspond to the chemical composition of the AA 1050 alloy according to PN – EN 573-3:1998.

Table 1

Comparison of the chemical composition of the aluminum alloy AA1050 Series PN – EN 573-3:1998 and test material.

	Chemical composition [wt.%]							
	Al	Fe	Si	Cu	Mn	Mg	Zn	Ti
AA 1050	99.54	0.304	0.066	0.004	<0.002	0.008	0.005	0.008
AA 1050 PN –EN 573-3:1998	≥99.50	≤0.40	≤0.25	≤0.05	≤0.05	≤0.05	≤0.07	≤0.05

Material for the study was provided in the form of a cold drawn bar with a cross section 40 × 10 mm, from which were cut longitudinal samples of 55 × 10 × 10 mm dimensions.

Prior to the process of pressing the sample was annealed at 500 ° C for 8 h and then cooled in a furnace. The annealed samples were lubricated using a graphite based lubricant and pressed in a square channel ECAP die with dimensions 10 × 10 mm. The applied die was characterized by internal angle $\phi = 90°$ and the angle of the external $\psi = 20°$. A view of the die with marked angles is shown in Fig. 1b. The ECAP process was performed using hydraulic testing machine, EU 20.

The samples were pressed by three schemes:

- Scheme I – The samples were pressed without rotation – the sample was pushed next sample,
- Scheme II – The samples were rotated after each cycle of alternating forward – backward. The bending process always occurred on the same surface – the sample was pushed next sample,
- Scheme III – The samples were pressed as in Scheme I, after each passed die was revs up and the sample was pulled out.

The samples were processed to 1 up to 8 passes. The micro-hardness was determined under load of 5N in an Innovatest 400 Series 423a Vickers micro-hardness meter. The tensile test was performed at room temperature on an MTS Criterion Model 43 hydraulic testing machine.

Tensile samples with gauge dimensions of 14 × 3 × 5 mm were machined from the ECAP samples and their tensile axes were paralleled to the pressing direction. The fracture surface of the tensile testing samples were conducted using a scanning electron microscope (SEM) Joel JSM5510LV.

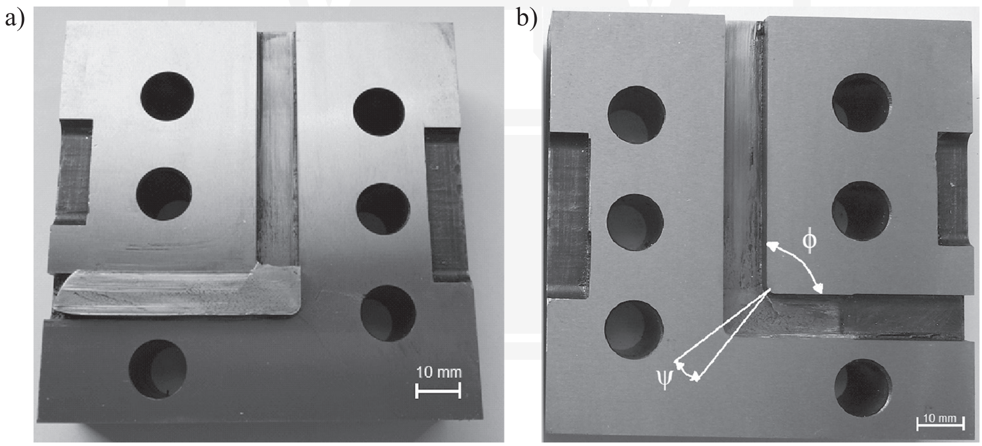

Fig. 1. A picture of ECAP die used in this study: a) die with sample, b) characteristic angles

3. Results

The micro hardness was measured on the cross section on the samples deformed by routes I and II. Measuring points were located at distances of 1 mm. On the samples deformed by route III the measurement was made on lateral surface at points which were located at distances of 3 mm.

The annealed material had a micro hardness level of about 22.5 HV, yield stress – 30 MPa and elongation – 39.8%. Fig. 2 presents a summary of the micro hardness values obtained for each pass in each routes.

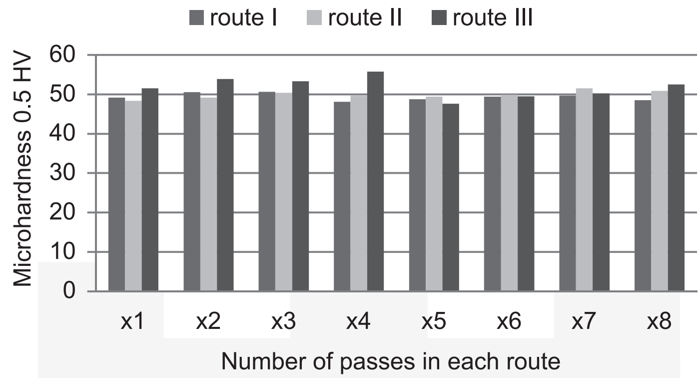

Fig. 2. Summary of micro hardness values obtained for each pass in each route

The highest increase of micro hardness was achieved in route I. The measurements were made on the lateral surface because of the limited amount of research material. This method of measurement led to an overvaluation of the micro hardness due to strong deformation of the sample surface due to the friction of the surface of the die. Comparing the samples whose micro hardness was measured on the cross section it was observed that the highest value was achieved in the sample deformed by route II after the seventh pass – about 52 HV. This value was more than double than value of the annealed sample.

Tensile tests enabled the evaluation of variation of the yield stress and the elongation. Fig. 3 and Fig 4 show respectively the summary of the yield stress values and elongation values achieved for each pass in each route.

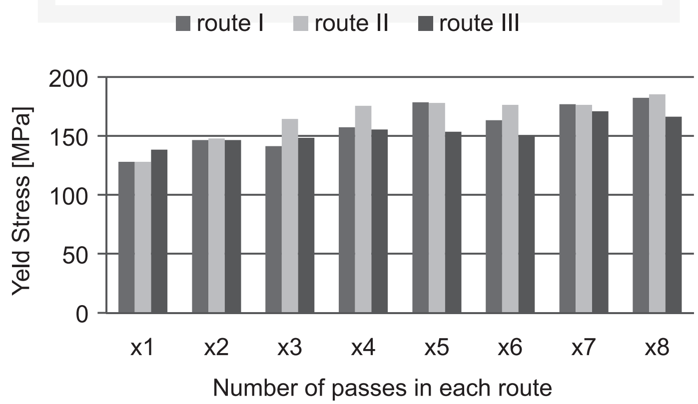

Fig. 3. Summary of achieved values of yield stress for each pass in each route

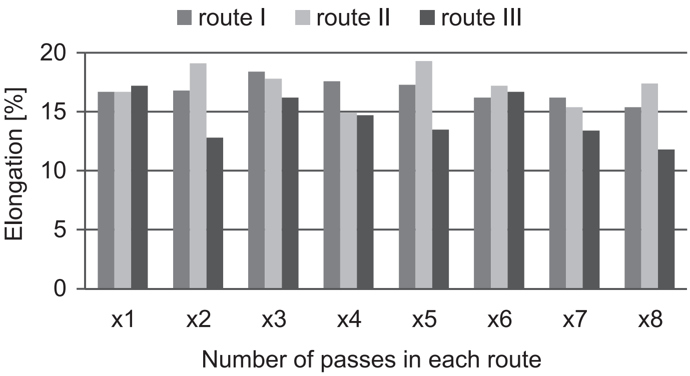

Fig. 4. Summary of values of elongation achieved for each pass in each route

The highest value of yield stress was 185 MPa. This was achieved after the eighth pass of route II. This value is six times higher than the value of the annealed sample. The lowest values of yield stress were achieved for samples deformed by route III. The greatest elongation was achieved by the sample deformed by route II after the fifth pass and this was almost 20%. The lowest recorded values for this parameter were reached by the samples deformed by route III.

Fractography showed that the fractures in all the deformed samples were ductile. There were no significant differences in the topography of fractures of particular samples. Fig. 5a and Fig 5b show example images of fractures of samples deformed by route II after the second and eighth passes.

a)
b)

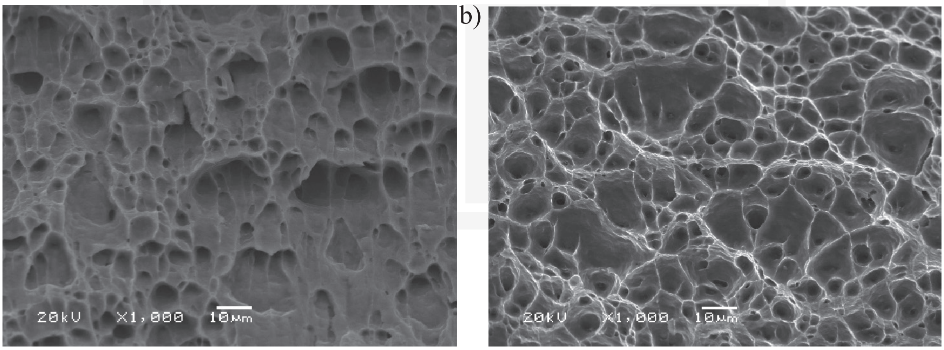

Fig. 5. Fractures of samples deformed by route II: a) after second pass, b) after eighth pass

4. Discussion

The aim of this paper was to analyse the effect of the deformation route in Equal Channel Angular Pressing (ECAP) on the mechanical properties of aluminium alloy AA 1050. An annealed material had low mechanical properties (yield stress – 30 MPa) and high formability (elongation 39.8%). After the first pass of ECAP a significant increase in yield stress and micro hardness and a decrease of plasticity were observed. There was more than a four times increase in yield stress which was 128 MPA for routes I and II and 139 MPA for route III. The formability was limited, which can be observed in the decrease of the elongation which was 19.1% for routes I and II and 17.2% for route III. Such a significant increase in yield stress and decrease in plasticity is a consequence of strong plastic deformation of the material and an increase in dislocation density. The effect of this is to strengthen the material. Subsequent passes of ECAP led to further improvement in the mechanical properties with plasticity at a similar level. This is probably caused by significant grain refinement, which can be achieved by structure fragmentation and an increase in subgrain misorientation angle [13]. The aim of SPD methods is to achieve microstructure with the largest share of high angle grain boundaries. Decrease in grain size leads to an increased volume fraction of grain boundaries. This leads to an increase in the number of barriers to the movement of dislocations. At the same time this does not limit the capability of the dislocation glide. It allows for an increase in the mechanical properties while plasticity maintains a relatively high level.

The best combination of mechanical properties was achieved in route II. The highest yield stress was reached in pass eight and amounted to 186 MPa with elongation at a level of 17.4%. The highest plasticity was also recorded in route II. This was 19.3% after fifth pass with yield stress at a level of 178 MPa. The lowest combination of mechanical properties was achieved in route III. The reason for this is probably the lower value of cumulative strain in samples which were taken apart from the die compared to the samples which were pressed through the die. The conduct of deformation in routes I and II led to stronger deformation of a sample, which is connected with higher cumulative plastic strain and higher increase in dislocation density. Higher dislocation density leads to the appearance of cellular a substructure which, due to the coalescence of subgrains, leads to an increase in misorientation angle and significant grain refinement. Numerous scientific studies confirm that an increase in deformation degree leads to an increase in subgrain misorientation angle. As a consequence significant grain refinement and the appearance of high angle grain boundaries can be observed [5, 11, 12].

Variations in micro hardness correlate with the mechanical properties obtained. The highest increase in micro hardness was recorded after the first pass. There were no significant changes in subsequent passes. The highest micro hardness was obtained for route III after the fourth pass and this amounted to 55.8 HV. The difference in the values between routes I and II is probably due to the method of measurement. The micro hardness was measured on the cross section on the samples deformed by routes I and II and on the lateral surface on the sample deformed by route III. Micro hardness analysis showed high homogeneity of microstructure on the cross section for routes I and II, which is evidenced by the relatively small spread of values.

Fractographic observations confirm high formability. For all the fractures analysed the mechanism of transcrystalline ductile fracture was observed. The results confirm the analysis of the effect of the ECAP process on the mechanical properties of aluminium alloy 1050 conducted. The specific method of conducting plastic deformation allows both high strength and ductility to be obtained. Comparing these properties with those of aluminium alloy 1050 deformed by conventional methods an increase in both strength and ductility was observed. After classic cold working the value of yield stress does not exceed 145 MPa with elongation at a level of 7%. After ECAP the obtained value of yield stress was at level of 186 MPa with elongation of 17.4%. The results obtained in this study correlate well with similar work. Changing the route of the plastic deformation has a positive effect on the mechanical properties [5, 14].

5. Conclusions

1. Mechanical properties increased with successive cycles for each scheme, while the ductility remained at a similar level.
2. The value of the yield strength $R_{p0,2}$ increased six-fold compared to the annealed for scheme I and II at an elongation of respectively 15.4% and 17.4%, after eight passes.
3. The best combination of mechanical properties were obtained for the samples deformed according to scheme II, while the worst for scheme III.
4. Changing of deformation route by rotating the sample by scheme II had a positive effect on the mechanical properties after the ECAP process.

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