Archives
of Materials Science
and Engineering

Volume 43
Issue 2
June 2010
Pages 69-76

International Scientific Journal
published monthly by the
World Academy of Materials
and Manufacturing Engineering

ECAP methods application on selected non-ferrous metals and alloys

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Received 28.02.2010; published in revised form 01.06.2010

ABSTRACT

Purpose: Paper presents results of investigations mechanical properties and microstructure samples selected nonferrous metals after ECAP. These properties and microstructure are influenced by technological factors during application ECAP method.

Design/methodology/approach: The sample bars were plastically deformed during the ECAP process. The methods of the light microscopy and the hardness test for evaluation of mechanical properties and microstructure were used.

Findings: Measurement of micro-hardness shows an increase value after application higher number of passes in agreement with ultra high fine grain occurrence. The method determines the dependencies of force on the route during the ECAP process.

Research limitations/implications: Achieved hardness and microstructure characteristics will be determined by new research.

Practical implications: The results may be utilized for a relation between structure and properties of the investigated materials in future process of manufacturing.

Originality/value: These results contribute to complex evaluation of properties new nonferrous metals after application ECAP method. The results of this paper are determined for research workers deal by the process severe plastic deformation.

Keywords: Metallic alloys; ECAP method; Mechanical properties; Microstructure

Reference to this paper should be given in the following way:

S. Rusz, L. Čížek, L.A. Dobrzański, S. Tylšar, J. Kedroň, ECAP methods application on selected non-ferrous metals and alloys, Archives of Materials Science and Engineering 43/2 (2010) 69-76.

MATERIALS

1. Introduction

In many technical processes of forming the deformation is substantially greater than conditions at the tensile test. In this case a torsion tests have already been used for a long time at investigation of strengthening behavior and development of material structure. These new activities demonstrated at the beginning of the nineties, that it is possible to manufacture nano-crystalline metallic materials by very high plastic deformation at low homological temperatures. It is possible to achieve on ductile metallic materials at the tensile test a deformation from 30% to 70%. At the torsion test it is possible to achieve on the same materials several hundreds percent. Obtaining of nano-crystalline structures requires typical magnitudes of deformation of the order from 100 to 1000%. High deformation at comparatively low homological temperatures is an efficient method for manufacture of ultrafine grained massive materials. News technologies, which use high deformation for obtaining of fine-grained structure, comprise namely the following ones [1-10]:

- High Pressure Torsion,
- Equal Channel Angle Extrusion,
- Cyclic Channel Die Compression,
- Cyclic Extrusion Compression,
- Continuous Extrusion Forming,
- Accumulative Roll Bonding,
- Constrained Groove Pressing,
- Thixoforging.

HPT – High Pressure Torsion

This method belongs to popular manners of creation of intensive plastic deformations. Effect of high pressure (several GPa) and torsion causes intensive angular deformation. This method makes it possible to obtain grains with dimensions of approx. 10 nm or even smaller.

TE - Twist Extrusion

The principle of twist extrusion consists in creation of an intensive angular deformation by extrusion of the sample of angular shape through the die with a twisted channel. The shape and cross-section of the channel does not change along the axis of extrusion. The channel is twisted alongside this axis.

ARB - Accumulative Roll Bonding

The principle of this method consist in the following: two sheets of identical thickness are rolled together. During one pass the thickness of two sheets is reduced to the thickness of one original sheet. The sheet is divided and this operation is repeated many times. The process is connected with refining of micro-structure.

Thixoforging

The methods of choice are modified chemical gram-refining procedures or (in the near future) semi-continuous DC-casting in which the structure is modified by electromagnetic stirring. The immediate advantages of using the new forming routes have been seen to lie in enhanced mechanical properties (compared to castings), which may be equivalent to forged values. Furthermore, the need to employ less material and hence less weight, and higher productivity are positive factors in the adoption of thixoforming. Parts targeted for investigation include brake cylinders and automobile road wheels.

ECAP technology

This paper deals by ECAP technology investigations that have been oriented by overall objectives of acquiring new knowledge concerning deformation resistances, stress condition impacts, structure and properties of non-ferrous metals, namely Mg-Zr light metal alloy.

ECAP is realised by angular deformation. The die consists of two channels of equal section, which intersect and form e.g. right angle (see Fig. 1). Angular deformation occurs at the die during extrusion of material through it. This procedure may be repeated in order to obtain more intensive plastic deformation and finer grain.

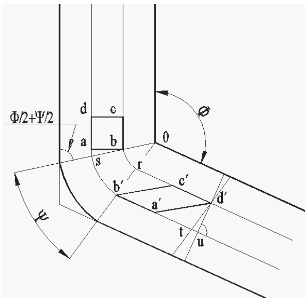

Fig. 1. Principle of ECAP, where Φ is the angle of transition of two channels and Ψ curvature of transition

The principle of the ECAP (Equal Channel Angular Pressed) technology has been known since the nineties of the past century. Nevertheless concrete utilisations of this technology for nanostructure material developments have been rather rare. This paper informs on ECAP technology investigations that have been oriented by overall objectives of acquiring new knowledge concerning deformation resistances, stress condition impacts, and physical/ technological conditions as decisive factors of material formability processes that provide for nano-sized grain structures of very high plasticity, and very good mechanical properties.

The ECAP technology provides for large volume ultra-fine grain structures at which point the extrusion does not reduce original cross section profiles. Especially automobile, military, and space industries are principal beneficiaries of this technology. The investigation principal goal consisted in analysing of the ECAP technology mathematical modelling concerning alloy sample extruded by passing through channel. Application of modelling of ECAP technology on steels and non-ferrous metals and alloys is often described by many authors [5-11]. As example of results of ECAP method modelling Fig. 2 shows development of magnitudes of strain intensity for used aluminium AlMn1Cu alloy [11].

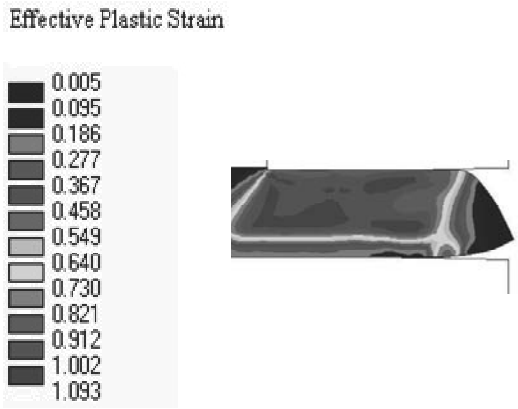

Fig. 2. Developments of strain intensity for channel radii R_1 = 5.5 mm, R2 = 0.2 mm for AlMn1Cu alloy [11]

2. Experimental methods and materials

This paper informs namely on ECAP technology investigations that have been oriented by overall objectives of acquiring new knowledge concerning deformation resistances, stress condition impacts, structure and properties of selected light metals and its alloys. The principle of the forming tool for development of ultra fine-grained materials is described.

A tool with the geometry given in bracket (R1 = 4 mm, R2 = 0.5 mm, Ψ = 90˚, Φ = 90˚, a = 45 mm and b = 10 mm) was used (see Fig. 1). Innovation of base tool with channel deflections by 10° - 30° and addition of screw sections on horizontal part is described in work [12] (see Fig. 3). The parameter b was extended to 15 mm. The working site of development of new technologies has at its disposal a hydraulic press of the type DP 1600 kN. The tool frame heating of samples made possible. Entire arrangement of tool shows Fig. 4. Channel deflection by 20° in the case of Al and 10° in the case of Mg-Zr was used.

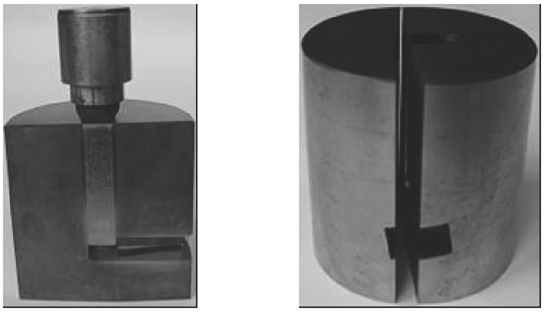

Fig. 3. Tool for ECAP method application screw sections on horizontal part

Fig. 4. Entire arrangement of tool

Technical pure aluminum (99%) and Mg-Zr alloy as cast state [13] were used. Chemical composition of the Mg-Zr alloy is given in Table 1.

Processing in the case of Al was realized at ambient temperature and within the range 200°C to 320°C in the case of Mg-Zr alloy [12]. Selected macro photography of samples after processing is showed in Fig. 5. For this alloy the optimal temperature of processing 220°C was found. At the temperature below 220°C the sample after processing was failure (see Fig. 5b). At more passes than 3 processing was partially successful at higher temperature and study of that processes will continued. The 4th pass at temperature 320°C was realized.

Table 1.
Chemical composition of the Mg-Zr alloy

Alloy	Zr	Al	Zn	Mg
Mg-Zr	0.07	0.07	0.01	rest

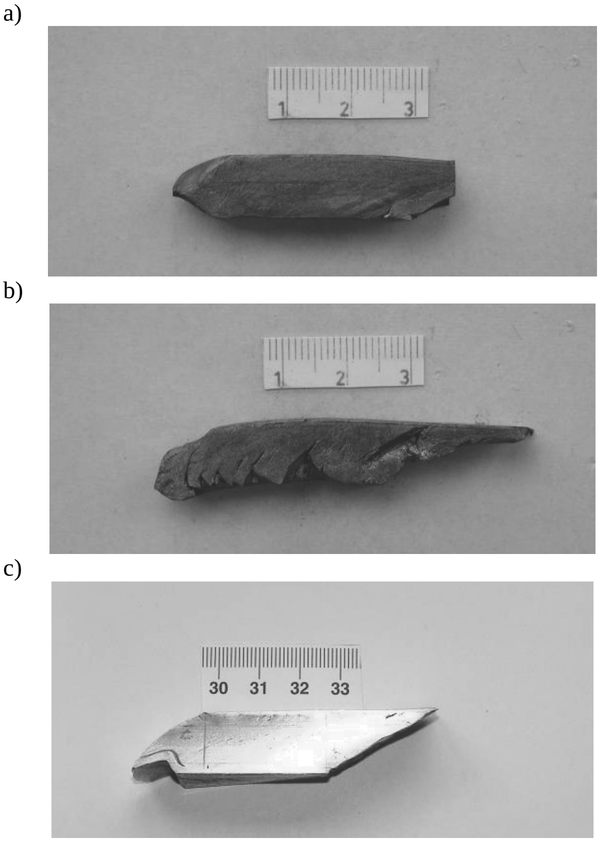

Fig. 5. Example of samples Mg-Zr after processing at a) 270°C - 3rd pass, b) 200°C - 1st pass and sample Al at c) ambient temperature - 5th pass

2.1. Measurement of passes strengthening

Examples obtained strengthening curves of used light metals and its alloys in choice passes are shown in the Figures 6-10. The tensometric method with computer processing was used [12].

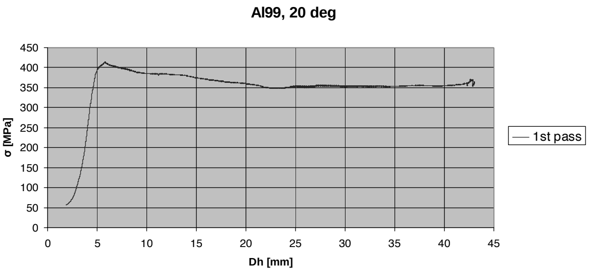

Fig. 6. Example of obtained curve of strengthening - 1st pass Al

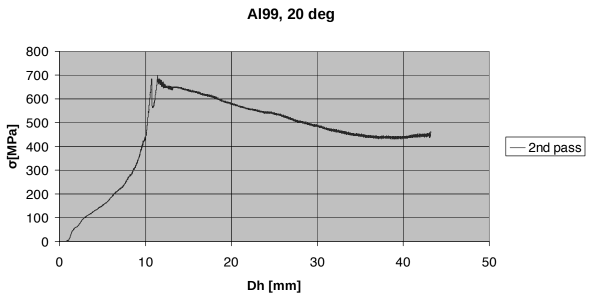

Fig. 7. Example of obtained curve of strengthening - 2nd pass Al

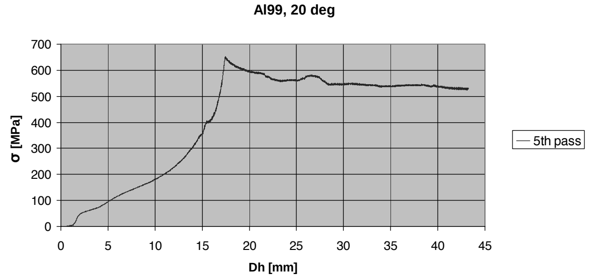

Fig. 8. Example of obtained curve of strengthening - 5th pass Al

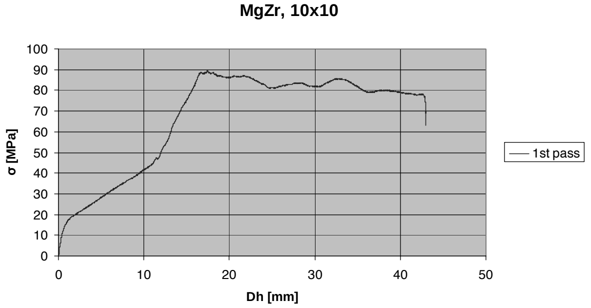

Fig. 9. Example of obtained curve of strengthening 1st pass Mg-Zr (temperature of processing 220°C)

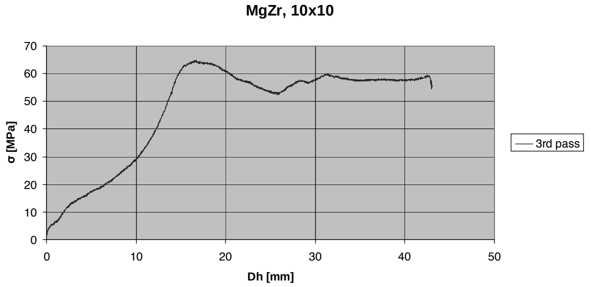

Fig. 10. Example of obtained curve of strengthening - 3rd pass for Mg-Zr (temperature of processing 220°C)

2.2. Measurement of hardness

The extruded samples of Al after all passes was then cute into individual series for manufacture of individual testing specimens for metallographic evaluation and mechanical tests in parallel and upright direction oriented to deformation.

Mechanical properties of studied samples by Vickers hardness method were tested. Results of Vickers hardness method are showed in Figure 11 in the case of Al and in Table 2 in the case of Mg-Zr alloy.

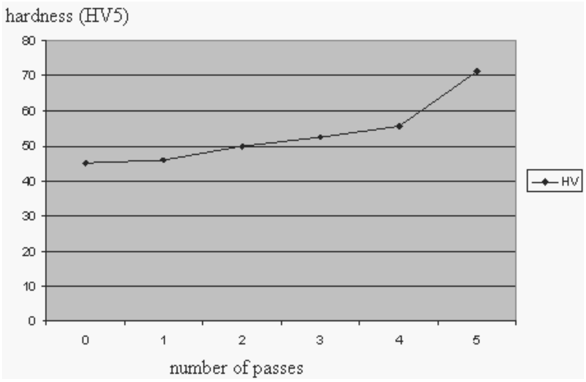

Fig. 11. Influence of number of passes on hardness HV5 for Al

Table 2.
Hardness of the Mg-Zr alloy

No of pass	Initial state	1st pass	2nd pass	3rd pass	4st pass
HV5	27	36	35	35	33

2.3. Metallographic analysis

Metallographic evaluation was made with use of the light microscopy Neophot 2. For metallographic analyses a series of samples after passes were prepared. After usual metallographic preparation the samples of alloy Mg-Zr were chemically etched in Nital and samples of aluminium were electrolytically etched in solution HBF4 under following conditions: 22V/2/45s. From the reason strongly deformed samples microstructure of that were difficult observed and method of polarizing light was used.

Microstructure of the used alloys in initial state is shown in Figures 12 and 13. Microstructure of the samples after ECAP processing is shown in Figures 14-26.

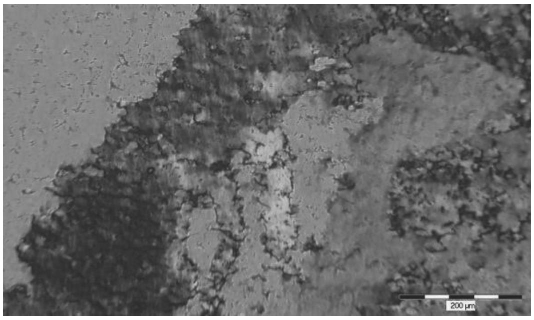

Fig. 12. Al microstructure - initial state

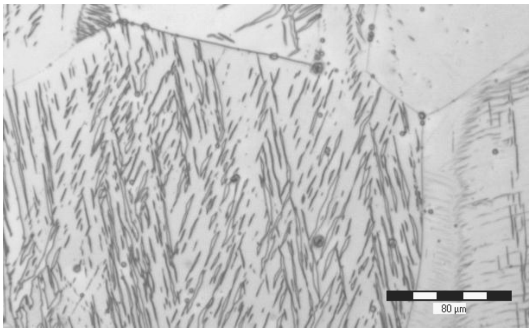

Fig. 13. Microstructure of the alloy Mg-Zr in initial state

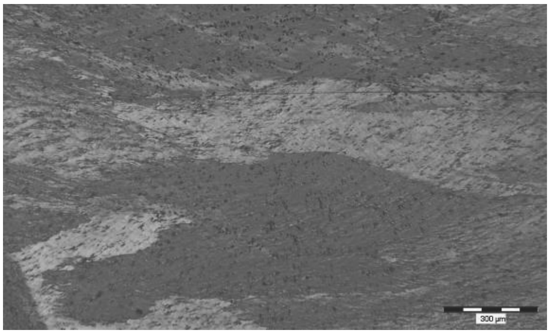

Fig. 14. Al microstructure after the 1st pass (parallel cut)

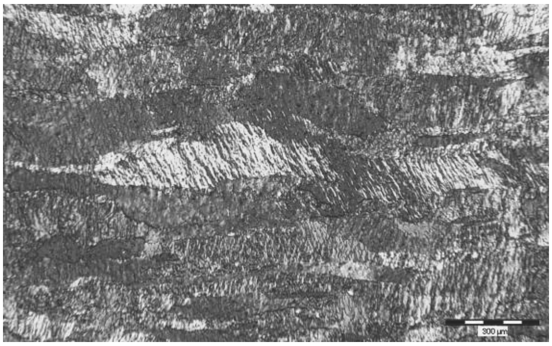

Fig. 15. Al microstructure after the 1st pass (upright cut)

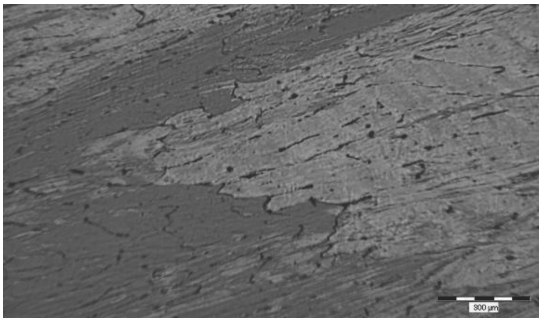

Fig. 16. Al microstructure after the 2nd pass (parallel cut)

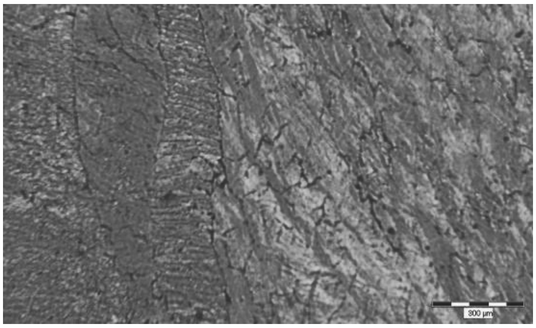

Fig. 17. Al microstructure after the 2nd pass (upright cut)

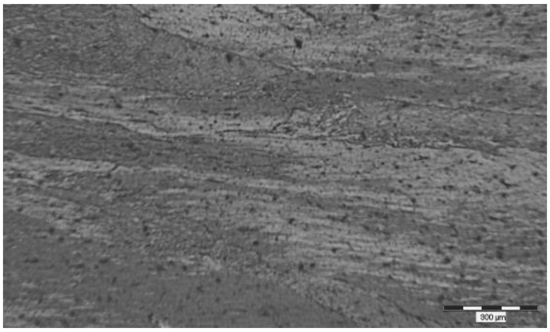

Fig. 18. Al microstructure after the 4st pass (parallel cut)

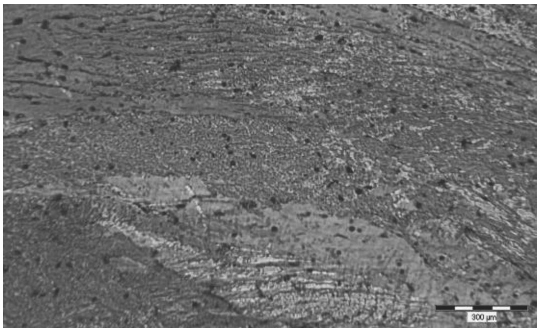

Fig. 19. Al microstructure after the 4st pass (upright cut)

Fig. 20. Al microstructure after the 5th pass (parallel cut)

Fig. 21. Al microstructure after the 5th pass (upright cut)

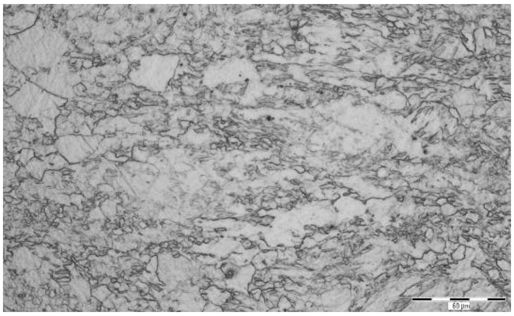

Fig. 22. Microstructure of the alloy Mg-Zr after the 1st pass (parallel cut)

Fig. 23. Microstructure of the alloy Mg-Zr after the 1st pass (upright cut)

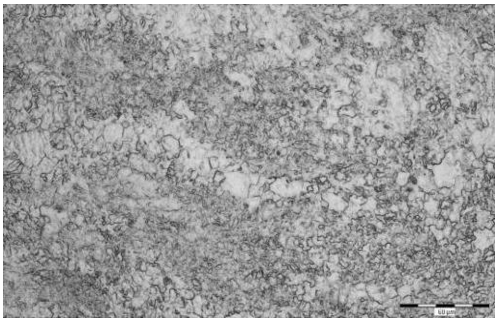

Fig. 24. Microstructure of the alloy Mg-Zr after the 3rd pass (parallel cut)

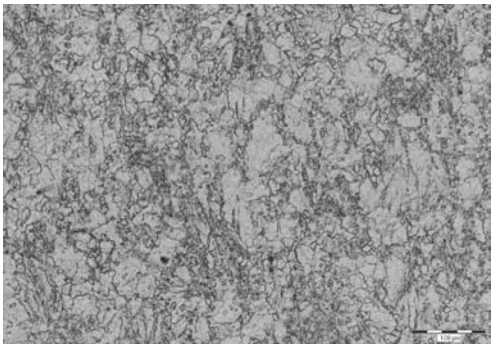

Fig. 25. Microstructure of the alloy Mg-Zr after the 3rd pass (upright cut)

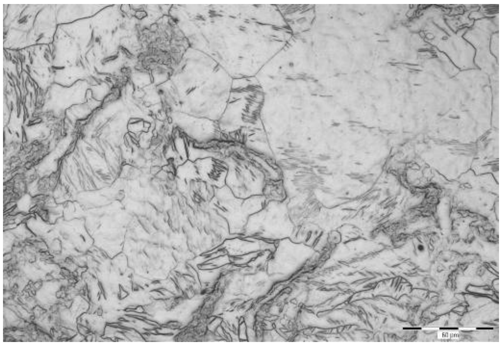

Fig. 26. Microstructure of the alloy Mg-Zr after the 4th pass (parallel cut)

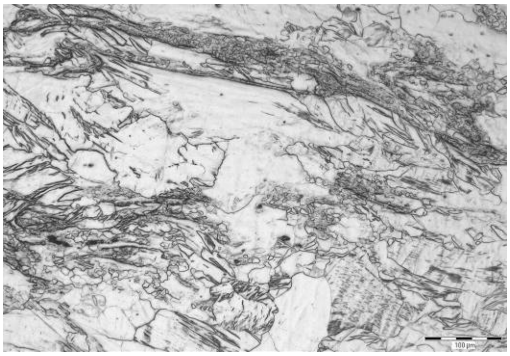

Fig. 27. Microstructure of the alloy Mg-Zr after the 4th pass (upright cut)

3. Description of achieved results

3.1. Evaluation of passes strengthening

As it is seen from Figures 6, 7 and 8 for aluminium the maximum value of strengthening at the 1st pass reached 400 MPa and slightly reduce to 350 MPa passing through the channel. At the 2nd pass this value increase on 700 MPa and reduce to

420 MPa passing through the channel. At the 5th pass reached the maximum approximately same level as in the 2nd pass, but reduce to 520 MPa passing through the channel.

In the case of Mg-Zr alloy the maximum value of strengthening is much lower than in case aluminium and the reduce show minimum value passing through the channel in both cases of passes. Value of strengthening in the 1st pass is higher than in the 3rd pass.

Results of Vickers hardness method for Mg-Zr alloy are showed in Table 2. Average values of hardness from five measurements were calculated.

3.2. Evaluation of hardness

Average values of hardness in this picture from five measurements were calculated. Examples of obtained curves of strengthening in choice passes are shown in the Figure 11 in the case of Al and in Table 2 in the case of Mg-Zr alloy. These values in both cuts do not showed any differences.

These values slightly increase from 1st to 4th passes. After fifth pass this value increase more rapidly and reached up 70 HV5 in the case of Al.

In the case of Mg-Zr alloy these values slightly increase in 1st pass and after 2nd pass stay nearly the same. Hardness encreasing after the 4th pass by higher temperature at processing was affected.

3.3. Metallographic analysis

Microstructure of initial state samples Al and Mg-Zr alloy is shown on the Figures 12 and 13. This microstructure consists from large grains in agreement with fact that materials were used as cast state [13-16].

The microstructure of samples after channel passing on surface parallel with direction of passing and perpendicular to direction of passing (upright cut) is shown in Figures 14 - 27.

Metallographic evaluations both of materials have also confirmed more intensive refining of grains after each pass as is namely seen on Figures of the last passes.

In the case of aluminium the grains of samples parallel with direction of passing after channel passing are uniformly elongated up to the 4st pass and microstructure perpendicular to direction of passing after channel passing shows higher density of slip bands than on surface parallel with direction of passing.

In the case of Mg-Zr this difference is not occurred and after the 3rd pass the microstructure shows more fine grain. The grain size increasing after the 4th pass by higher temperature at processing was affected.

4. Conclusions

- In the case of Al the influence of the changed design of the ECAP tool was unequivocally confirmed. The route of deformation is changed and it therefore brings about substantial increase of the deformation intensity, namely at the 4th and 5th passes through the tool. Process of multiple plastic deformations is thus much more efficient. Metallographic evaluations have also confirmed more intensive refining of grains already after the first pass.
- On the basis of obtained results it is possible to draw the following conclusions:
- The ECAP process on Mg-Zr alloy was the first time applied on new developed die and the bottom channel of the tool was deflected by 10° and slightly expanded in its output part.
- Microstructure of initial state of the Mg-Zr alloy is formed by large polyedric grains of Mg based solid solution with dimensions in the range of 100 – 500 μm.
- The influence of the changed design of the ECAP tool was unequivocally confirmed.
- Maximum value of strengthening is reached at the 1st pass. At the 2nd pass this value decrease and continue to the 4th pass approximately on the same level.
- Metallographic evaluations microstructures of the Mg-Zr alloy have also confirmed more intensive refining of grains already after the 1st pass.
- For reaching the better results on Mg-Zr alloy more experiments at variable conditions will be applied.

Acknowledgements

The work was financed by aim of GAČR of the Czech Republic GA-101/08/1110 and sponsored of project MSM 6198910015.

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