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Superplastic properties of magnesium alloys

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ABSTRACT

Purpose: The paper summarises results of experiments aimed at development of structure of modified Mg-Al-Zn alloys at hot deformation.
Design/methodology/approach: Methods ARB and ECAP were used in the described experiment. It was proved that hardly forming materials could achieve very high plastics properties.
Findings: After making plastics deformation, the using materials of alloys AZ61 and AZ91 analysed superplastics behaviour, it was certified by obtaining results, when ductility to rupture of alloy AZ91 was 418 %, it is demostrated at conclusion of the article.
Research limitations/implications: The experiment proved big influence of previous plastics deformation to ending values of mechanical properties. It was verified that better results are at rolling in more steps compared to rolling in one pass.
Practical implications: The low submission temperature at last pass through die it causes obtaining higher final properties.
Originality/value: It was obtained the material about grain size d ≈ 0,7μm during using the technology of ECAP. Abreast of it the technology ARB enabled to get material of grain size in interval d ≈ 1-10 μm. The sekond technology brings higher strength properties. Only 3 cycles were sufficient to lower original grain size under limit 10 μm
Keywords: Mlastic forming; Superplasticity; Magnesium alloys; ECAP

1. Introduction

Ratio of exploitation of magnesium based materials very rapidly increases at present. This is given not by its service properties, but also by its very low mass and also certain possibility of its use as replacement of Al based materials [1-3]. Production of final products made of Mg alloys is, however, accompanied by many factors, which must be mastered for its successful implementation into practice [4]. These issues comprise among others the problems related to forming of these alloys, i.e. the problems ensuing for their crystallographic substance, such as small number of slip planes or occurrence of inter-metallic phases, which deteriorate formability [5]. Partial contribution to solution of these problems, apart from metallurgical modifications, consists also in unconventional methods of forming based on SPD processes, which can be a certain variant of elimination of some of existing drawbacks of classical forming processes [6,7].

2. Experimental methods

Forming of Mg-Al-Zn alloys mentioned above (namely AZ91 after T4) was realised by conventional way, i.e. by rolling, Fig. 1. There were, nevertheless, used tow different ways of rolling in order to enable determination of differences of different approach at deformations as such. These rolled products were in the next stage subjected to the technology of Equal Channel Angular

Pressing (ECAP) [8]. Materials processed in this manner were subjected to a hot tensile test for determination of the obtained mechanical values.

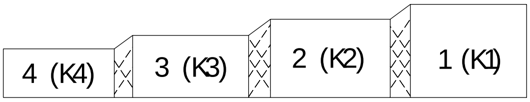

Fig. 1. Shape of samples prior to rolling

Another SPD method that was used was the ARB technology, which was applied on alloys AZ91+T4, AZ61+T4. Table 1 gives their chemical composition.

Table 1.
Chemical composition of AZ61 and AZ91

Alloy	Chemical composition %						
	Al	Zn	Mn	Si	Cu	Fe	Mg
AZ91	8.95	0.76	0.21	0.04	0.002	0.008	Bal.
AZ61	5,92	0,49	0,15	0,04	0,003	0,007	Bal.

2.1. Conventional rolling and ECAP

Materials made of the alloy AZ 91 (Fig.2) and AZ 91+T4 (Fig. 3), which were first rolled by:

a) single pass,
b) 3 passes with intermediate heating to rolling temperature (fig. 4)

and then pressed, were subjected to hot tensile test in order to determinate a possibility of super-plastic behaviour. Equal channel angular pressing was made in two stages.

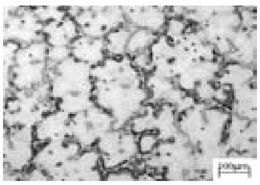

Fig. 2. AZ91 alloy without T4

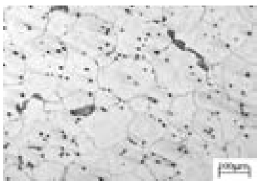

Fig. 3. AZ91 alloy after T4

The first stage consisted of 4 passes at the temperature 250°C. It was followed by the second stage consisting of 1 pass ECAP at the temperature 180°C (Fig. 5).

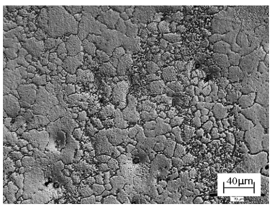

Fig. 4. AZ91+T4 after rolling (3rd pass)

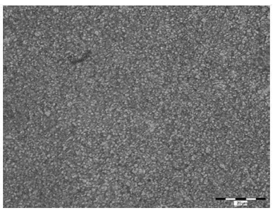

Fig. 5. AZ91 + T4 after rolling and ECAP

The samples were similarly as in the previous cases re-heated to the chosen forming temperature in a muffle furnace with connected inert atmosphere Ar_2. After obtaining of the required temperature and a 5-minute dwell at this temperature the material was charged into thermally insulated matrix with resistance heating, the temperature of which was identical to that of the chosen forming temperature [9].

2.2. Hot Tensile test

Temperature used at the tensile test was 250 °C and strain rate was $\dot{e} = 2x10^{-4}$. The samples obtained after processing by ECAP technology were adjusted to the required shape and then subjected to the tensile test (Fig. 6), during which the set temperature was controlled by PID regulator, which used a thermo-couple situated directly on the tested sample.

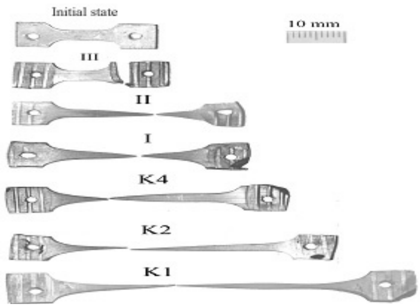

Fig. 6. Samples of AZ91+T4 alloy after ECAP and hot tensile test

Material rolled first by single pass (I, II, III) and then pressed, achieved elongation of approx. 200 %, while materials first rolled by several passes and then pressed, achieved elongation of up to 413 % [10]. Before the tensile test microstructures of both groups did not differ significantly from each other.

Table 2 gives obtained values of elongation in individual samples after hot tensile test, where there are apparent the differences mentioned above between various methods of rolling applied prior to application of the ECAP technology, which has important influence on final plastic properties of obtained materials. An increase of plasticity with growing applied deformation can be observed at rolling by both methods, i.e. at rolling by single pass and rolling by several passes. In the latter case the obtained ductility was higher, which was probably caused by more homogenous structure obtained byre-crystallisation processes, which at this type of rolling could have developed more than at single-pass rolling.

Table 2.
Values of strength and elongation of AZ 91 alloy +T4 after ECAP

Marking of sample	AZ 91 + T4	
	Elongation [%]	UTS [MPa]
I	294	15
II	286	19
III	-	-
K1	418	28
K2	384	32
K4	358	58.7

Saple taken from the alloy AZ 91 elongated at the temperature of 250°C under constantly applied strain around the value of 15 MPa to rupture, as it is demonstrated in Fig. 7

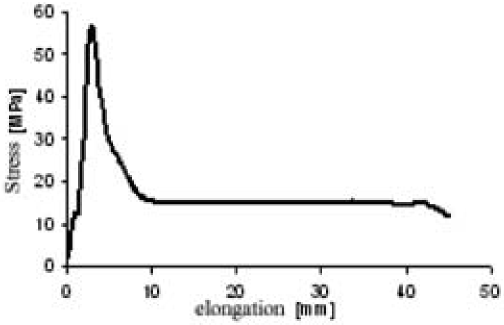

Fig. 7. Diagram of ECAPed AZ91 alloy after hot tensile test

2.3. ARB Process

For experimental verification of the ARB process there were produced two strips from the alloys AZ91+T4, AZ61+T4, which served as initial material. Initial dimensions of each strip were the following: thickness 4 mm, width 50 mm and length 200 mm. Experiment was made at the temperature of 380°C [11]. The heat distortion temperature for this technology was chosen also with respect to the results of previous experiment, at which gradual samples were rolled. The samples were rolled at the first pass by deformation of 62.5% in direction of height. In all other passes by 50% height deformation. Strain rate varied in the interval from 16.83 to 17.78 s^{-1}.

At several places marked by an arrow there are visible traces of original boundaries of individual rolled layers, which have mostly disappeared. This was observed both for the alloy AZ91 and the alloy AZ61. Number of visible places of original boundaries decreased with increasing number of accomplished cycles.

As it is demonstrated by the enclosed photos, there can be seen evident traces of crystallisation (Figs. 8, 9), which refined the structure already after 3 cycles almost 20x, if we take into consideration the original structure with average size of 120 μm (Fig. 3.).

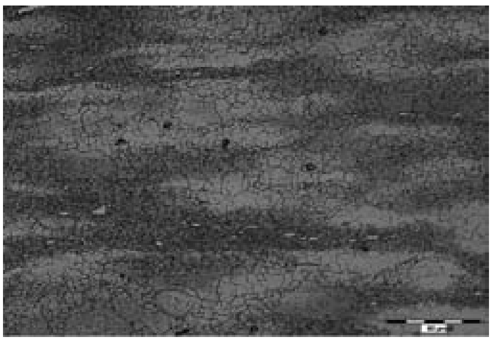

Fig. 8. Final microstructure of of AZ61 after 3rd pass at ARB process

Micro-structure of rolled materials indicates formation of new grains inside the original grains, elongated in direction of rolling. Central parts of the rolled product are represented by fine-grain structure more than surface parts. The original boundaries disappeared at many places and new grains began to form at their place.

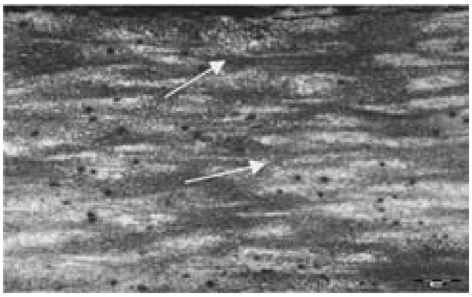

Fig. 9. Final microstructure AZ91 after 5th pass at ARB process

High efficiency of this process is demonstrated also in the Fig. 10, which shows growth of strength of the alloy AZ91 in dependence on number of realised cycles in relation to the original non-deformed state. The values of strength increased more than 2.5 times after five accomplished cycles [12].

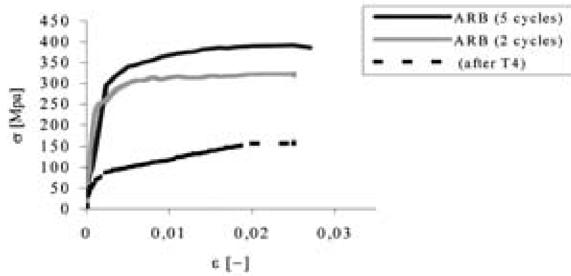

Fig. 10. Mechanical properties of AZ91 at the temperature 360°C

The figures 11 and 12 demonstrate that interposed deformation at the ARB process sufficed already after the 3rd cycle for decreasing of the grain size from the original size down under 10 μm in both types of alloys.

Comparison of obtained strength in individual types of alloys after application of various forming technologies is shown in Fig. 13. It is evident, that the best method for obtaining the highest values of strength is the ARB process, however, this is achieved at the expense of plastic properties. Contrary to that the ECAP technology is an optimum compromise.

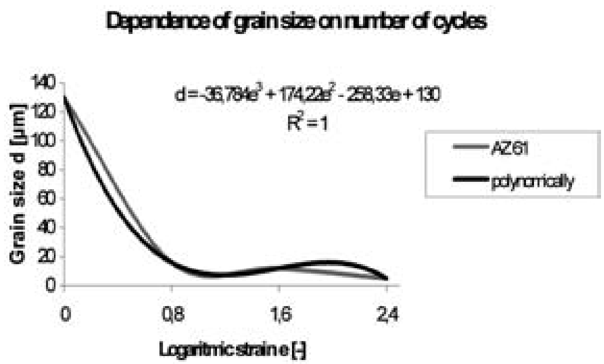

Fig. 11. Grain size on logarithmic strain dependence of AZ91 alloy at ARB process

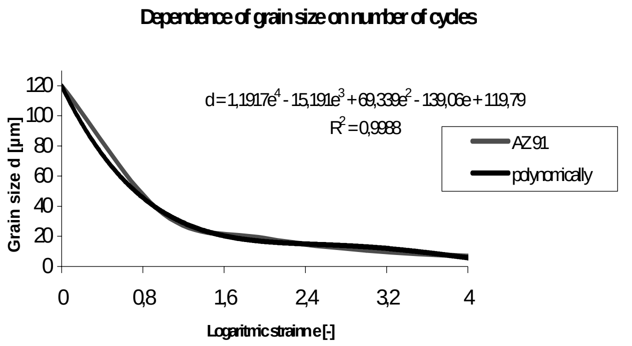

Fig. 12. Grain size on logarithmic strain dependence of AZ61 alloy at the ARB process

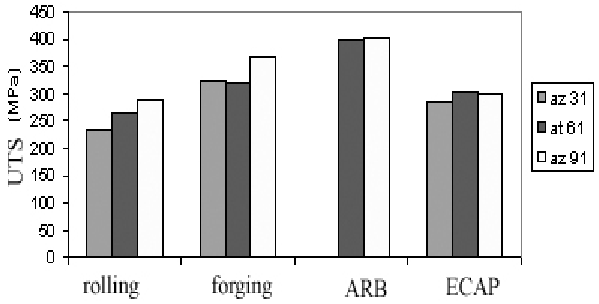

Fig. 13. UTS of Mg alloys at different technologies [8]

3. Conclusions

It is evident from micro-structures and mechanical tests that at high temperatures big elongation and lower strength are achieved after ECAP in comparison with conventional methods of forming, which is caused probably by the following factors:

1) There occurred disintegration of original precipitates to small particles, which facilitated movement of dislocations (e.g. by transversal slip), resulting in recovery of microstructure.
2) Comparatively small grain size, which enables slip deformation mechanism at the grain boundaries.

It means that during plastic deformation realised by the ECAP technology there occurred disintegration of staminate precipitates. There is also obvious occurrence of precipitates in the form of formations, the size of which exceeded 10 µm, but only in materials that were rolled by single pass. In materials rolled by several passes the distribution of precipitates is comparatively homogenous, with decreasing magnitude of deformation there is visible a growing proportion of longer staminate formations, which did not disintegrate into these smaller particles, which indicates also influence of magnitude of previous deformation at rolling. It was therefore proved that the used ARB technology is a perspective tool for obtaining of highly fine-grain structures in Mg-Al alloys. It contributes at the same time to homogenisation of micro-structure and to substantial limitation of negative consequences of dendritic segregation on mechanical properties of these alloys.

Acknowledgements

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