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Simulation and practical verification of ECAP of magnesium alloy AZ91

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Analysis and modelling

ABSTRACT

Purpose: Equal channel angular pressing (ECAP) technique, which involves a simple large shear deformation during passage through two intersecting channels, was applied to the AZ91 Mg alloy to obtain an ultrafine-grained microstructure.
Design/methodology/approach: For the stress and strain intensity investigation, there was used computer simulation.
Findings: ECAP temperature was controlled to decrease with pass number for obtaining finer grains. Four pressings were conducted at 250°C, while the fifth pressing was conducted at 180°C. The degree of grain refinement and homogeneity of grain-size distribution increased with pass number.
Practical implications: FEM simulation was examined on AZ 91 alloy by practical tests. Head reason for make this simulations is the possibility of exersise in praxe.
Originality/value: The experimental result agreed well with that obtained from numerical analyses carried out based on the finite element method (FEM). This results can be used in next development of SPD methods.
Keywords: Numerical techniques; ECAP; FEM simulation; Microstructure

1. Introduction

High plastic deformation is obtained at use of ECAP technique by extrusion of the sample through a die with different angle between planes of deformation channel [1-7]. Technique of equal channel angular pressing was simulated by the program Forge 2005 based on MKP with use of matrices with two different angles between individual channels, namely 90° and 105°.

2. Computer simulation in the program Forge 2005

Deformation temperature was in both cases 250°C. There was, however, taken into consideration also potential heat transfer between the sample and matrix as it can be seen on simulation. Later on it was confirmed that true temperature at deformation achieved in samples even 270°C, which can be explained as result of deformation heat generated at plastic deformation. Dimensions of used samples with rectangular section were 8mm x 8mm x 50mm. Plastic deformation ran according to the technological „route Bc“, i.e. with rotation of the sample by 90° around longitudinal axis after each pass. Speed of operation of extruding punch was 3 mm/s, lubrication of sample and channels by lubricant MoS_2 was taken into consideration.

Results of simulation for the matrix with the angle 90° between channels are shown in figures 1, 2, and for the matrix with the angle 105 ° are shown in figures 3 - 7.

3. Practical verification of computer simulation

Magnesium alloy AZ91 after heat treatment (T4) used for this technique was first hot rolled (380°) by two different methods:
a) by single pass
b) by 3 passes with intermediate heating to rolling temperature.

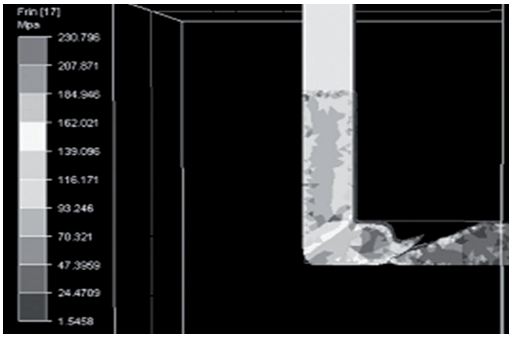

Fig. 1. Strain intensity during 1 pass

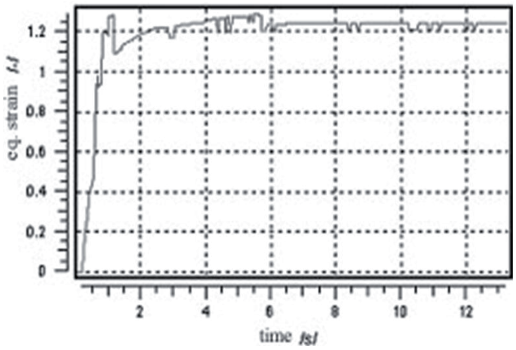

Fig. 2. Course of deformation intensity

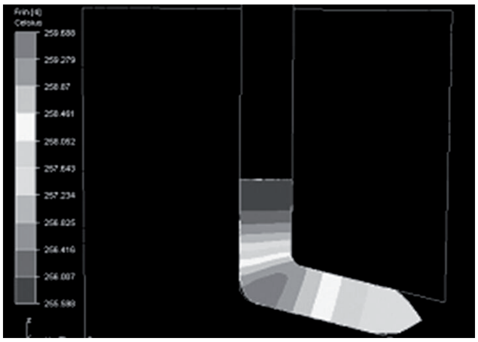

Fig. 3. Temperature field of material at 1pass

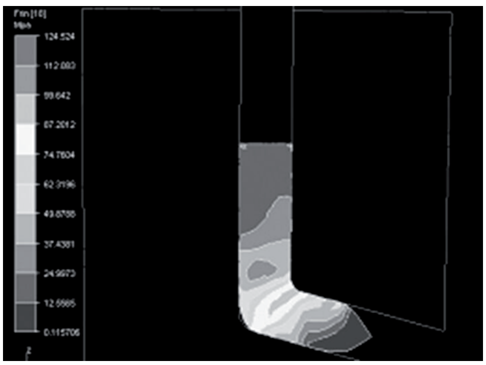

Fig. 4. Strain distribution at 1 pass

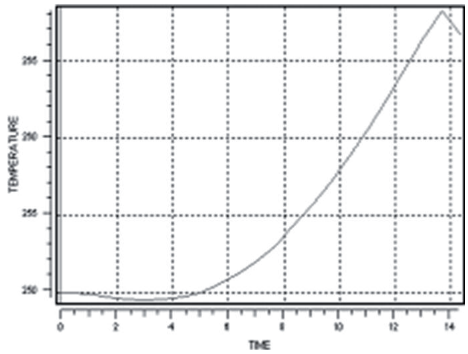

Fig. 5. Course of temperature in dependence on time

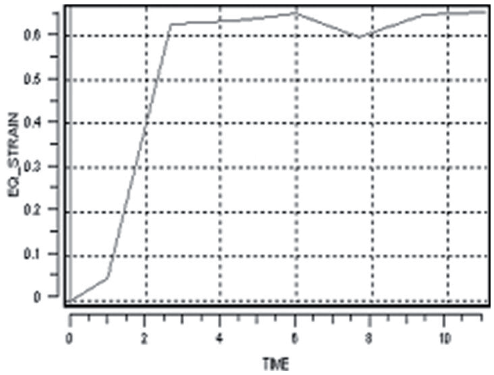

Fig. 6. Dependence of working pressure on time

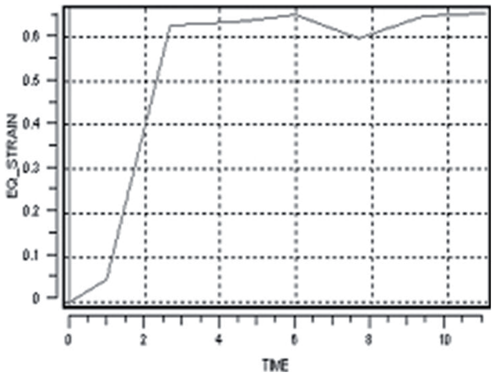

Fig. 7. Course of deformation intensity

Equal channel angular pressing was made in two stages. The first stage consisted of 4 passes at the temperature 250°C. It was followed by the second stage consisting of 1 pass at the temperature 180°C. The samples were similarly as in 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 material was charged into thermally insulated matrix with resistance heating, the temperature of which was identical to that of the chosen forming temperature. Temperature in the matrix channel was controlled by the PID regulator with use of inserted thermocouple. The samples were between individual passes put back into the furnace. At forming of alloys AZ91 as cast, i.e. without any preliminary heat treatment, by ECAP technique there occurred material destruction already at the second passage [8,9]. This confirmed negative influence of as cast structure with massive formation of β phase [10] on ability to sustain big plastic deformations.

Differences of structure after equal channel angular pressing in comparison to the as rolled state or state without deformation are visible in figures 9 - 13. In the alloy AZ91 there are very well noticeable particles of β phase, which precipitated in the form of very fine formations, the average size of which was approx. 1µm. Due to the fact that deformation ran in the second phase at the temperature reduced to 180°C, restoration processes did not occur in these samples in full extent.

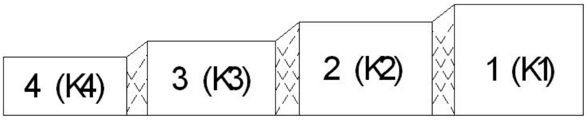

Fig. 8. Shape of samples prior to rolling

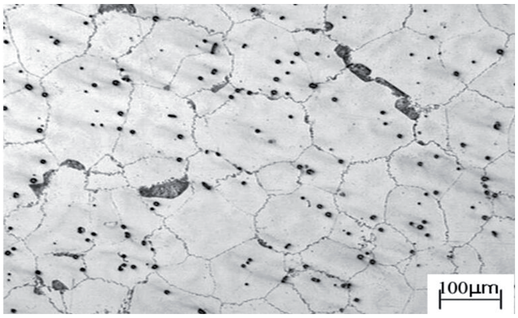

Fig. 9. Alloy AZ91 after T4

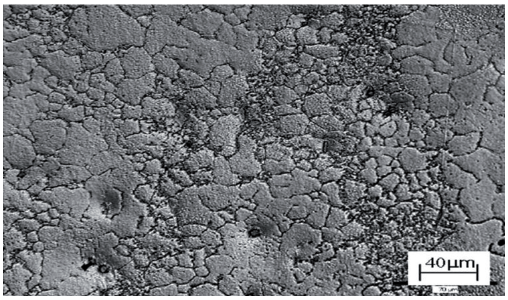

Fig. 10. Degree K1 (def. 52%)

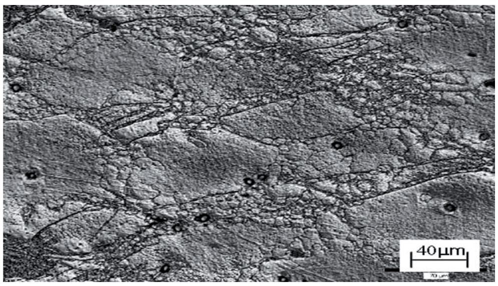

Fig. 11 Degree 1 (def. 52%)

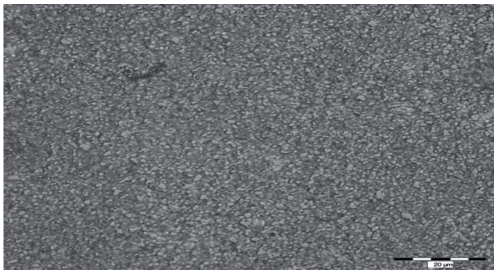

Fig. 12. Degree K1 after ECAP

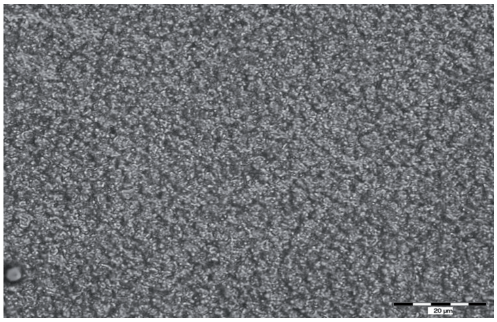

Fig. 13. Degree 1 after ECAP

$$\varepsilon_n = 1.15 \cdot N \cdot \cot g(\phi / 2) \qquad (1)$$

Situation was somewhat different in case of samples that were rolled prior to ECAP in a single pass. Final sizes of grains were also very small, nevertheless, they did not achieve the level of the samples rolled by several passes. Their structure was also not so homogenous as in the previous case. Precipitates were segregated more finely in samples (I) than in samples (II and III).

At the same time high temperature used at the experiment leads to precipitation of $Mg_{17}Al_{12}$ from over-saturated solution of Mg(Al,Zn,Mn). Precipitation in alloys AZ91 lasts approx. 8 hours [5,6], while duration of 2 passes of ECAP lasts approx. 50 minutes. Precipitation could, however, occur even during such a short period since it was facilitated by big plastic deformation [11].

4. Results

Overall shear deformation according to (1) after 5 passages through the matrix with the angle φ = 105° between channels was 4.41. Influence of previous deformation, i.e. magnitude of pass reduction at preceding rolling, is evident on the enclosed photos. It is obvious that the sample, which was rolled prior to ECAP by three passes (K1), had after ECAP homogenous and very fine-grain structure, average size of grain being around 0.5 µm. Final grain size after ECAP increased with decreasing previous deformation of material during rolling (K2 → K4) together with increasing share of precipitated phase – as it is demonstrated in Fig. 12, 13. It means that previous deformation prior to extrusion itself had a significant impact not only on final grain size after extrusion, but also on quantity and size of precipitates [12, 13], which were segregated most often in the state when material was subjected at rolling only to a minimum deformation.

5. Conclusions

Influence of ECAP on microstructure consists therefore in considerable reduction of grain size. At the experiment size of the original grain was reduced up to 60 times. It was moreover discovered with use of X-ray inspection that inside sub-grains the grains were further divided down to the sizes of approx. 100nm. Experiment has also confirmed the fact, that history of previous deformation (rolling) has partial influence on obtained final grain size. As a result of growing number of passages there increases dislocation density [14, 15]. The highest share has a – type of Burgers vectors, which is explained by their smallest activation energy next to the c, c+a present types of Burgers vectors.

Acknowledgements

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