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INFLUENCE OF DEFORMATION PROCESS BY ECAE ON STRUCTURE AND PROPERTIES OF AZ61 ALLOY

WPŁYW PROCESU ODKSZTAŁCANIA METODĄ ECAE NA STRUKTURĘ I WŁASNOŚCI STOPU AZ91

The structure and properties of AZ61 alloy after deformation by ECAE were characterised. Alloy structure was examined after the successive passes of ECAE process, to study the effect of deformation on the morphology of γ phase precipitates and the size and shape of grains. Based on EBSD analysis, the occurrence of high angle boundaries was stated. An attempt was made to describe the mechanisms that are operating when the deformation route is changed at 300°C in the AZ61 alloy processed by ECAE method. Alloy hardness after the first cycle of deformation was stabilised at the level of 80-90 HB. Based on the hardening curve and the occurrence of high angle grain boundaries (>15°), the possibility of further deformation of the AZ61 alloy was confirmed.

Keywords: magnesium alloy; ECAE process; structure, EBSD analysis

W pracy scharakteryzowano strukturę i własności stopu AZ91 po odkształceniu metodą kanałowego wyciskania (ECAE). Obserwowano strukturę stopu po kolejnych przejściach procesu ECAE badając wpływ odkształcenia na morfologie wydzieleń fazy γ oraz wielkość i kształt ziarn. Na podstawie analizy dyfrakcji elektronów wstecznie rozproszonych (EBSD) stwierdzono występowanie granic dużego kata. Podjęto próbę opisania mechanizmów działających podczas zmiany drogi odkształcania w temperaturze 300°C w metodzie ECAE stopu AZ91. Twardość stopu po pierwszych cyklach odkształcenia stabilizowała się na poziomie 80-90HB. Na podstawie krzywej umocnienia oraz występowania granic ziarn dużego kąta (>15°) stwierdzono możliwość dalszego odkształcania stopu AZ91.

1. Introduction

The protection of natural energy resources by the reduction of weight contributes to the fact that lightweight structures are now one of the most important features of a modern transport industry [1-5]. Here, very high potential hold the alloys of magnesium which, owing to the extensive research and the development of new and advanced technologies, are gaining always wider popularity and more and more extensive applications. Magnesium and its alloys are now used as the lightest of all the possible structures in automotive production technologies [1,4,5]. Despite so many advantages and possibilities, the use of magnesium alloys is still very limited. Magnesium has low strength at elevated temperatures, poor creep resistance and low corrosion properties [7, 10-12]. Currently, studies are being conducted to improve these properties through the use of advanced alloys and various processes of treatment. Cast magnesium alloys seem to have already found some niche applications, while the number of applications of the wrought magnesium alloys is growing all the time. In Europe, cast magnesium alloys make about 85-90% of all products using magnesium. The highest rate of application have alloys of AZ61 and AZ31 containing 9 and 3% Al, respectively. Wide popularity also enjoy AM50 and AM60 alloys with 5 and 6% Al, respectively, and with an addition of Mn [1, 3]. These alloys have good casting properties, especially in high-pressure die casting and good mechanical properties. Cast alloys are used for parts of vehicles, such as the wheel rims, instrument panels, and steering wheels, and also for parts of aircraft and components used in other areas of life, including e.g. casings for ordinary and video cameras, radio equipment, and gardening tools. New capabilities of modelling the structure of alloys through plastic forming allow continuous improvement of the properties of magnesium-based alloys [5, 7, 8].

The research works carried out at present have as their main aim the increase of mechanical properties, formability – in particular, to make the alloy easily mouldable through plastic working. Some studies aiming at an improvement of alloy formability are related with the modification of crystalline structure, adding to the alloy lithium and rare earth elements as alloying components; other studies have as their main aim changing the deformation route in the process of plastic forming at elevated temperatures [9, 10]. Studies conducted previously have shown that deformation by ECAE allows obtaining much higher properties in alloys based on the metals such as aluminium, copper, nickel and titanium. Magnesium alloys have not yet been thoroughly investigated, although there are reports that the ECAE process did not cause any more signifi-

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cant changes in their mechanical properties [5, 7, 8]. The main reason for the lack of change can be structural instability due to the deformation of magnesium at elevated temperatures. The structural instability is associated with overlapping of several mechanisms. The mechanisms of hardening and recrystallisation take place in a dynamic and simultaneous way, while the effect of precipitation that occurs in the process of deformation at elevated temperatures is still unknown [6, 7].

Based on the analysis of structure at various stages of the deformation process, an attempt was made to describe the mechanisms operating during changes of the deformation route in the ECAE process when applied to magnesium alloys. By changing the angle of desorientation and analysis of phases present in magnesium alloys it was possible to give characteristics of the structure of AZ61 alloy after deformation and suggest the effect of thus produced structure on further deformability of the alloy.

2. Experimental procedure

For testing, the commercial AZ61 alloy was used in as-cast state and with the chemical composition as shown in Table 1. The ingot was not homogenised before the process of deformation. The average grain size was 30 μm. The ingot was cut into samples with dimensions of 10×10×30 mm. Using equal channel angular extrusion method (ECAE), the samples were extruded, conducting the deformation process up to pass IV (ϕ = 4.6) and rotating the sample according to the scheme Bc.

TABLE 1

The chemical composition of magnesium alloy [%]*

Al	Zn	Mn	Ni	Cu	Fe	Si
6,4	0,65	0,13	0,003	0,003	0,005	<0,02

* The content of Zr, Ag, and rare-earth metals was not determined.

The process of extrusion was carried out on a laboratory press with a maximum capacity of 60T at a temperature of 300°C. The examinations of polished sections after pass I (ϕ = 1.15), pass II (ϕ = 2.3), pass III (ϕ = 3.45) and pass IV (ϕ = 4.6) were carried out by light microscopy on an Olimpus GX71 microscope. Observations were carried out from the longitudinal direction on the central part of the sample. To determine the orientation of the grains, the metallographic analysis was carried out by EBSD on a Philips XL30 scanning electron microscope. The chemical analysis of the γ phase precipitates was performed using the EDS attachment. The average width of grains / bands was estimated from the results of EBSD. Brinell hardness was measured with a HPO 250 hardness tester.

3. Results and discussion

Alloy structure after the first passes of ECAE underwent transformation from the as-cast structure into a band one. During the growth of deformation, the refinement of the structure took place. Macrostructure observations showed that the sample after pass IV (ϕ = 4.6) was compact and free from any surface defects. The observations carried out on an optical microscope (Fig. 1) revealed that in the structure after the next passes, numerous families of the shear bands were formed. A change in the shape of the γ phase was also observed; after the first pass it has taken a laminar shape. The structure after passes II (ϕ = 2.3) (Fig. 1b) and IV (ϕ = 4.6) (Fig. 1c) was of a band type, but γ phase was subjected to further transformations to form clusters or, probably, to dissolve in the matrix. With the increase of deformation, the refinement of the γ phase became evident.

A natural barrier to the motion of dislocations are small precipitates that dissolve and re-precipitate during the thermally activated deformation [6, 11]. Microstructure observations by SEM (Figs. 2, 3) confirmed changes that occurred in the structure as a result of the successive passes of the ECAE extrusion process. The microstructure of the sample after pass II (ϕ = 2.3) (Fig. 2) was characterised by the presence of the large precipitates of the γ phase and a eutectic in the form of the fine coagulated clusters of precipitates. After pass IV (ϕ = 4.6), the precipitates of the γ phase were of strongly laminar character (Fig. 2a). Finely dispersed precipitates were visible within the grain boundaries (Fig. 2b). Similar precipitates were observed in F. Czerwinski's study [6], where the structure of an Mg-8% Al-2% Zn alloy after the extrusion process was analysed. In some areas, the presence of very fine eutectic surrounded by the laminar precipitates of the γ phase was also observed.

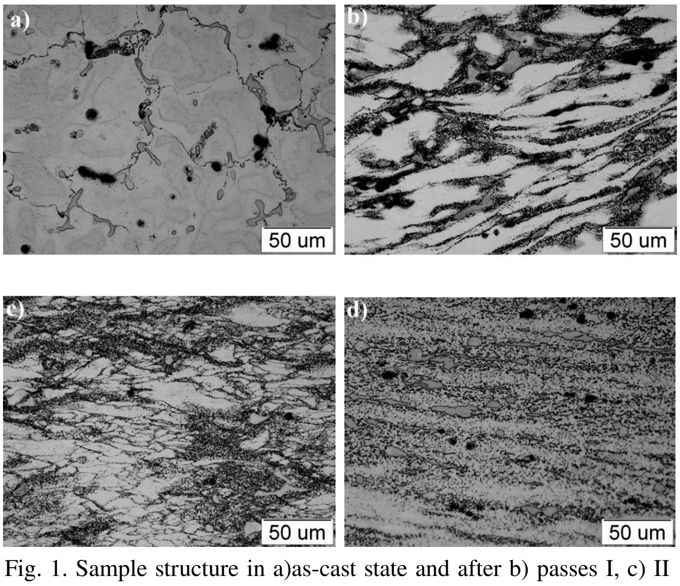

Fig. 1. Sample structure in a)as-cast state and after b) passes I, c) II and d) IV of ECAE

The presence of the secondary fine dispersed precipitates visible along the grain boundaries and a fine eutectic around the γ phase may indicate the dynamic process of precipitation during deformation.

The structure refinement that has been observed in the subsequent cycles of deformation affected not only the size of the γ phase precipitates and very fine precipitates forming around this phase, but also and mainly the grain size.

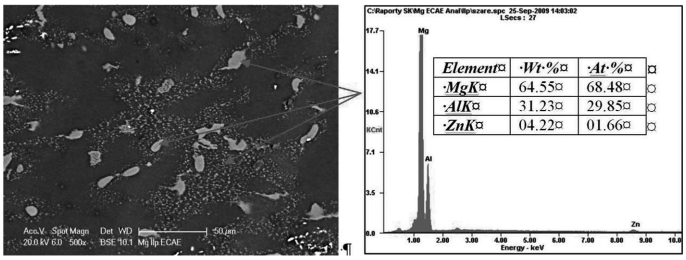

Fig. 2. Sample microstructure after pass II of ECAE with chemical analysis of the γ phase precipitates

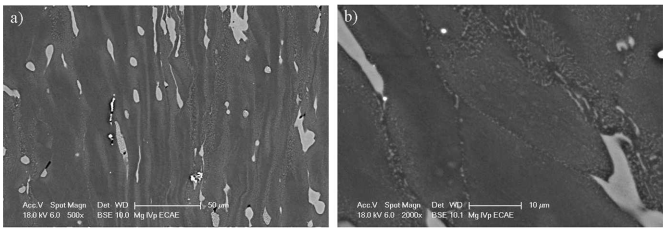

Fig. 3. Sample structure after pass IV of ECAE, a) laminar precipitates of the γ phase at 500x magnification and b) fine precipitates of eutectic along the grain boundary at 2000x magnification

The analysis of orientation maps made after the successive passes of ECAE process (Fig. 4) shows that with the increasing deformation, a refinement of the structure has occurred, starting with the initial state when the average grain size was 30 μm to about 6 μm after pass IV (ϕ = 4.6). As a result of further passes, an increase in the number of high angle boundaries was also reported. Examining the orientation it was also observed that, in practice, the majority of the grain boundaries (apart from the boundaries after pass I (ϕ = 1.15)) in magnesium deformed at 300°C had a large angle (<15°). The effect of temperature is also of some importance, as the appearance of a large number of the high angle boundaries (<15°) may be due to a continuous dynamic recrystallisation during deformation, which has also been mentioned in the studies of other authors, e.g. [7, 8]. This also affects the difference in grain size between pass I (ϕ = 1.15) and pass IV (ϕ = 4.6), which is not as large as in the aluminium alloys [13]. On the other hand, the constrained movement of dislocations in magnesium at a temperature below 200°C results in a rapid hardening of the alloy and, as a consequence, exhausts the potential for accumulation of the deformations. Magnesium alloys are processed at elevated temperatures (above 200°C) since all attempts to process them at lower temperatures must lead to the formation of discontinuities on their surface. This is due to the specific crystallographic structure of magnesium. At temperatures below 200°C, the deformation occurs in a base slip system (the plane (0001)). Exceeding 200°C makes planes from the family {10-11}take on the characteristics of the most dense arrangement and the slip systems associated with them may get involved in the process of deformation. The angular relationships between the prism base planes make the occurrence of a cross slip possible, thus increasing additionally the plastic properties of the alloy [10].

The deformation of material by ECAE changes the structure and increases the mechanical properties, e.g. hardness. On the graph of the plotted hardness values, an increase in hardening between the starting material and samples after deformation is observed. However, this difference in hardness

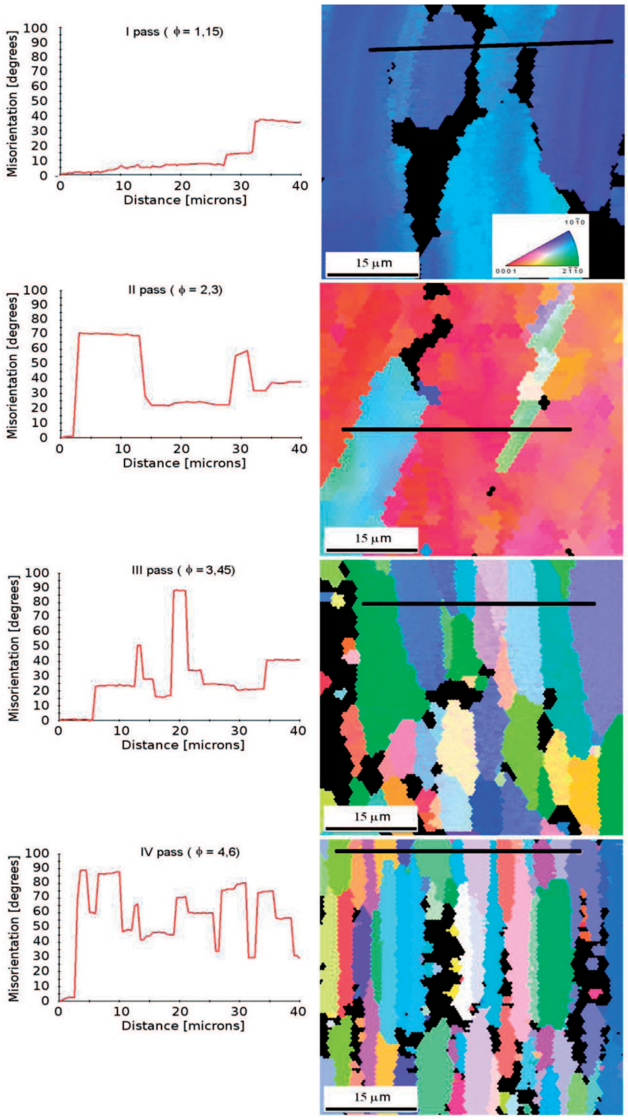

Fig. 4. Angle of desorientation and grain refinement in the MgAl6Zn0.6 alloy deformed by ECAE. Colours correspond to crystallographic orientations indicated in the inverse pole figure. Black areas are the places of the occurrence of precipitates, which were not analysed

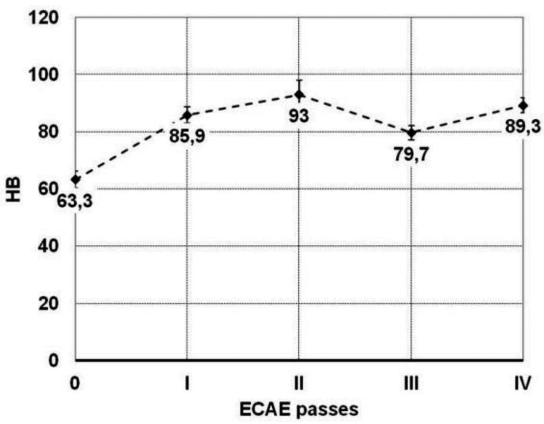

Fig. 5. Hardness of AZ61-MgAl6.4 alloy after deformation by ECAE

between the sample in as-cast state and after the successive passes of the ECAE process is in magnesium alloys not as large as in the aluminium alloys subjected to ECAE, which means that the situation is much the same as in the case of the difference in grain size. It is due to better deformability of aluminium and ECAE process carried out at room temperature. No major differences in hardness were observed between the first and the last pass. The next passes brought only very insignificant changes at a level between 80 and 90HB.

4. Summary

Tests were carried out on a commercial AZ61 alloy ingot. By the method of equal channel angular extrusion (ECAE), samples were extruded, carrying out the deformation process up to pass IV ($\phi = 4.6$) at 300°C.

As a result of the deformation mechanism associated with the movement of dislocations and thermally activated processes during deformation by ECAE, partial rebuilding of the structure and grain refinement processes have occurred. ECAE at elevated temperatures results in a dynamic process of precipitation. The following phenomena take place: change in the shape of the γ phase and its dissolution with the subsequent release of small precipitates from the solution at grain boundaries, and coagulation of the acicular eutectic precipitates. When deformation occurs in the subsequent cycles, the grain refinement and an increase in the number of the high angle boundaries (<15°) occur. Rebuilding of the structure at large plastic deformations does not cause a significant increase in the mechanical properties, as hardness compared to the starting material increases by only about 25%. Small differences in the obtained values of hardness and grain size after subsequent cycles can only prove the dynamic processes taking place in the structure, leading to improved plastic properties of the AZ61 alloy.

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