EFFECT OF EQUAL CHANNEL ANGULAR PRESSING ON TWIN-ROLL CAST AZ31 MAGNESIUM STRIP

ZIMINA Mariia[1], POKOVÁ Michaela[1], BOHLEN Jan[2], KURZ Geritt[2], LETZIG Dietmar[2], CIESLAR Miroslav[1]

[1] *Charles University in Prague, Faculty of Mathematics and Physics, Prague, Czech Republic, EU, m.zimina@seznam.cz*

[2] *Magnesium Innovation Centre (MagIC) Helmholtz-Zentrum Geesthacht, Geesthacht, Germany, EU*

Abstract

Twin-roll casting is a technique which allows production of high quality thin magnesium alloys strips with enhanced microstructure. However, further treatment using severe plastic deformation or annealing is required to improve mechanical properties of strips. Equal channel angular pressing is a very effective tool for grain refinement. In the present study the effect of annealing on the microstructure of twin-roll cast AZ31 magnesium alloy strip after equal channel angular pressing was studied. A significant grain refinement occurs already after two passes in both as-cast and aged alloys. Light and scanning electron microscopy were used for microstructure observations. The evolution of mechanical properties was investigated using Vickers microhardness measurements. The increase of microhardness with increasing number of ECAP passes was observed.

Keywords: Magnesium alloy, twin-roll casting, ECAP

1. INTRODUCTION

Development of new casting and deformation techniques and its application to light structural materials, such as magnesium alloys, is now under a huge interest. Moreover, sheet production of magnesium alloys is hindered because the formability of magnesium at room temperature (RT) is limited. Since rolling forms strong basal texture in magnesium sheet with the c-axis parallel to the normal direction [1], the activation of non-basal slip systems is restricted. Thus, due to the limited number of slip systems, elevated temperatures are required for activation of non-basal slip systems, such as prismatic $\{10\bar{1}0\}<11\bar{2}0>$ or pyramidal $\{10\bar{1}1\}<11\bar{2}0>$ and $\{11\bar{2}2\}<11\bar{2}3>$.

One of the casting technologies successfully applied on magnesium alloys is twin-roll casting (TRC). It allows production of magnesium alloy strips of the 4-6 mm thickness with high solid solution supersaturation and relatively large grains [2]. This process incorporates casting and hot rolling into one step and, therefore, is assumed to be more efficient. Such strips can be easily used for a further processing by heat treatment or severe plastic deformation (SPD). The latter allows preparation of materials with decreased grain size and improved mechanical properties. Fabrication of ultrafine grained (UFG) materials with the grain size of about 1 µm and less improves the strength of the material at low temperatures through the Hall-Petch relation [3, 4]. The refinement of the microstructure has a significant impact on essential properties of magnesium sheets, such as strength, ductility and corrosion resistance [5, 6]. Due to a bigger total grain boundary fraction and, thus, higher impedance to the dislocation motion, UFG magnesium alloys can in some cases exhibit superplasticity [7, 8]. It was also shown by Kubota et al. [9] that the intergranular fracture occurs in magnesium alloys with relatively large grain size. On the other hand, Mohri et al. reported [10] the limitations faced in alloys with the small grain size. Thus, the decreasing of the grain size can change the fracture mechanism and mechanical behavior of magnesium alloys.

Recently, a variety of SPD technologies was developed. Among them equal channel angular pressing (ECAP) [11], high pressure torsion (HPT) [12] and accumulative roll-bonding (ARB) [13] are the most commonly used for the lightweight alloys. ECAP has been successfully used on different magnesium alloys [14]. Several studies have dealt with the continuous ECAP which can be applied on metal sheets [15]. Thus, the combination of TRC and ECAP appears to be an effective approach for the grain refinement of magnesium sheets.

This paper examines the microstructure, grain size and texture of the 5.6 mm thick TRC AZ31 magnesium strip after one, two, four and eight ECAP passes. The influence of a heat treatment before the ECAP process on final microstructure is considered. The relation between Vickers microhardness and the number of ECAP passes is studied. Microstructure observations and orientation maps were obtained using electron back scatter diffraction (EBSD).

2. EXPERIMENT

Twin-roll cast AZ31 magnesium alloy with chemical composition listed in **Table 1** was used for further ECAP processing. Temperature of the melt before TRC was 650 °C and casting rate was 1.8 m / min. Samples with dimensions 4.9 x 4.9 x 40 mm^3 were cut from the TRC strip with the longer side parallel to the transverse direction (TD) of the strip. Two sets of samples were used for the ECAP processing: 1st - as-cast and 2nd - aged at 450 °C for 10 h in an air furnace and then quenched. The samples were deformed at 230 °C with processing speed of 7 mm / min. The angle of intersection between the two channels was 90° and the route B_c was chosen for the deformation. For the microstructural and texture studies specimens were grinded and finally polished using ion mill. EBSD experiments were performed using FEI Quanta FEG scanning electron microscope. Orientation maps were measured by scanning an area 150x150 μm^2 with a step of 0.2 μm. Vickers microhardness ($HV_{0.1}$) values were also examined on ECAP samples and compared with the initial state.

Table 1 Chemical composition of TRC AZ31 magnesium alloy (wt. %)

Al	Zn	Mn	Ca	Cu	Fe	Mg
3.45	0.98	0.28	0.002	0.002	0.004	balance

3. RESULTS AND DISCUSSION

Fig. 1 shows micrographs of a twin-roll cast AZ31 magnesium strip in the as-cast and annealed states. Aging at 450 °C for 10 h leads to recrystallization and a significant decrease in the grain size from 150 to 50 μm. This decrease can be explained by the dissolution of secondary phase particles arranged into a dendritic structure is observed after the aging. This effect was shown earlier by Humphreys [16].

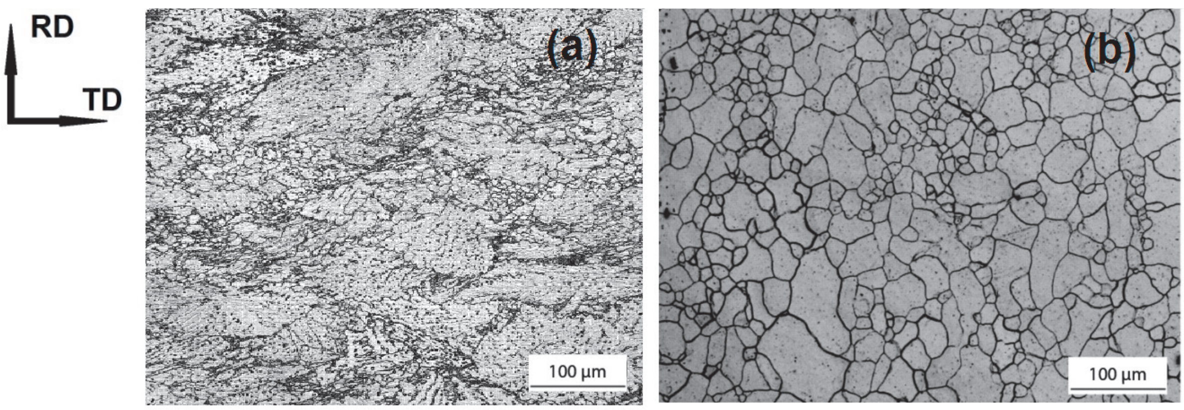

Fig. 1 Microstructure of (a) as-cast and (b) annealed (at 450 °C for 10 h) TRC AZ31 magnesium alloy strip

ECAP processing of the AZ31 magnesium alloy specimen cut from the TRC strip with the TD parallel to the pressing axis at 230 °C was made. One ECAP pass on the as-cast material leads to the formation of a bimodal microstructure which is in agreement with earlier studies [17]. **Fig. 2a** shows that finer grains of the size of about few microns are formed on the boundaries of large elongated grains. The average diameter of larger grains is about 100 µm. Although the material aged at 450 °C for 10 h before ECAP also exhibit the bimodal structure after one pass (**Fig. 3a**), smaller grains are larger (5 µm) than those observed in the as-cast material. However, grains orientation does not differ in the as-cast and aged alloy and a majority of grains regardless the size has c-axes parallel to the TD.

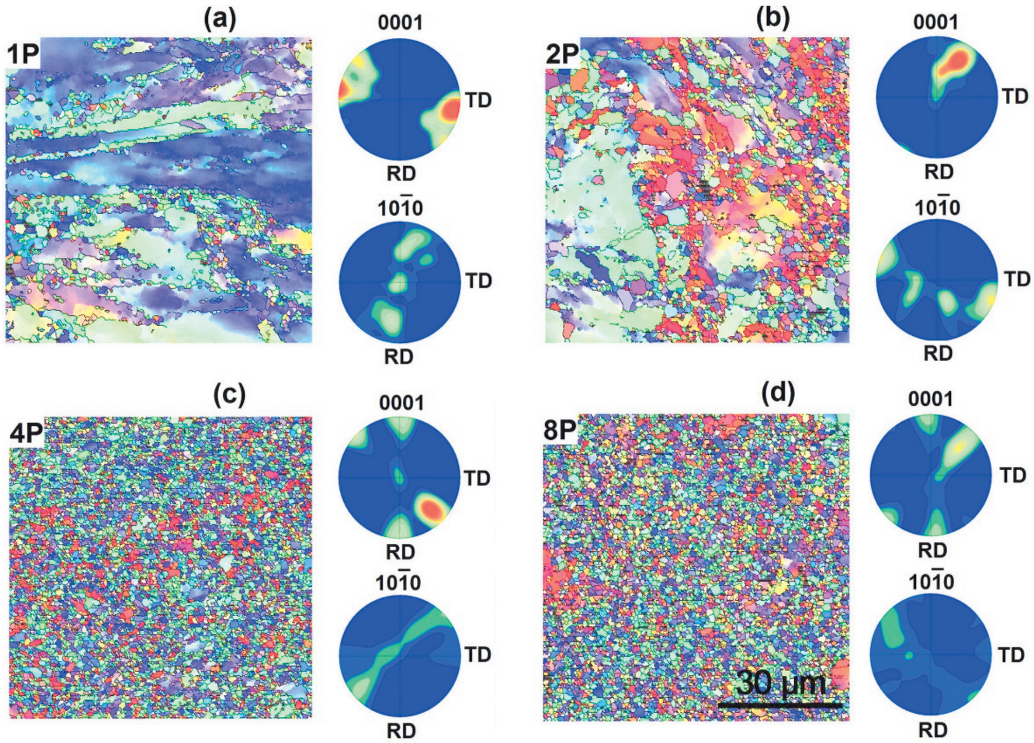

Fig. 2 Orientation maps and pole figures of as-cast TRC AZ31 magnesium alloy strip after a) one, b) two, c) four and d) eight ECAP passes

After the second ECAP pass the grain refinement in both materials is observed. However, the bimodal microstructure is still more pronounced in the as-cast material (**Fig. 2b**), while more homogeneous distribution of the grain size is present in the aged specimen (**Fig. 3b**). The microstructure comprises larger grains of 50 µm and finer ones of 4 and 8 µm in as-cast and aged materials, respectively. The rotation of the specimen due to the chosen route B_c results in the 90° tilt of the texture around the normal direction (ND) in both samples.

After four ECAP passes balancing of the microstructure occurs in both samples accompanied by the grain refinement (**Figs. 2c** and **3c**). In the as-cast alloy grains of less than 1 µm are formed. Their c-axes lie in (RD, TD) plane and they are rotated 45° with respect to RD. On the other hand, coarser grains of the size of around 3 µm are observed in aged specimen. **Figs. 2d** and **3d** show that further ECAP processing does not significantly alter the microstructure and texture of the TRC AZ31 magnesium alloy.

According to the Hall-Petch relation between the grain size and strength (Equation 1), where σ_γ is a yield stress, d - average grain diameter, k_γ and σ_0 - empirical constants, grain refinement will result in the improvement of mechanical properties.

$$\sigma_\gamma = \sigma_0 + k_\gamma \cdot d^{-1/2} \quad (1)$$

The microhardness observations presented in **Fig. 4** indicate the increase of the strength in the as-cast and heat treated alloy after ECAP. When compared to the initial values microhardness increases by 25 % after already the first pass and by almost 35 % after eight ECAP passes in both materials. However, microhardness values are higher for the as-cast TRC strip during the entire processing and achieve 90 MPa after eight passes.

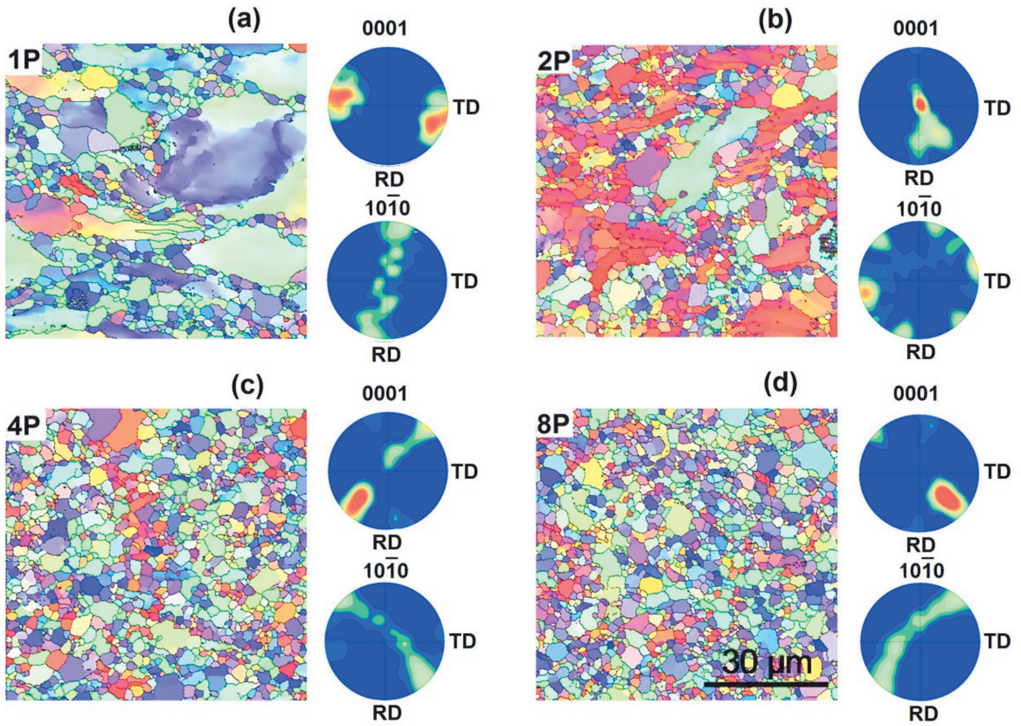

Fig. 3 Orientation maps and pole figures of TRC AZ31 magnesium alloy strip aged at 450 °C for 10 h after a) one, b) two, c) four and d) eight ECAP passes

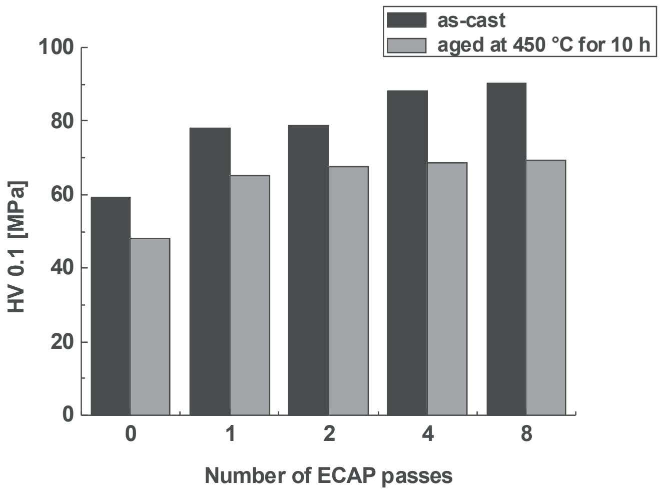

Fig. 4 Vickers microhardness (HV0.1) of the as-cast and aged at 450 °C for 10 h TRC AZ31 magnesium alloy after one, two, four and eight ECAP passes

4. CONCLUSION

TRC AZ31 magnesium alloy strip was processed by ECAP at 230 °C. TD of the strip was parallel to the deformation axis. The effect of pre-annealing at 450 °C for 10 h before ECAP on the microstructure and texture was considered. Bimodal microstructure was observed in both the as-cast and the aged materials after one and two passes. However, after two passes it is more pronounced in as-cast alloy. Vanishing of such a microstructure occurs after four ECAP passes followed by a significant grain refinement. Grains formed after eight passes are significantly finer in the as-cast material than in the annealed one. The EBSD studies showed a consistent rotation and strengthening of the texture during SPD in both materials. Microhardness increases with increasing number of ECAP passes and is higher for the as-cast AZ31 magnesium alloy.

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