INFLUENCE OF THE HEAT TREATMENT ON THE TEXTURE OF TWIN-ROLL CAST AZ31 MAGNESIUM ALLOY

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Abstract

Weight reduction is one of the major issues in many industrial areas. New structural materials which meet the highest standards, good mechanical properties, such as strength and ductility, and thermal stability are required. Aluminum and magnesium alloys attract particular attention because of their low density. Among various methods of manufacturing lightweight alloys, twin-roll casting is nowadays frequently used to produce flat rolled magnesium materials. This cost-effective process has beneficial influence on microstructure. The mechanical properties of such materials are remarkably improved compared to conventionally cast alloys. Nevertheless, the continuous casting technique is characterized by strong texture of the rolled strip.

The present paper reports on the comparison of microstructure and texture of twin-roll cast AZ31 magnesium strip in the as-cast and annealed states. The microstructure studies were made by light microscopy and scanning electron microscopy. The texture was investigated using X-Ray diffraction and electron back-scatter diffraction.

Keywords: Magnesium, twin-roll casting, texture, EBSD

1. INTRODUCTION

The needs to reduce the weight and to improve the mechanical properties of structural materials for the industrial usage lead to the increase of the number of scientific investigations in the field of material science. The crystallographic structure and *c*/*a* ratio of materials strongly affect the properties of alloys. Structural materials with hexagonal close-packed structure (HCP), such as magnesium and its alloys, are used as the outer parts of the vehicles and in computer industry as frames for the lightweight devices [1]. For polycrystalline materials with HCP structure only a limited number of slip systems is present. Depending on the orientation of grains in the material, certain slip systems can be activated. At room temperature (RT) the basal slip system plays the dominant role, while increasing temperature results in the activation of prismatic $\{10\bar{1}0\}<11\bar{2}0>$ and pyramidal $\{10\bar{1}1\}<11\bar{2}0>$ and $\{11\bar{2}2\}<11\bar{2}3>$ slip systems. These limitations induce twinning, which becomes the major deformation mechanism at RT in magnesium alloys. Twinning preferentially occurs in the $\{10\bar{1}2\}<10\bar{1}1>$ system and produces elongation only along the *c*-axis. Therefore, it leads to the tension/compression anisotropy of HCP materials. The main issue of the material research is the improvement of mechanical properties of magnesium alloys at RT. There are two common ways to increase the ductility. The first one relies on the grain refinement using a variety of deformation techniques, such as equal channel angular pressing (ECAP) [2, 3], extrusion (ECAE) [4] or asymmetric rolling [5, 6]. The second one is based on the weakening of the basal texture. In magnesium there is a wider variety of possible deformation textures compared to materials with cubic structure [1]. However, the deformation imposed during twin-roll casting (TRC) leads to the observed changes in the texture, which can be controlled ones the TRC process is understood [7]. Kim et al. [8] have found that during asymmetric rolling the intensity of basal components of texture decreases from upper layers through the center of the strip to the lower surface. Moreover, after annealing the intensity of {0002} peaks in pole figures also decreases. Change of the {0002} texture to the other components depending on the distance from the specimen surface was also observed in extruded AZ31 magnesium alloys [9].

Twin-roll cast (TRC) AZ31 magnesium alloy exhibits different extent of deformation through the material thickness, and thus a heterogeneous structure. Therefore, this study concerns the influence of the heat treatment on the microstructure and texture in different parts of the TRC strip. This information is essential for further improvement of processing of magnesium alloys with unique mechanical properties. Two techniques are usually used to establish the texture: electron back-scatter diffraction (EBSD) and X-ray diffraction (XRD). In this contribution the comparison of selected results obtained in the form of XRD pole figures and EBSD orientation maps was done.

2. EXPERIMENTAL

AZ31 magnesium alloy was prepared by TRC technique. Details about the used process are described elsewhere [7]. During TRC the 650 °C melt of the AZ31 goes through the nozzle between two water-cooled rotating rolls. Solidified strips of the 5.6 mm thickness were prepared at the processing speed 1.8 m/min. The chemical composition is listed in **Table 1**.

Table 1 Chemical composition of AZ31 magnesium alloy in wt.%

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

Specimens of AZ31 magnesium alloy were cut from the strip and annealed at 450 °C for 10 h. Samples were then prepared for microscopy observations using standard metallographic techniques. The microstructure images were made by the Olympus GX51 light microscope and NIS-Elements AR 3.0 software.

2.1 EBSD

The advantage of the EBSD technique is the ability to detect weak textures at small scale. During the measurement the information about the grain size and orientation is collected simultaneously. **Fig. 1** shows the scheme of the EBSD experiment performed on the scanning electron microscope (SEM) Quanta FEG 400. The sample was tilted 70° with respect to the initial horizontal position so that the angle between the incident beam and the sample was 20°. The surface was scanned within the area of 500x500 μm^2 by the electron beam with the energy of 20 kV. The data were handled using OIM Analysis 6 software.

Specimen preparation consisted of the grinding and polishing using 1 and ¼ µm diamond pastes. In order to avoid surface oxidation, ethanol-glycerol lubricant was used. The final polishing was made with standard colloidal silica suspension (OP-S). Thereafter, the argon ion milling was applied.

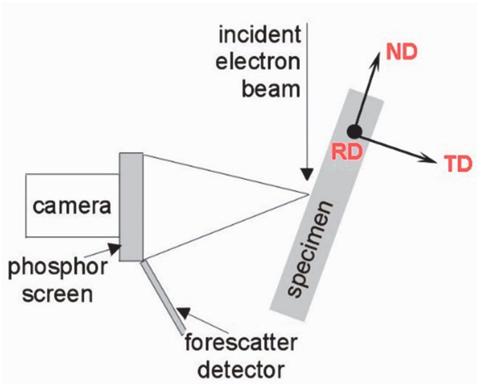


Fig. 1 The scheme of the EBSD experiment with respect of directions in AZ31 TRC magnesium alloy

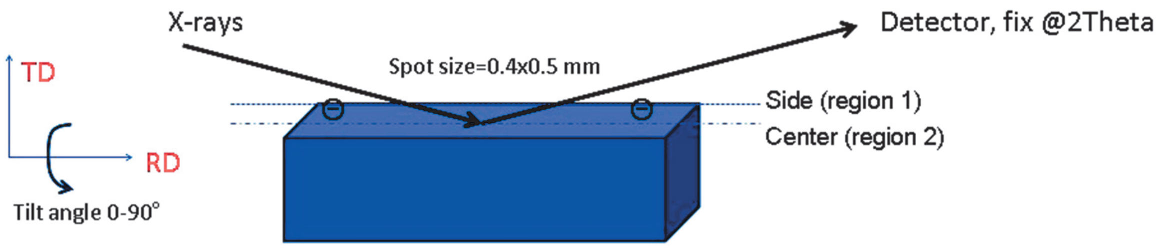


Fig. 2 The scheme of the Schultz reflection method with respect of directions in AZ31 TRC magnesium alloy. Θ - diffraction angle, Φ - rotation angle, Ψ - tilt angle

2.2 XRD

X-Ray diffraction was done on Rigaku Smart Lab, 9kW Thin-Film In-Plane X-ray Diffractometer at a voltage 8keV using Shultz reflection method. The intensity of Bragg reflection was measured for pairs of Ψ and Φ at fixed θ-2θ position and is presented as a pole figures built by the commercial software. **Fig. 2** shows the scheme of the X-Ray diffraction and orientation of the sample during the experiment.

All observations were made in the transversal direction (TD) of specimens, as indicated in figures.

3. RESULTS AND DISCUSSION

3.1 Microstructure

Fig. 3a shows the cross-section of the AZ31 alloy after TRC. The structure is heterogeneous and is characterized by grain size varying through the cross-section of the strip. During TRC solidification occurs not uniformly and bands with different microstructure are formed. In the surface regions the strong deformation during the processing is responsible for the crystallization of smaller grains with size of about 50

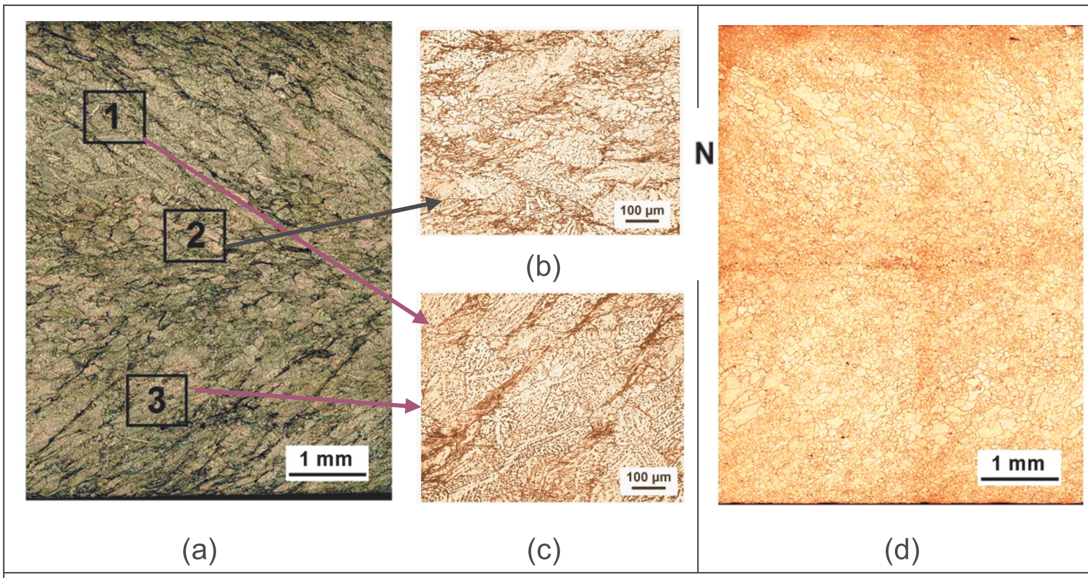


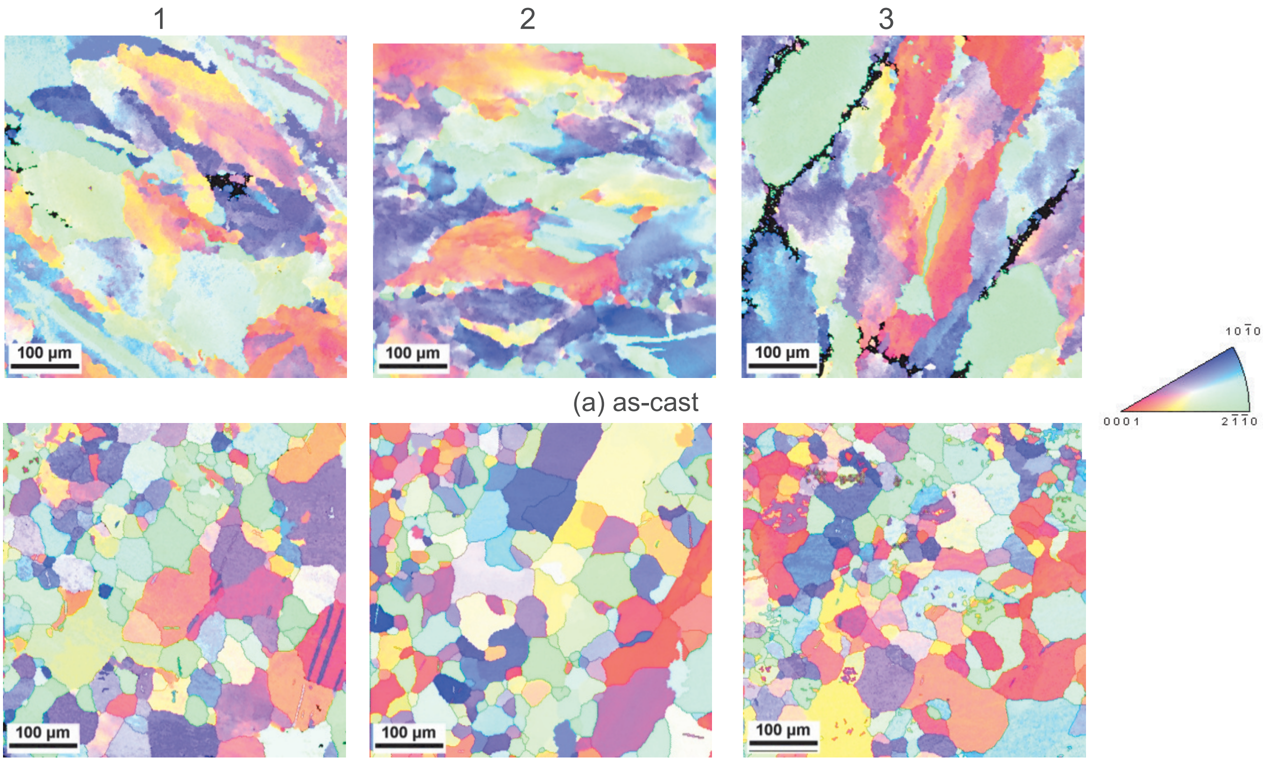
Fig. 3 Cross-section of the as-cast (a) and homogenized at 450 °C for 10 h (d) TRC AZ31 magnesium alloys in transversal direction observed by light microscopy. The micrographs from the central part of the strip (b) and bulk of the sample (c) are presented

μm. In the bulk of the material large elongated grains tilted towards the RD were observed. The average size of those grains is about 200 μm. The central segregation band marked as frame 2 in **Fig. 3a** is caused by heterogeneous solidification and partially by segregation of Al-Mn phases [10, 11] and other impurities in the material. The grain size differs along this band from several tens to several hundreds of micrometers (**Fig. 3b**). Conventionally cast AZ31 magnesium alloys are usually characterized by a dendritic structure in the bulk of the material with the presence of $Al_{12}Mg_{17}$ phase [12]. In the as-cast TRC AZ31 magnesium alloy secondary phases are distributed mainly inside the grains as is shown in **Fig. 3c** and in reference [13]. The microstructure of the AZ31 alloy after homogenization annealing is presented in **Fig. 3d**. Almost full recrystallization occured accompanied by grain refinement. Grain size decreased to 50 μm and less. The structure became more homogeneous. Moreover, after heat treatment the $Al_{12}Mg_{17}$ phase dissolved.

3.2 Texture

The areas studied by the EBSD are marked in **Fig. 4** as follows: 1 - upper part of the bulk of the sample, 2 - center of the strip, 3 - lower part of the bulk. These designations will be used in the following text. In **Fig. 4** surface-orientation maps obtained from the EBSD measurements are presented. The central (2) region with smaller grains is characterized by a strong basal texture in the as-cast sample (**Fig. 4a.2**). This situation has changed after homogenization and the reorientation of grains by ~90° occurs (**Fig. 4b.2**). In accordance with observations of Bunge [14] and Humphreys et al. [15] some texture components are rotated around simple crystal directions. In our case the rotation of 90° around ND was observed.

In the regions 1 and 3 elongated grains were observed. As it is shown in **Fig. 4a.1**, **4a.3**, in the as-cast state there are grains with two prevailing orientations, namely, $\{0001\} < 11\bar{2}0 >$ and $\{2\bar{1}\bar{1}0\} < 10\bar{1}0 >$ seem to be



(b) after homogenization at 450 °C for 10 h

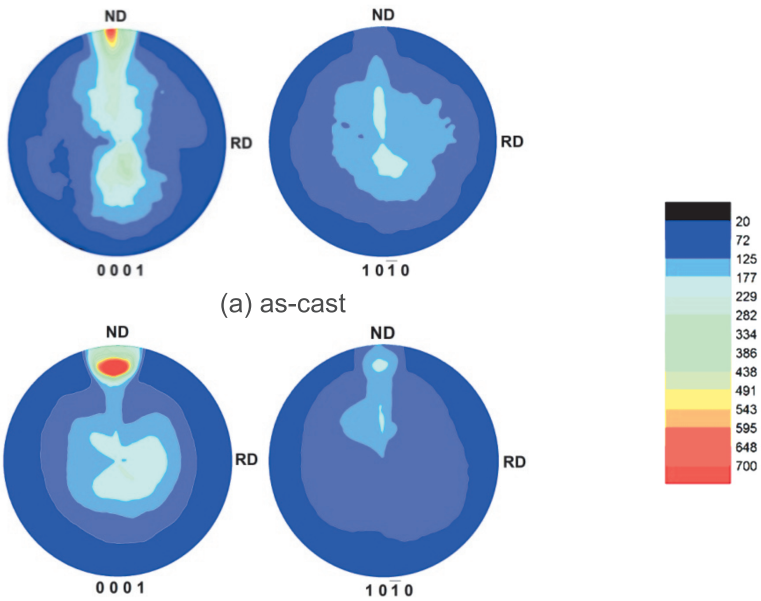
Fig. 4 Surface-orientation maps made by EBSD method from different parts of the specimen cross-section: region 1 - upper, region 2 - central, region 3 - lower part of the specimen as marked in **Fig. 3a**

preferable textures. After homogenization (**Fig. 4b.1, 4b.3**) most of the grains are tilted towards the RD. Thus, homogenization heat treatment leads to the balancing of the texture along the cross-section of the TRC material, because very similar texture was observed in the regions 1 and 3 compared to the center of the strip indicated as region 2.

3. XRD

In order to compare the results obtained from EBSD with the ones received from XRD, we used the pole figures measured in the region marked as 1. **Fig. 5** shows the results for the as-cast and homogenized TRC AZ31 alloy. In the as-cast AZ31 magnesium alloy two intensive areas (**Fig. 5a**) in the (0002) XRD pole figure were observed. It corresponds to two possible textures presented in this region of the material. The EBSD measurements showed the same results. After homogenization the strengthening of the basal $\{0001\}<11\bar{2}0>$ texture occurs as is shown in **Fig. 5b**. However, grains with $\{2\bar{1}\bar{1}0\}<10\bar{1}0>$ orientation are still presented.

Possible local inhomogeneity along the rolling direction which is often observed in TRC materials can cause slight disagreement in the results obtained by the EBSD and XRD. Therefore, more statistical measurements are needed.



(a) as-cast

(b) after homogenization at 450 °C for 10 h

Fig. 5 (0002) and $(10\bar{1}0)$ pole figures of region 1 of AZ31 TRC magnesium alloy by XRD in: a) as-cast and b) homogenized states

SUMMARY

After twin-roll casting at the chosen process parameters the AZ31 magnesium strip of the 5.6 mm thickness was produced. Although this TRC strip was cast under optimal conditions, the microstructure is still heterogeneous. During homogenization at 450 °C for 10 h the recrystallization accompanied by the grain refinement occurs. The grain size decreases to 50 μm and less. The diffraction experiments were performed using EBSD and XRD methods. According to the heterogeneous structure, two regions in the cross-section of the alloy in TD were studied. The strong basal texture in the bulk of the as-cast alloy transforms to the structure with grains rotated by 90° with respect to the initial orientation. Nevertheless, the data obtained by both techniques after heat treatment are slightly different. This might be the result of the inhomogeneity along the RD observed in the material or due to the respectively small studied area. In order to achieve better understanding of the reasons for this disagreement more statistical data are needed.

ACKNOWLEDGEMENTS

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