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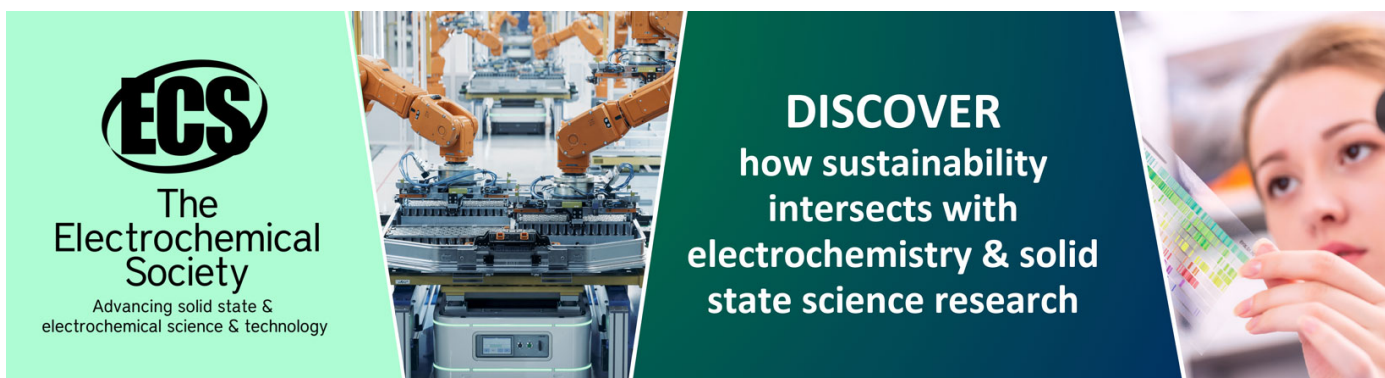
Texture and anisotropy of yield strength in multistep isothermally forged Mg-5.8Zn-0.65Zr alloy

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Texture and anisotropy of yield strength in multistep isothermally forged Mg-5.8Zn-0.65Zr alloy

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Abstract. The effect of multistep isothermal forging (MIF) on microstructure, texture and anisotropy of ambient temperature yield strength of MA14 (Mg-5.8Mg-0.65Zr (% wt)) magnesium alloy hot-pressed rod was analyzed. It has been found that the initial axial texture is quite stable under 1st MIF step up to strain $\epsilon \sim 4.2$ at 400°C and has been gradually transformed into much weaker single-peak one at further processing at 300 and 200°C to total strain of 10.2. Such texture changes were accompanied by strong grain refinement, along with significant reduction of the alloy strength anisotropy.

1. Introduction

It is well known, that magnesium-based alloys are quite attractive materials for industrial applications owing to extraordinary high specific strength (balance of high strength and low density) and damping properties. However, because of rather strong anisotropy of service and technological properties, they are less competitive than cubic light materials, such as aluminum alloys [1]. Therefore, development of effective and cost-affordable commercial method to decrease anisotropy of their properties, especially of tensile strength parameters, is quite essential. Such method should be conditioned by simplicity in mass-productions. Besides, it should result in deep structure-texture transformations via deformation grain refinement up to fine and even ultrafine sizes (grain size less than 10 and 1 μm , consequently) to process evenly distributed grain orientations in bulk billets. Judging to literature data, multistep isothermal forging (MIF) [2,3] corresponds to these requirements, even despite its very few applications for magnesium alloys.

The purpose of the present investigation is the study of structure, texture and strength evolutions in the hot-pressed rod of MA14 (ZK60) alloy during MIF.

2. Material and procedure

Billets with sizes of 70×70×170 mm cut out from a commercial hot-pressed 90 mm rod of MA14 (Mg-5.8Mg-0.65Zr (% wt)) alloy were processed to MIF in three sequential steps at 400, 300 and 200 °C using hydraulic press with isothermal die set. Each step has been consisted of several cycles, involving few setting with axis changing (see more details in [4,5]). The orientations of the axes (directions of deformation) in the initial rod and in the MIF billet are shown in Fig. 1. Total number of cycles was 18 with corresponding true strain of a billet $\epsilon=10.2$ (i.e., 4.2 at 400, 3.0 at 300 and 3.0 at 200°C). The alloy structure and texture were analyzed by means of electron backscattered diffraction (EBSD) method using Tescan Mira LM scanning electron microscope and HKL CHANNEL 5 software. Pole figures were processed using the data of 5-6 EBSD maps 100×100 μm^2 from different areas, being enough for correct texture analysis [6]. Texture was also characterized by maximum intensity (I_{max}) of the {0001} pole figures and the integral texture index (F), estimated as [7]:

$$F_i = \int_0^{\frac{\pi}{2}} I(\varphi) \sin(\varphi) \cos^2(\varphi) * d(\varphi) \quad (1)$$

where φ is the angle of the pole orientation, $I(\varphi)$ – texture intensity at φ .

Tensile tests were carried out on Instron 5982 using flat samples with 10x2x2 mm gage, cut from initial rod and MIF billet with orientations indicated in Figure 1. The alloy yield strength (YS) anisotropy was characterized by the coefficient ΔYS , determined as:

$$\Delta YS = 2 \frac{YS_{max} - YS_{min}}{YS_{max} + YS_{min}} \quad (2)$$

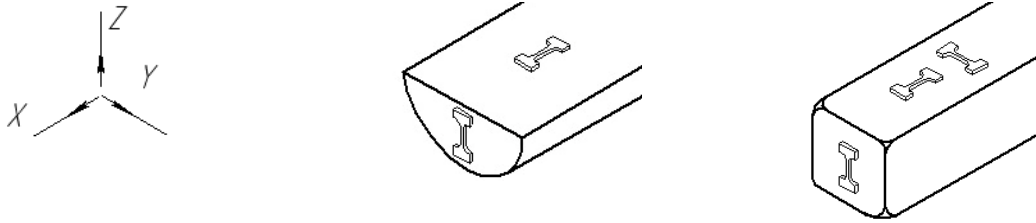


Figure 1. Rod and MIF billet with axis designation and corresponding tensile samples orientations.

3. Results and discussion

It was found that MIF led to the alloy deep grain refinement: initial coarse fibered structure, containing ~40% of fine 9 μm grains, was transformed into predominantly recrystallized one with 7 μm grains even after first MIF step, and under subsequent processing - into near homogeneous one with 2-4 μm in size grains [4].

The $\{0001\}$ pole figures and inverse pole figures (IPF) plotted for X direction in the initial rod (a) and in the MIF billets processed at various steps (b through d) are represented in Fig. 2. Initial rod had the typical for a hot-pressed semi-product axial texture with an axis of the symmetry parallel to the pressing direction (X) and with maximum intensity more than 12 (Fig. 2a). Hence, the X directions in IPF fill in all ranges along the line from $\langle 01\bar{1}0 \rangle$ to $\langle \bar{1}2\bar{1}0 \rangle$. Surprisingly, but after the 1st step of MIF, the texture similar to initial one was still observed, even though it was characterized by high intensity and additional sharpening of X orientation density in IPF at near $\langle \bar{1}3\bar{2}0 \rangle$ and $\langle \bar{1}3\bar{2}1 \rangle$ as well as its spreading toward the pyramidal components $\langle \bar{1}2\bar{1}2 \rangle$ and $\langle 01\bar{1}2 \rangle$ (Fig. 2b).

2nd step of MIF led to significant texture changes (Fig. 2c). The maximum intensity of the practically single component texture $\{11\bar{2}2\}$ was only a bit higher than 5, that is more than twice weaker, than after the first MIF step. According to IPF data the deformation microstructure is reoriented to provide the higher orientation density in a wide range between $\langle \bar{1}2\bar{1}2 \rangle$, $\langle \bar{1}2\bar{1}1 \rangle$, $\langle 01\bar{1}2 \rangle$ and $\langle 02\bar{2}1 \rangle$ directions with three relatively weak maximums of orientations (Fig. 2c). It is necessary to note that spreading of the initial texture was not so expected, as the temperature of the second step was still in single-phase region. However, in our case, the alloy was processed to severe plastic deformation, under which homogeneous recrystallized fine-grained structure has been formed.

Under the 3rd MIF step, near 45° rotation of a texture maximum was found in the $\{0001\}$ pole figure, resulting in a single component having the same intensity (Fig. 2d). The final structure is characterized by a fiber texture, the maximum of orientation density of X axes of which roughly occurs between $\langle 01\bar{1}2 \rangle$ and $\langle \bar{1}2\bar{1}2 \rangle$.

Evolution of the alloy yield strength and its anisotropy under MIF is shown in Table 1 and Figure 3 along with I_{max} and F changes vs strain. As seen, the initial alloy demonstrates strong strength anisotropy: the YS in the pressing direction is nearly 30% higher, than in the transverse one. After the 1st cycle of MIF, the alloy strength in longitudinal direction has not been changed, but it decreased on ~30 MPa in transverse directions, increasing ΔYS value.

Further forging at 300 °C led to significant YS decrease along the billet and some rise in other directions, resulting in anisotropy minimum. After the last MIF step the alloy strength decreased in all directions, lightly increasing the YS anisotropy.

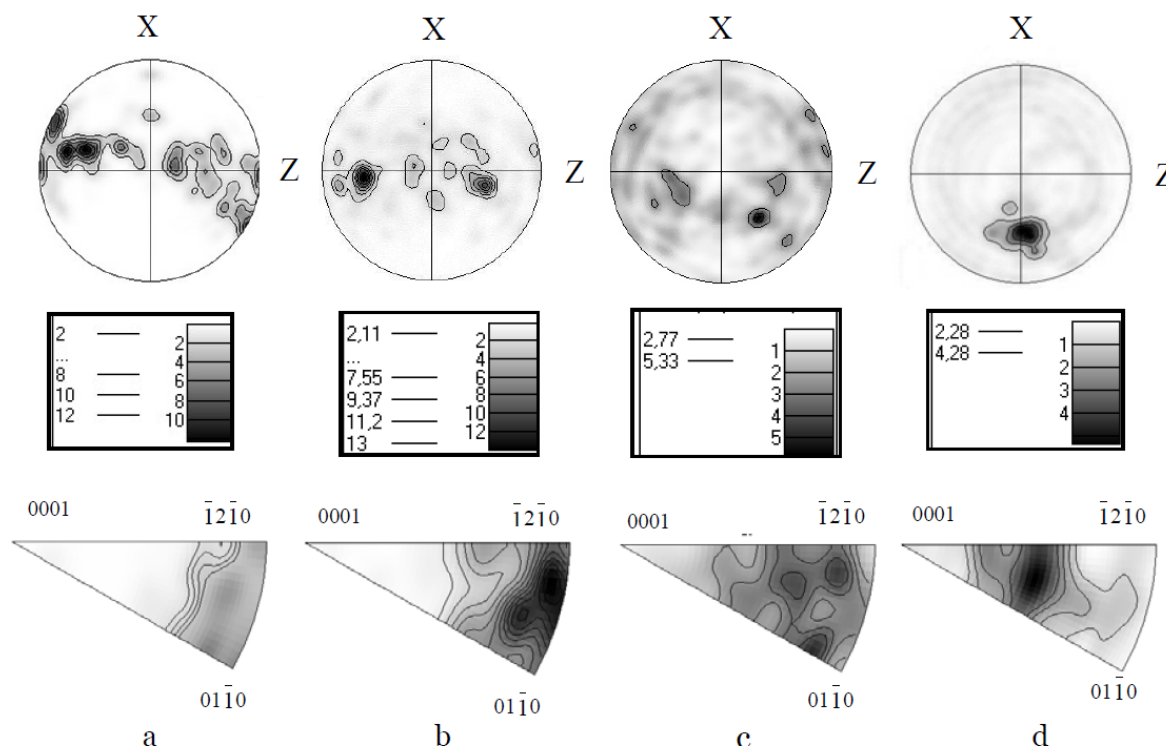


Figure 2. Pole figures {0001} and inverse pole figure for X direction in the initial rod (a) and in the MIF billet after 1st (b), 2nd (c) and 3rd (d) steps.

Table 1. MA14 alloy yield strength in different conditions

Condition	YS, MPa		
	X*	Y	Z
Hot-pressed rod	200	-	130
MIF 1 st step	200	105	95
MIF 2 nd step	145	135	150
MIF 3 rd step	135	115	100

*- X, Y, Z correspond to samples tensile directions (cutting) in Figure 1.

It is well known that except texture, yield strength of a material depends on a number of structural factors [8]. For the current alloy they are: the lattice friction, solutes, precipitates, grain size, dislocation density, etc., which along with the corresponding parameters can influence the yield strength. Although in the present case the average alloy strength is decreased in general, testifying prevailing influence of some softening structural factors, owing to recrystallization, decomposition of magnesium solid solution, formation and coarsening of precipitates under processing at temperatures below solvus, etc. [4-6], it is evident that its anisotropy is strongly governed by the texture.

Due to the data at Figure 3 there could be found some correlations between the changes in the YS anisotropy, maximum texture intensity and integral texture index under the alloy processing. Thus, it can be concluded, that the alloy Δ YS is clearly depends on texture

parameters. These data had also clearly shown that due to sequential changes in loading directions, taking place during MIF performed under decreasing temperature conditions, the texture of the Mg alloy significantly weakens, thereby resulting in decrease in its strength anisotropy.

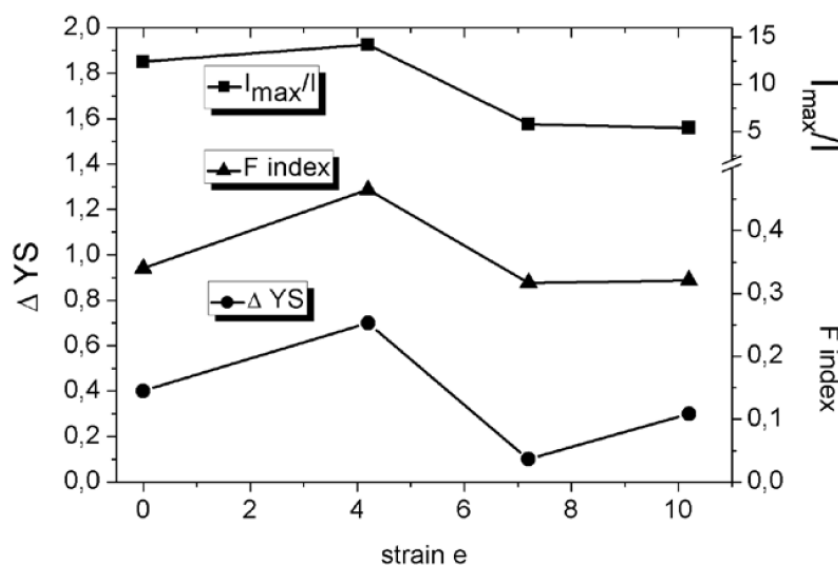


Figure 3. Dependences of the alloy coefficient of yield strength anisotropy (ΔYS), maximum texture intensity ($I_{\max}/I$) and texture index F on MIF strain.

4. Conclusions

MIF, performed under decreasing temperature conditions in the range from 400 to 200°C, results in significant grain refinement and weakening the texture of the hot-pressed Mg alloy MA14, thereby promoting decrease in its yield strength anisotropy. MIF at 400°C has a minor effect on the alloy yield strength and its anisotropy, corresponding to minimum changes in type of texture in spite of strong microstructural changes. Further MIF at 300°C gives the main effect on YS anisotropy due to changes in type of texture and its intensity decrease. There is a strong correlation between the maximum texture intensity, the integral texture index and strength anisotropy. In particular, high texture intensity results in high yield strength anisotropy and, to the contrary, texture weakening promotes a less anisotropy of strength. The latter becomes more pronounced in case of texture type changes.

Acknowledgment

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