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Improvement of Commercial Mg–Al–Zn–Mn Alloys by Rolling

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***Abstract*— The structure and properties of a wrought Mg–Al–Zn–Mn alloy (MA5 brand) were characterized by SEM and direct pole figure (DPF). The crystallographic texture and strength anisotropy of the alloy subjected to unconventional thermomechanical treatment (lengthwise section rolling) clearly show marked improvement in its service parameters due to the formation of a fine-grained structure with low strain anisotropy.**

Keywords—wrought magnesium alloy; anisotropy of properties; crystallographic texture; thermomechanical treatment

I. INTRODUCTION

Magnesium alloys are attractive as structural and functional materials in numerous applications due to a unique combination of high strength and low density, [1, 2]. Among these most promising are wrought alloys because of their strength characteristics and good potential for improving their mechanical, physical and chemical (e.g., resorption in biological fluids) parameters properties as compared to cast alloys. The strength characteristics of wrought magnesium alloys are often defined by sharp texture and strong anisotropy arising during material processing. Strongly different (by a factor of two) compressive and tensile yield strengths of magnesium alloys in the axial direction are typical for the rods produced by extrusion. As is known, homogeneous plastic deformation of magnesium and its alloys is strongly restricted due to the lack of independent slip systems [2].

Today there are many approaches to obtaining high-strength magnesium alloys. For example mechanical alloying and widely known equal channel angular pressing method [3, 4]. However, none of them solves the problems associated with anisotropic properties or efficiency of production.

The modern trend in this line of R & D is designing new magnesium alloys doped with rare earth metals (REM). Such alloys exhibited almost complete absence of texture due to the formation of intermetallic nanoparticles [5–9]. However, in practice it is accompanied by an increase in production cost and pollution hazards. Moreover, such systems as Mg–Al–Zn, Mg–Al, and Mg–Zn–Zr still remain promising for the development of new approaches to their production and processing that would lead to the higher performance of related alloys. It can be achieved through the development of new effective methods of thermomechanical treatment (TMT) that would result in formation of a desired structural state in these alloys.

It is well known that the formability of magnesium alloys is fully determined by the geometry of the deformation zone [14]. However, industrial-scale production of semi-finished wrought magnesium alloys involves simple processes, such as forging, stamping, extrusion, and sheet rolling. New methods of deformation treatment—which differ from sheet rolling or extrusion by the geometry of deformation zones—can be regarded as a challenge for improving the mechanical properties of magnesium wrought alloys containing no REM. Such TMT methods could be expected to markedly improve the grain size, without formation of sharp texture [10–13].

In the present study, we investigated the influence of TMT (by lengthwise section rolling) on the structure formation, texture and strength properties of commercial Mg–Al–Zn–Mn alloy (of MA5 brand).

II. EXPERIMENTAL

In experiments, we used semi-finished industrial rods of magnesium wrought alloy MA5 (9.7Al–0.47Zn–0.26Mn, obtained by extrusion at 400–450°C followed by quenching). TMT was performed by lengthwise section rolling at elevated temperatures and maximum true strain e = 1.59. Tension and compression tests were carried out by using an Instron machine. The microstructure of the alloys was characterized by scanning electron microscope (Quanta FEG600 and Phenom microscopes).

The mechanical anisotropy in the axial direction of rolled rods was characterized by factor K:

$$K = 1 - (\sigma_{0.2}^{\mathrm{comp}} / \sigma_{0.2}^{\mathrm{rens}}) \times 100 \qquad (1)$$

where $\sigma_{0.2}^{\mathrm{comp}}$ and $\sigma_{0.2}^{\mathrm{tens}}$ stand for compressive and tensile yield strengths, respectively. The crystallographic texture was analyzed by using direct pole figures (DPF).

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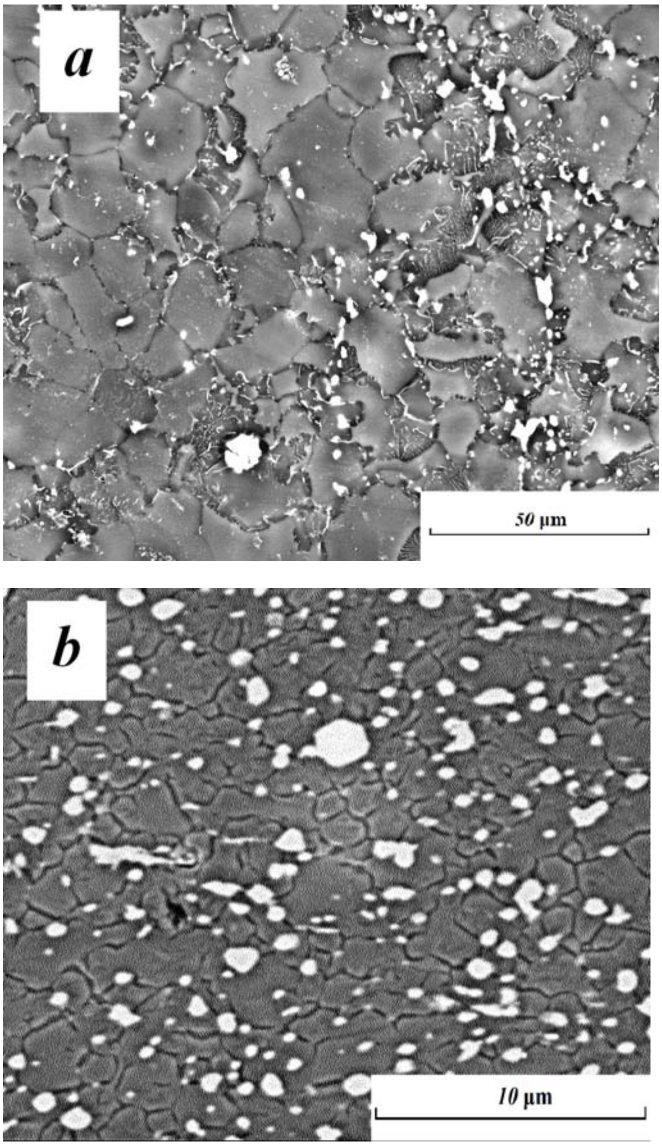

Fig. 1. SEM image of MA5 alloy before (a) and after (b) rolling to $e = 1.59$.

III. RESULTS AND DISCUSSION

Fig. 1 shows SEM images of alloy magnesium MA5 before (a) and after (b) rolling to $e = 1.59$ while Fig. 2, the grain size distribution. These data demonstrate that TMT results in formation of the homogeneous ultra-fine grain structure with an average grain size of 1.5 µm and uniformly distributed intermetallic inclusions. It should also be noted that the commercially available MA5 alloy consists of coarse grains and unevenly distributed intermetallic precipitates. Because of these macroscopic factors, plastic deformation does not develop homogeneously, which gives rise to the anisotropy of the alloy properties.

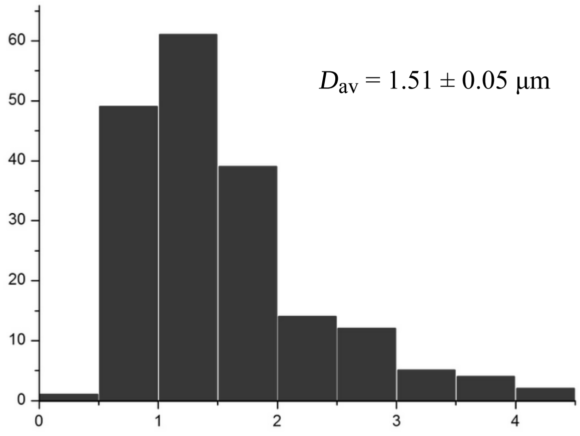

Fig. 2. Grain size distribution of the magnesium MA5 alloy after rolling.

Fig. 3 presents the measured σ0.2 values in comparison with those for commercial alloys produced by extrusion abroad and for domestic MA5 alloy, as-purchased and after TMT. As it seen the yield strength in compression and tension have been markedly improved by TMT. It also follows that our values for the alloy subjected to TMT are superior over those typical of industrial analogs.

Besides anisotropy, the material also exhibited different behavior in compression tests the transverse and axial directions. Fig. 4 presents the results of compression tests for MA5 rod subjected to TMT. The comparison shows that curve 1 exhibits a region that corresponds to activation of twinning and is absent in curve 2. The existence of twinning region (despite a small grain size, below 1 µm) is indicative of the presence of some certain texture.

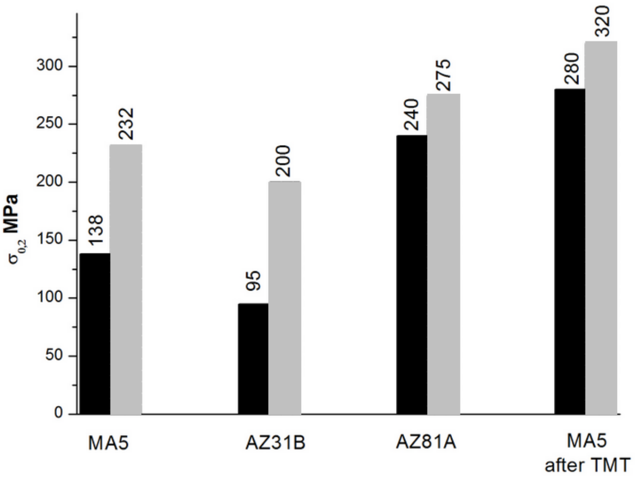

Fig. 3. Comparion of mechanical properties of commercial AZ31B and AZ81A alloys [15, 16] (indicated) produced by extrusion and our data for MA5, as-purchased [1] and after TMT: (1) yield strength (black bars) for compression and (2) yield strength fot tension (grey bars).

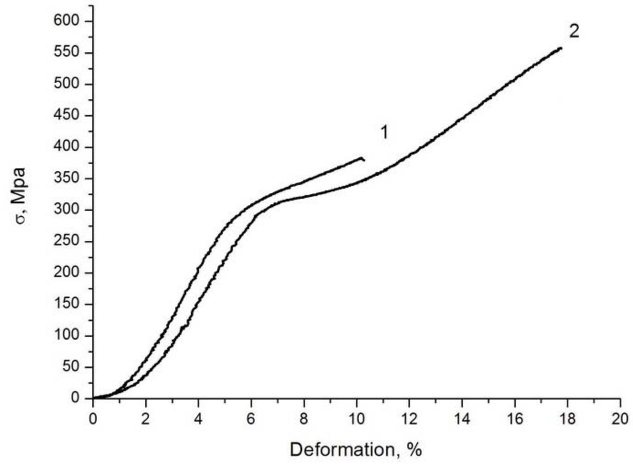

Fig. 4. Results of compression tests for MA5 rod after TMT in the transverse (1) and axial (2) direction.

Fig. 5 shows a direct pole figure (DPF), taken in a reflex from $(11\bar{2}0)$ planes in a cross-section of a rolled rod (subjected to TMT). Symmetrical pole density distribution indicates an axial type of texture. This result implies that the rolling did not afford to get rid of texture formation; moreover, the extent of texture sharpness cannot be derived on the basis of these data.

This result significantly exceeds the values exhibited by commercial wrought magnesium alloys and even exceeds those for cast alloy AZ81A of close chemical composition (Fig. 3).

When the large grains refinement reached, the crystallographic texture development occurs not so acute during treatment. Then it becomes possible to achieve high degrees of deformation and significantly increase the strength characteristics of the alloy.

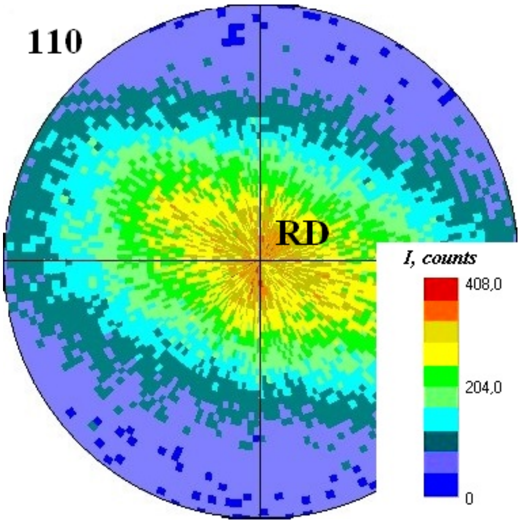

Fig. 5. Direct pole figure $(11\bar{2}0)$ for the cross-section of MA5 rod subjected to rolling.

IV. CONCLUSION

Unconventional thermomechanical treatment, lengthwise section rolling, of commercial Mg–Al–Zn–Mn alloy can be used to markedly improve its strength properties, at their low anisotropy (anisotropy coefficient $K = 12.5\%$).

Our results demonstrate the possibility of upgrading the industrial production of magnesium wrought alloys by the introduction of new process charts that would allow processing of magnesium alloys by using both simple and complex deformation schemes. Such production processes can either replace or complement the existing ones.

ACKNOWLEDGMENT

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