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EFFECT OF PLASTIC DEFORMATION ON THE STRUCTURE AND PROPERTIES OF ALLOY IMV7-1 OF THE Mg – Y – Gd – Zr SYSTEM

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The microstructure and strength properties of hot-pressed alloy IMV7-1 of the Mg – Y – Gd – Zr system are studied after additional cold and hot rolling deformation. It is shown that the strength properties of the pressed alloy can be elevated by cold deformation at an admissible level of ductility.

Key words: magnesium alloys, rare-earth metals, decomposition of supersaturated solid solution, mechanical properties, plastic deformation.

INTRODUCTION

In the recent years much attention in the field of magnesium alloys with rare-earth metals (REM) has been devoted to alloys of the Mg – Y – Gd – Zr system, which possess very high strength properties at room and elevated temperatures [1 – 5]. Deformable magnesium alloy IMV7-1 with composition Mg – (5 – 6.5)% Y – (3.5 – 5)% Gd – (0.15 – 0.7)% Zr [6] possesses high strength characteristics after hot pressing (extrusion) with about 90% compression and subsequent artificial aging [5].

The aim of the present work was to study the effect of additional cold or hot plastic deformation on the properties of hot-pressed alloy IMV7-1.

METHODS OF STUDY

We studied a strip from alloy IMV7-1 with cross section 200 × 40 mm. The strip was produced at a plant by hot pressing of a round ingot with 92% deformation.

By the data of the chemical analysis the alloy contained (in wt.%) 4.71 Y, 4.58 Gd, and 0.31 Zr. This virtually matched the standardized composition of alloy IMV7-1 according to certificate [6]. The subsequent plastic deformation was performed by rolling. A part of the hot-pressed strip of alloy IMV7-1 was subjected to cold rolling over the direction of the hot pressing and the other part was subjected to hot rolling in the transverse direction. The cold rolling and the hot rolling were implemented in a DUO 320 mill in several passes. The cold rolling reduction per pass was about 1%; the total reduction was 9%. The preform for the hot rolling was heated in the range of 450 – 480°C for 1 h. Intermediate heating operations were conducted at the same temperatures in three passes with a hold of 15 min. The average degree of the deformation between the intermediate heating operations was about 16%; the total deformation was 65%.

We studied the structure and the properties of the strip after the deformation and heat treatment by the methods of light microscopy, measurement of the hardness and of the electrical resistivity and tensile testing. The microstructure was analyzed under a REICHERT MeF light microscope. The laps for the study were prepared by mechanical polishing followed by etching in a reagent consisting of 60% $C_2H_4(OH)_2$ + 20% CH_3COOH + 1% NH_3 + 19% H_2O or by chemical polishing in a 30% aqueous solution of HNO_3 which played the role of an etchant simultaneously. The resistivity was measured in a device based on a BSZ-010-2 micro ohmmeter for specimens with functional part 6 mm in diameter and working length 22.8 mm. The error in the determination of the resistivity was ± 0.7%. The hardness was evaluated by the Brinell method at a load of 250 kg using a TSh-2M device and a ball 5 mm in diameter. The indents were obtained in a plane parallel to the major surface of the strip. The tensile tests were conducted in an Instron 3382

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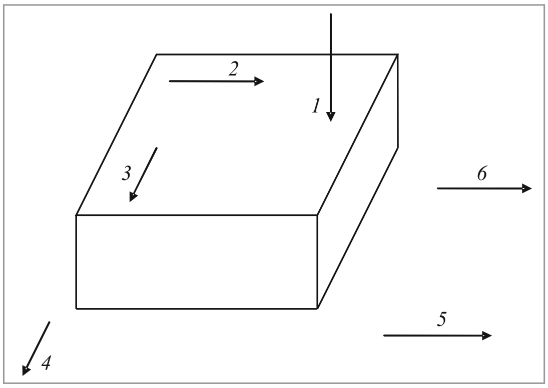

Fig. 1. Scheme of the directions of cold and hot rolling of the strip of alloy IMV7-1 of the Mg – Y – Gd – Zr system: *1*) plane of measurement of the hardness; *2*, *3*) directions of cold and hot rolling, respectively; *4*, *5*) directions of tension in the mechanical test after pressing and hot or cold deformation, respectively; *6*) direction of pressing of the plate.

universal testing machine. Figure 1 presents schematically the directions of rolling of the strip and of the tensile tests. The direction of the electric current in the specimen for measurement of the resistivity coincided with the direction of tension of the specimens in the mechanical tests.

RESULTS AND DISCUSSION

Alloy IMV7-1 hardens during aging. As a rule, the hardening is the highest after a hold at 200°C [5]. In the present work we chose this temperature for aging the alloy after cold and hot rolling. For comparison, we studied the alloy after hot pressing without subsequent rolling. The results of the measurement of the hardness and of the resistivity of alloy IMV7-1 after the aging are presented in Fig. 2. We established that the hardness varies with the aging time typically for magnesium alloys with rare-earth metals of the yttrium subgroup. The dependence $HB = f(\tau_{ag})$ has a specific incubation period (up to about 8 h) in the beginning of the aging, when the hardness grows not considerably, and a stage of abrupt growth of the hardness to a maximum value (Fig. 2*a*). The resistivity under short holds (up to about 8 h) also varies little, and decreases considerably when the aging time is increased (Fig. 2*b*), which indicates substantial depletion of the magnesium solid solution of yttrium and gadolinium. Zirconium dissolves little in the magnesium solid solution of alloys of the Mg – Y – Gd – Zr system, and its participation in this process is not taken into account in the aging process [7].

These data show that aging at 200°C is accompanied with growth in the hardness of the alloy both after hot pressing and after additional cold and hot rolling (Fig. 2*c*). The highest values of the hardness are close for all the three states and are attained in about 100 h, i.e., 1170 MPa (hot pressing), 1185 – 1190 MPa (hot pressing + cold rolling) and 1160 – 1190 MPa (hot pressing + hot rolling).

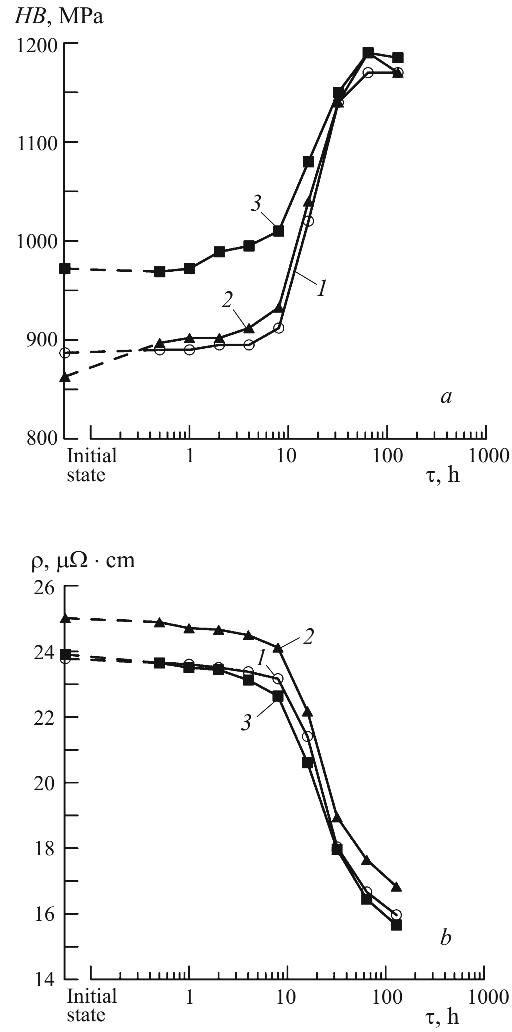

Fig. 2. Dependence of the hardness (*a*) and resistivity (*b*) of alloy IMV7-1 on the duration of aging at 200°C: *1*) after hot pressing (HP); *2*) after HP and hot rolling with ε = 65%; *3*) after HP and cold rolling with ε = 9%.

The general behavior of the hardness of the alloy in the hot-pressed condition and after the additional cold or hot rolling is similar. However, some differences occur in the values of the hardness and its changes for each initial condition. In the case of cold rolling the hardness values are maximum before cold rolling. A low but noticeable increase in the hardness is observed at a shorter aging time (starting with 2 h) after hot pressing without subsequent rolling. In the alloy subjected to hot rolling after the pressing the initial values or the hardness are minimal, but grow noticeably even after a short aging hold of about 0.5 h. Then the growth of the hardness also decelerates in the hot-pressed condition without rolling. Further aging causes marked growth of the hardness at the same aging time as in the hot-pressed alloy.

The variation of the resistivity (ρ) of alloy IMV7-1 in the hot-pressed condition and after the additional cold and hot rolling is similar on the whole, but some special features exist in each initial state. For example, the start of abrupt de-

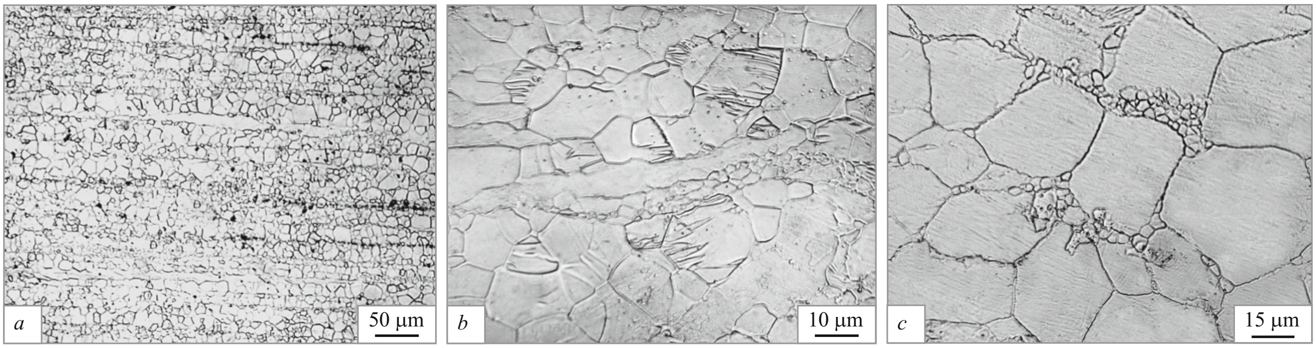

Fig. 3. Microstructure of alloy IMV7-1 in different states: *a*) after hot pressing; *b*, *c*) after hot pressing and cold and hot rolling, respectively; *a*) the plane of the lap is parallel to the pressing direction; *b*, *c*) parallel to the rolling direction.

crease in ρ, which indicates acceleration of the precipitation of yttrium and gadolinium from the supersaturated magnesium solid solution, starts earlier after cold rolling (about 2 h) than after hot pressing without rolling. When the aging time is increased to about 30 h, the values of ρ become closer. In the case of hot rolling the most typical feature of the resistivity is a noticeably higher value than after hot pressing and after hot pressing with subsequent cold rolling.

Comparing the curves describing the variation of the hardness and of the resistivity for the three states of the alloy we established that rolling, especially the cold one, accelerated the decomposition of the magnesium-base supersaturated solid solution. However, this acceleration was not considerable. Such conclusion may be derived from the small shift of the curves describing the variation of the hardness and of the resistivity in some regions toward shorter aging holds for the alloy subjected to cold or hot rolling as compared to the alloy pressed without subsequent rolling.

The higher values of ρ of the alloy after hot rolling than after the other two deformation variants (Fig. 2*b*) seem to be caused by changes in the crystallographic texture of the strip, which forms during its rolling in the direction perpendicular to that of the hot pressing and cold rolling. The lower hardness of the alloy after hot rolling as compared to the initial state (after hot pressing) is explainable by finish of the recrystallization process already in the hot-pressed strip, which is confirmed by the results of the study of the microstructure (Fig. 3). The considerable decomposition of the magnesium solid solution in the alloy during aging indicates that the solution has been quite supersaturated during the air cooling of the strip after the hot pressing and hot rolling.

For a more exhaustive estimate of the effect of plastic deformation and subsequent aging on the possibility of additional hardening of alloy IMV7-1 we determined its mechanical properties in the following states: (*1*) hot rolling with ε = 9% after hot pressing, (*2*) cold rolling with ε = 9% after hot pressing plus subsequent aging, (*3*) hot rolling with ε = 65% after hot pressing, and (*4*) hot rolling with ε = 65% after hot pressing and subsequent aging. The aging mode (200°C, 16 and 24 h) was chosen on the basis of the data obtained (Fig. 2*a*) with the aim to provide a high strength at enough ductility. With allowance for the acceleration of the decomposition of the supersaturated solid solution in cold rolling, the aging time of alloy IMV7-1 after the latter was shortened from 24 to 16 h. The specimens after the cold rolling and after the hot rolling were cut over the direction of the deformation.

Table 1 presents the results of mechanical tests of alloy IMV7-1 in the states mentioned and, for comparison, after hot pressing (without rolling) and aging as in [5]. It can be seen that cold plastic deformation raises the mechanical properties, especially the yield strength but lowers the ductility, which still remains not very low. Hot plastic deformation does not virtually raise the strength properties of the hot-pressed strip without additional aging, but lowers the ductility. Aging at 200°C promotes additional growth in the strength properties in all the states studied. However, after such aging the growth in the strength properties is accompanied by decrease in the ductility and becomes too low for magnesium alloys subjected to cold or hot deformation.

The study of the microstructure of the hot-pressed strip has shown that it is represented by fine equiaxed recrystallized grains and some deformed grains of magnesium solid solution stretched over the direction of the deformation (Fig. 3*a*). The microstructure of the alloy after hot pressing

TABLE 1. Mechanical Properties of Alloy IMV7-1 after Different Treatment Variants

Treatment	σ_r, MPa	$\sigma_{0.2}$, MPa	δ, %
Hot pressing [5]	320	230	21.4
Hot pressing + aging at 200°C for 24 h [5]	400	315	6.4
Hot pressing + cold rolling (9%)	360	320	10.1
Hot pressing + cold rolling (9%) + aging at 200°C for 16 h	415	360	2.4
Hot pressing + hot rolling (65%)	305	235	12.6
Hot pressing + hot rolling (65%) + aging at 200°C for 24 h	400	280	3.3

Note. The tests were performed at 20°C over the rolling direction.

and cold rolling ($\varepsilon = 9\%$) is also represented by fine recrystallized grains and some deformed grains of magnesium solid solution, but strain-induced twins are observable inside some fine equiaxed grains (Fig. 3*b*). The structure of the alloy after hot pressing and hot rolling ($\varepsilon = 65\%$) consists of rather coarse equiaxed recrystallized grains formed in heating under rolling, over the boundaries of which we observed smaller recrystallized grains (Fig. 3*c*). Twins are absent except for a little number of individual grains. The structure of all the specimens also contains individual fine crystals of an α-Zr phase arranged in chains over the pressing direction.

CONCLUSIONS

1. Cold and hot rolling of hot-pressed alloy IMV7-1 of the Mg – Y – Gd – Zr system causes some acceleration of the decomposition of the supersaturated magnesium solid solution, but the general pattern of the kinetics of the decomposition and the hardening is preserved during aging.

2. Cold plastic deformation by rolling of hot-pressed alloy IMV7-1 makes it possible to elevate its mechanical properties without aging, especially the yield strength, at an acceptable level of ductility.

3. Hot rolling of hot-pressed IMV7-1 is less effective for raising its strength properties than cold rolling due to the development of recrystallization processes during the heating.

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