NONEQUILIBRIUM PHASE TRANSFORMATIONS DURING SOLID SOLUTION DECOMPOSITION IN MAGNESIUM ALLOYS CONTAINING THE RARE-EARTH METALS OF DIFFERENT SUBGROUPS

НЕРАВНОВЕСНЫЕ ФАЗОВЫЕ ПРЕВРАЩЕНИЯ ПРИ РАСПАДЕ ТВЕРДОГО РАСТВОРА В МАГНИЕВЫХ СПЛАВАХ, СОДЕРЖАЩИХ РЕДКОЗЕМЕЛЬНЫЕ МЕТАЛЛЫ РАЗЛИЧНЫХ ПОДГРУПП

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Abstract: *The nonequilibrium phase transformation during decomposition of Mg supersaturated solid solutions, containing two rare-earth metals of the different subgroups (cerium and yttrium) are presented and generalized. These processes in the alloys of ternary systems differ from those in the alloys of the adjoining binary systems. They reveal also the similar features in kinetics and the nonequilibrium phase formed during solid solution decomposition*

KEYWORDS*: MAGNESIUM ALLOYS, RARE-EARTH METALS, SOLID SOLUTION DECOMPOSITION, PHASE TRANSFORMATION.*

1. Introduction

Investigations of magnesium alloys, connected with development of light structural materials with high strength at near room and elevated temperatures indicated, that the best results could be achieved, if the rare-earth metals will be used as alloying elements [1,2]. Action of the individual rare-earth metals on mechanical properties of magnesium is different and this phenomenon is caused by different solubility of every rare-earth metals in solid magnesium and different behavior of them during nonequilibrium transformation consisting of decomposition of the supersaturated magnesium solid solution. In the binary magnesium alloys with the rare-earth metals, belonging to the same subgroup, either yttrium or cerium one, kinetics of the magnesium solid solution decomposition and accompanying this process structural transformations have the close features. But they are different for the rare-earth metals of different subgroups [2]. In the alloys with elements of the cerium subgroup decomposition of the magnesium supersaturated solid solution is accompanied with successive formation zones GP, metastable phases β" (ordering of the Mg_3Cd type), β' and equilibrium phase β [3]. In the alloys with elements of the yttrium subgroup decomposition of the magnesium supersaturated solid solution is accompanied with β´´ phase (Mg_3Cd type ordering), orthorhombic plate-like phase β´ and equilibrium phase β [4].

The aim of this publication is to review the results of the investigations of the supersaturated solid solution decomposition in the ternary magnesium alloys containing simultaneously two rare-earth metals belonging to different subgroups accompanied by the nonequilibrium phase transformations. These alloys attract a great attention now as the materials with better combination of advantages, which inherent to magnesium alloys containing the rare-earth metals of one of the subgroups.

2. Materials and methods

By this time decomposition of the supersaturated solid solution in the ternary alloys with two rare-earth metals of different subgroups was studied only in several systems. They are the systems Mg-Ce-Y, Mg-Nd-Y, Mg-Sm-Y, Mg-Sm-Tb, Mg-Sm-Er [5-10]. The supersaturated magnesium solid solutions in them were obtained in them after of annealing at enough high temperatures followed by quenching from them. Annealing temperatures were chosen basing on the known phase diagrams. Decomposition of the supersaturated solid solutions proceeded during isothermal ageing of the quenched samples at different temperatures in the 200-250ºC range. It was checked by the hardness and electrical resistivity measurements and observations of microstructure using optical and transmission electron microscopy (TEM). Preparation of the specimens for the microscopic observations, methods of determination of their properties and the used equipment are described in details in [5-10].

3. The similar features of the magnesium solid solution decomposition

Analysis of the results of the hardness and electrical resistivity measurements during ageing of the magnesium alloys above mentioned different systems revealed a number of the similar features in kinetics of the supersaturated solid solution decompositions. The typical curves of the hardness and electrical resistivity change during ageing for the alloys are presented in Figs.1-4. They show, in general, increase of hardness with increasing ageing time up to maximum with decreasing hardness then. But the hardness increase is not always gradual. In some cases two stages of the hardness increase occur. At the first stage the hardness increase is insignificant and at the second stage after kink the hardness increases steeply up to maximum. In the Figs.1-4 some hardness curves are shown for some binary alloys. One can see, that in the binary alloys of magnesium with the rare-earth metals of the cerium subgroup, Nd and Sm, only one stage in the hardness increase can be seen, unlike binary alloys with the rare-earth metals of the yttrium subgroup, Y and Tb, where two stages of the hardness increase can be seen. Such a change of the hardness during isothermal ageing is inherent to magnesium alloys with other rare-earth metals of each of the both subgroups [2]. Another significant difference in the hardness curves belonging to the binary magnesium alloys with the rare-earth metals of different subgroups is the higher hardness values for the alloys with elements of the last subgroup [2].

The first similar feature of the different ternary systems by hardness change during ageing consist of acceleration of the solid solution decomposition, when the element of the cerium subgroup (Ce, Nd) is added to the alloy containing element of the yttrium subgroup (Y) (Figs 1, 2) and deceleration of it, when the element of yttrium subgroup (Er) is added to the alloy containing element of cerium subgroup (Fig.3). This effect becomes evident, if dispositions of the hardness maxima on the curves relative to the ageing time axis are compared. With change of the ratio between contents

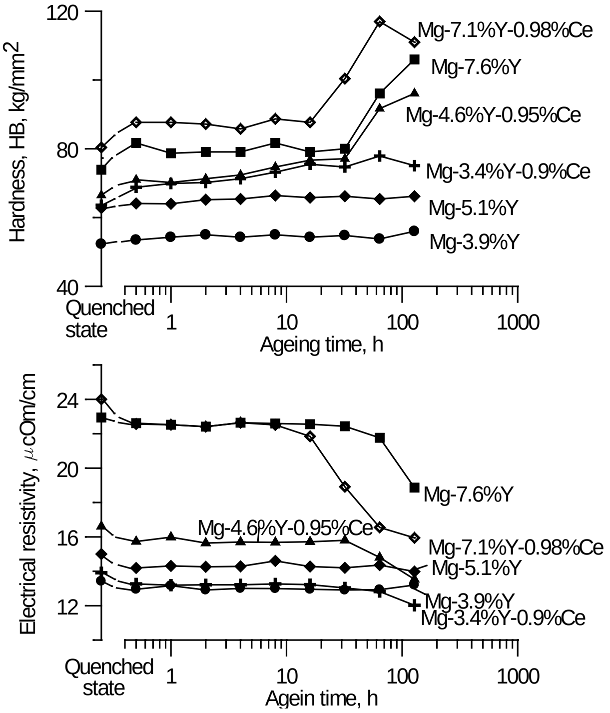

Fig.1. *Variation of the hardness and electrical resistivity upon isothermal aging of the Mg-Ce-Y alloys at 200 ºC [5].*

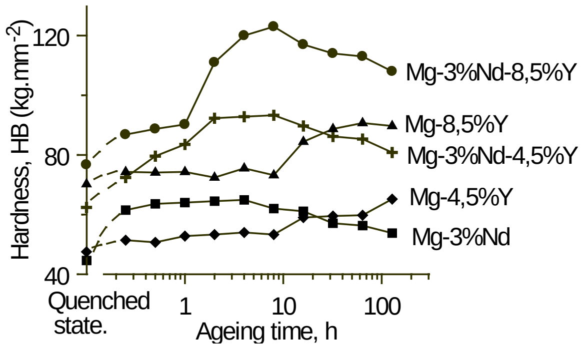

Fig.2. *Variation of the hardness upon isothermal aging of the Mg-Nd-Y alloys at 225 ºC [7].*

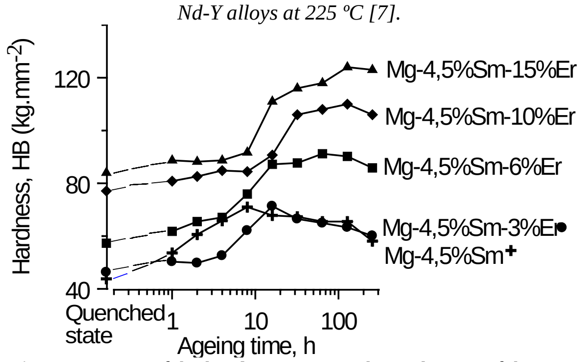

Fig.3. *Variation of the hardness upon isothermal aging of the Mg-Sm-Er alloys at 200 ºC [9].*

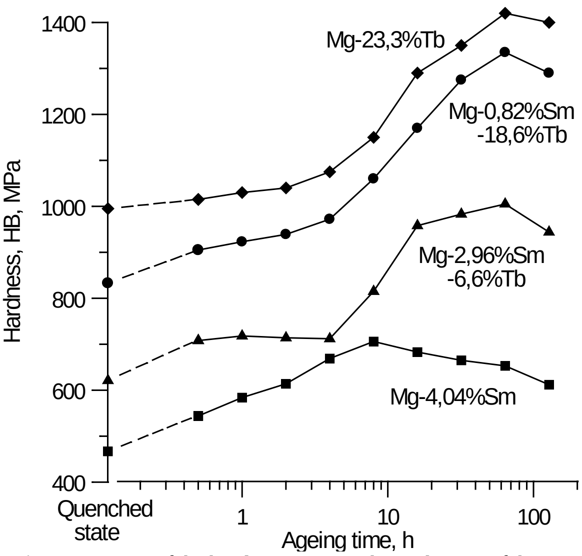

Fig.4. *Variation of the hardness upon isothermal aging of the Mg-Sm-Tb alloys at 200 ºC [10].*

of the rare-earth metals in the alloys in direction of increase of that belonging to the yttrium subgroup instead of that belonging to the cerium subgroup the hardness values become more and character of the hardness curves changes gradually from that being typical for the alloys with elements of cerium subgroup to that for the alloys with elements of yttrium subgroup. This can be seen clearly for the Mg-Sm-Tb alloys (Fig.4).

Another similar feature of the different ternary systems of magnesium alloys with the rare-earth metals of different subgroups is increase of the hardness maximum values, when the element belonging to the cerium subgroup is added to the alloys containing element of yttrium subgroup. This feature is evident in the alloys of the Mg-Ce-Y and Mg-Nd-Y (Figs.1, 2).

Investigations of the ternary magnesium alloys of above mentioned systems indicated, that the phases formed in them during magnesium solid solution decomposition at the stages of hardening were similar and nonequilibrium (metastable) ones. These phases were also typical for the binary magnesium alloys with the rare-earth metals of cerium and yttrium subgroups. No other types of the precipitated phases were observed in the ternary alloys.

In Fig.5 the microstructure and the related electron pattern of the Mg-Sm-Tb alloy are presented. The alloy was solution treated and aged then at 200ºC for 8 h. Such an ageing regime corresponds to the early stage of the solid solution decomposition and, therefore, the precipitates formed are not seen clearly. However, electron pattern corresponding to this structure indicates certain decomposition. They are two sorts. One of these sorts is the system of the point-like superstructure reflexes disposed by every three of them on the lines corresponding length between the large central reflex (000) and that of (100) type belonging to the Mg solid solution. These three superstructure reflexes divide the length between reflexes (000) and (100) into three equal parts. Such a disposition of the point-like superstructure reflexes corresponds to the precipitates of the orthorhombic metastable phase β′ observed on the binary magnesium alloys with the rare-earth metals of yttrium subgroup [4]. Along with these point-like superstructure reflexes, the electron pattern contains the parallel continuous lines passing in direction from the central reflex (000) to the reflex (100) of magnesium solid solution. Such parallel lines correspond to the tracks of the reciprocal lattice of the electron diffraction created by Mg solid solution and its existence indicates formation of the zones GP, that is typical for magnesium alloys with the rare-earth metal of cerium subgroup [3].

In Fig.6 microstructures of the Mg-Sm-Y system alloy aged to stage some more the hardness maximum is presented [8]. In its structure shown at two magnifications the plate-like large crystals can by seen. Morphology of these crystals indicates them to be typical ones for precipitates formed during decomposition of the binary magnesium alloys with the rare-earth metals of cerium subgroup. In this event, they are the particles of the metastable phase being that observed in the decomposed Mg-Sm alloys. In the areas between the large plate-like crystals in the structure, presented in Fig.6 there are also the very disperse precipitates. These disperse crystals could be identified using electron patterns as the metastable orthorhombic phase β′, which is typical for the decomposed magnesium solid solution in the binary magnesium alloys with the rare-earth metals of yttrium subgroup.

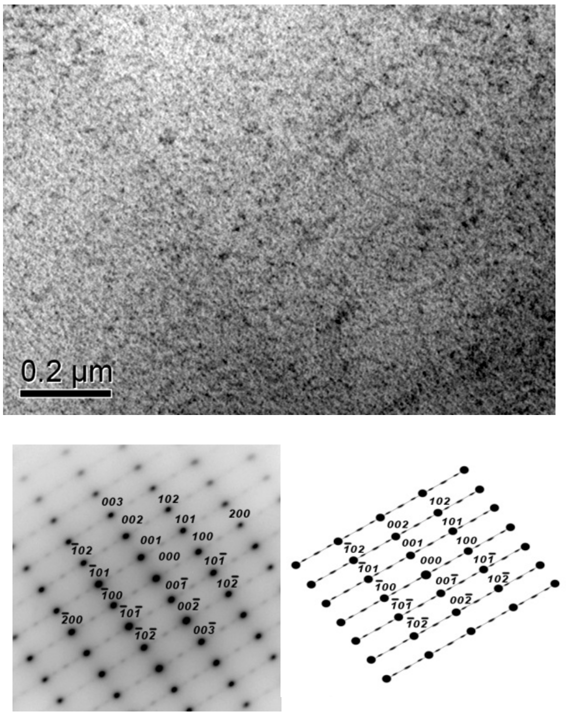

Fig.5. *Microstructure and related electron pattern with its scheme of the alloy Mg-4.35% Sm-11.5% Tb after ageing 200ºC, 2h [10].*

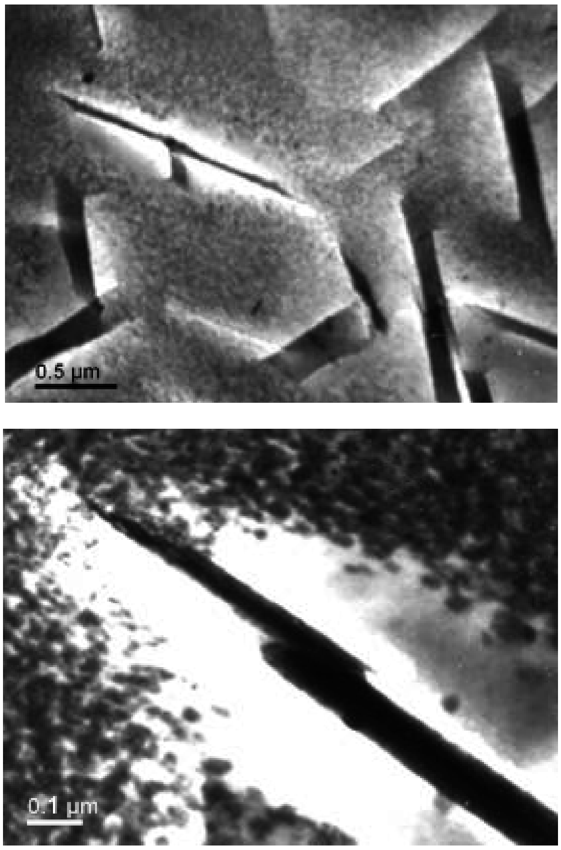

Fig.6. *Microstructure of the alloy Mg-5.2% Sm-5.2% Y after ageing 220ºC, 200 h at different magnifications [8].*

4. Conclusions

The nonequilibrium transformations during decomposition of the supersaturated solid solutions in the ternary The similar feature in formation of the phases during magnesium alloys with the rare-earth metals of different subgroups are characterized by similar features.

1. The similar features in kinetics are acceleration of the solid solution decomposition and increase of the hardness maximum, when a rare-earth metal of the cerium subgroup is added to the binary magnesium alloys with rare-earth metals of the yttrium subgroup.
2. solid solution decomposition is that the only formed phases are those occurred in the binary magnesium alloys with the respective rare-earth metals of both subgroups. The phases of both binary systems being disposed within the magnesium solid solution simultaneously.

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