

EFFECT OF HOT PLASTIC DEFORMATION ON DECOMPOSITION OF MAGNESIUM SOLID SOLUTION CONTAINING RARE-EARTH METALS

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Abstract: In the work effect of the rare-earth metals (REM) on structure of the decomposed Mg supersaturated solid solution after hot deformation was investigated. Investigation indicated Mg solid solution decomposition during hot deformation with precipitation of the RE-rich particles preferably on the Mg grain boundaries and boundaries between originated blocks. Precipitations on the grain and block boundaries prevent recovery, recrystallization, the grain growth, and increase plasticity of alloys.

KEYWORDS: MAGNESIUM ALLOYS, RARE-EARTH METALS, PLASTIC DEFORMATION, SOLID SOLUTION DECOMPOSITION, STRUCTURE.

1. Introduction

Polycrystalline magnesium and magnesium-based alloys are characterized by low plasticity during plastic deformation at near-room temperatures [1]. This is explained by the fact that the deformation of hexagonal close-packed crystal lattice is realized via sliding along single type of atomic planes, i.e., the basal sliding is realized. Other deformation mechanisms for the magnesium crystal lattice, in particular, twinning and pyramidal-plane sliding, are also possible, but their role is minor. Grain boundaries in magnesium and magnesium solid-solution prevent the development of basal sliding. This results in the fact that the crystal lattice in grain areas adjacent to boundaries becomes substantially more distorted than that of grain body. With increasing deformation temperature plasticity of magnesium and its alloys increases and this phenomenon can be explained by recovery processes and recrystallization. In the present study, we report results of investigation of the decomposition effect of the supersaturated magnesium solid solution, containing the rare-earth metals (REMs) on the structure-formation of magnesium solid-solution grains during hot plastic deformation and plasticity.

2. Materials and methods

The studies were performed using pure magnesium and magnesium alloys containing neodymium, yttrium, samarium, gadolinium, and dysprosium, which exhibit the substantial solubility in solid magnesium and a decrease of the solubility with decreasing temperature. The magnesium alloys with the aforementioned REMs are inclined to dispersion hardening [2]. The alloys were prepared by melting and cast then into a metallic mould. The obtained ingots were subjected to hot pressing to form rods 10 mm in diameter (the reduction of area is 90%). Samples were prepared from these rods and subjected to quenching to obtain the supersaturated solid solution. After heat treatment and plastic deformation (which includes the compression and tension), the test portion of samples was cut, and the structure was revealed using chemical polishing in a concentrated nitric acid. Simultaneously, the chemical polishing allows us to reveal the microstructure of samples; thus, the samples were not subjected to additional etching. In some cases, the mechanical polishing and etching in the 0.5% nitric-acid solution in alcohol were performed in order to reveal precipitates during solid solution decompositions. In addition to the optical microscopy, a number of structure investigations were performed using transmission electron microscopy (TEM). The foils for this study were prepared by thinning in 20% nitric acid in ethyl alcohol and rinsed clean ethyl alcohol. A JEM-200A transmission electronic microscope operating at 150 kV was used.

3. Results and discussion

In Fig.1a the structure of the pure magnesium is presented. The sample was previously annealed at high temperature 535°C

so, that the large grains were obtained. In the micrograph only two grains are seen and one of them is rounded by other. The sample was deformed then at room temperature and one can see significant distortion of the crystal lattice in area near the grain boundary, which is more, than the lattice distortions in the grain bodies, as could be expected in according to [3]. With increasing deformation temperature, recovery processes occur first of all within these areas with highly distorted crystal lattice, which are accompanied by the formation of blocks, and the recrystallization starts. In accordance with the more intense deformation near the grain boundaries in these areas the more and smaller blocks can be distinguished (Fig.1b).

The following data on the structure of REM-containing magnesium alloys subjected to hot deformation were obtained. The presence of REMs in the alloys was found to lead to the precipitation of disperse particles from the supersaturated magnesium solid solution, which are located at grain boundaries. As a result, the development of recovery and recrystallization processes within areas adjacent to grain boundaries decelerates. Figures 2a and 2b obtained by TEM demonstrate the decomposition of supersaturated magnesium solid solution at grain boundaries and blocks formed near them. One can see the larger precipitates to be disposed on the grain boundary and the smaller precipitates to be disposed on the block boundaries. In both cases the precipitates detain movement of dislocations and retain by this the grain growth. Optical micrographs in Figures 2c and 2d show the initiation of blocks and recrystallization nuclei at boundaries of the deformed grains remaining them extended form and consisting of the blocks. The subsequent increase in the deformation temperature is accompanied by the development of recrystallization as the small grains mainly along boundaries of initial large partially deformed grains (Fig. 2e). At high deformation temperatures, the recrystallization occurs completely (Fig. 2f). During hot deformation under creeping conditions, the presence of disperse REM-containing particles favors the formation of stepped grain boundaries (Fig. 2g).

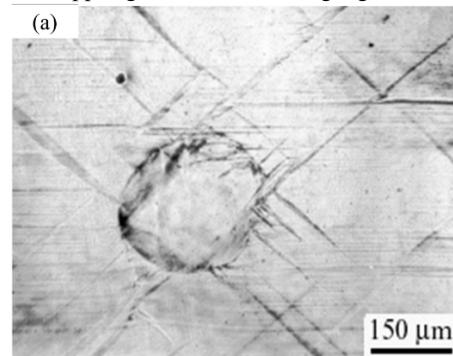


Fig. 1. Microrelief of magnesium samples subjected annealing at 535°C and (a) 5% tension at 20°C and (b) 5% tension at 350°C, block-formation.

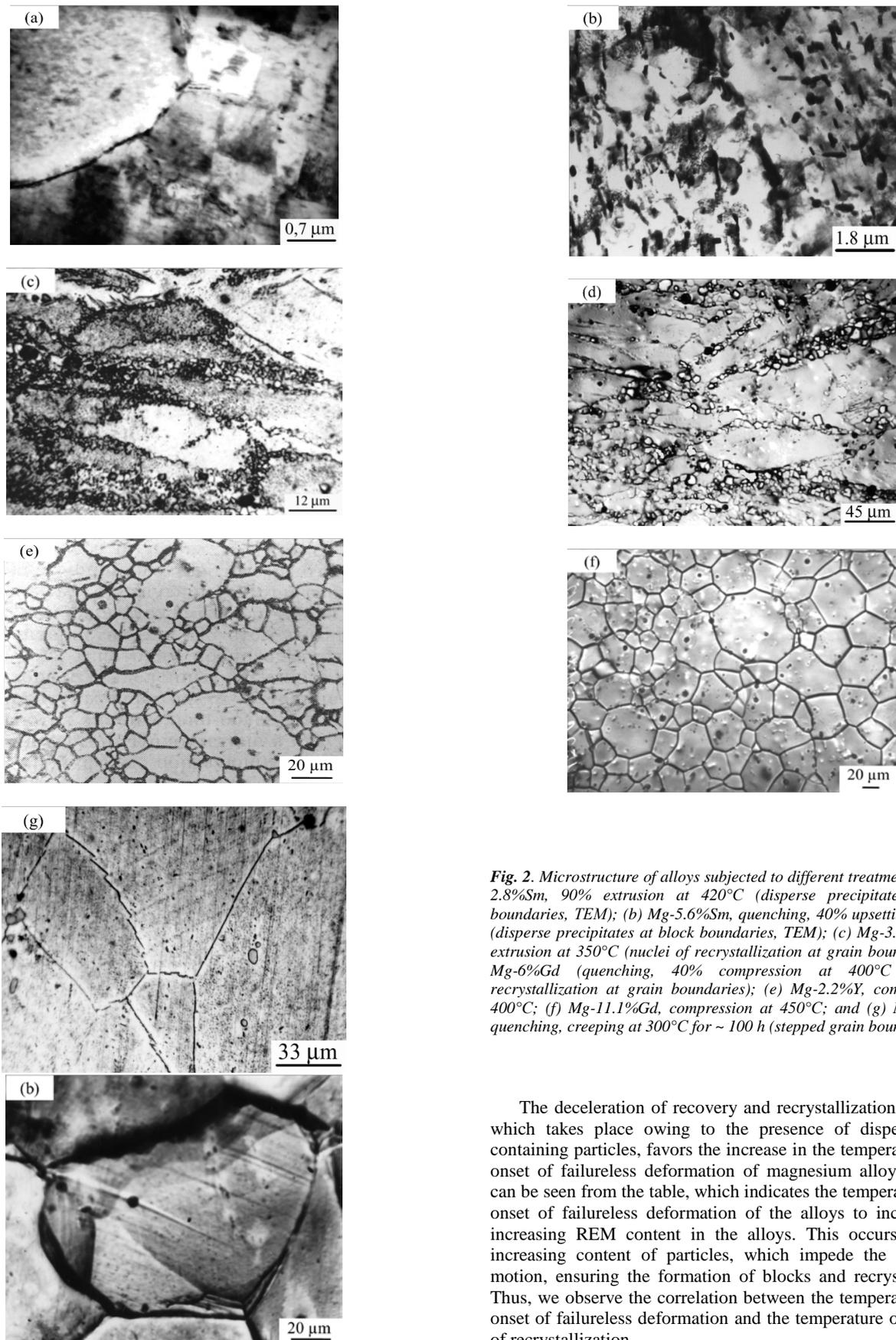


Fig. 2. Microstructure of alloys subjected to different treatments: (a) Mg-2.8%Sm, 90% extrusion at 420°C (disperse precipitates at block boundaries, TEM); (b) Mg-5.6%Sm, quenching, 40% upsetting at 450°C (disperse precipitates at block boundaries, TEM); (c) Mg-3.2%Nd, 90% extrusion at 350°C (nuclei of recrystallization at grain boundaries); (d) Mg-6%Gd (quenching, 40% compression at 400°C (onset of recrystallization at grain boundaries); (e) Mg-2.2%Y, compression at 400°C; (f) Mg-11.1%Gd, compression at 450°C; and (g) Mg-3.2%Nd, quenching, creeping at 300°C for ~ 100 h (stepped grain boundaries).

The deceleration of recovery and recrystallization processes, which takes place owing to the presence of disperse REM-containing particles, favors the increase in the temperature of the onset of failureless deformation of magnesium alloy. This fact can be seen from the table, which indicates the temperature of the onset of failureless deformation of the alloys to increase with increasing REM content in the alloys. This occurs owing to increasing content of particles, which impede the dislocation motion, ensuring the formation of blocks and recrystallization. Thus, we observe the correlation between the temperature of the onset of failureless deformation and the temperature of the onset of recrystallization.

Table. Results of compression tests for magnesium and magnesium REM-containing alloys

| REM content, wt % | Temperature of solution treatment before quenching or annealing | | Temperature of the onset of failureless deformation, °C | Temperature of the recrystallization onset, °C |
|-------------------|---|-----------------|---|--|
| | Operation | Temperature, °C | | |
| - | Annealing | 435 | 150-175 | 200-250 |
| 3.2 Nd | Quenching | 500 | 300-325 | 400-450 |
| 5.6 Sm | Quenching | 520 | 300-325 | 350-400 |
| 11.1 Gd | Quenching | 520 | 300-325 | 450-500 |
| 21.5 Gd | Quenching | 520 | 450-475 | 450-500 |
| 19.1 Dy | Quenching | 540 | 300-325 | 400-450 |
| 12.7 Y | Quenching | 550 | 300-350 | 400-450 |

4. Conclusions

1. Hot plastic deformation of magnesium and its alloys is accompanied by substantial crystal-lattice distortion within areas adjacent to grain boundaries.

2. The decomposition of magnesium solid solution during hot deformation leads to the precipitation of disperse REM-containing phase particles on grain boundaries.

3. Disperse REM-containing particles precipitated from the magnesium solid-solution decelerate the recovery and recrystallization processes and, thus, increase the temperature of possible substantial failureless deformation of magnesium alloys.

4. Precipitated disperse REM-containing particles favor the formation of stepped grain boundaries during hot deformation under creeping conditions.

5. References

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