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MICROSTRUCTURE EVOLUTION OF AZ91D MAGNESIUM ALLOY DURING EXTRUSION-TORSION SIMULTANEOUS PROCESSING

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Abstract

Extrusion-torsion simultaneous processing is a very new and useful technique for fabricating a rod-shape material with random and fine structures. The obtained sample was especially strengthened and grain-refined on the surface. By the addition of torsion from 10 rpm to 25 rpm, the crystal orientation of AZ91D magnesium alloy was drastically changed from basal crystalline orientation to random orientation. Crystal grain which occurred through the dynamic recrystallization tended to coarsen with the increase of extrusion-torsion temperature. Grain refinement under 2 μm was achieved at the lowest extrusion-torsion temperature of 523 K. Torsion speed had a slight influence on the microstructure evolution and hardness distribution compared with extrusion-torsion temperature.

Introduction

Magnesium alloys have been used in a wide variety of structural and functional applications due to their attractive properties such as low density and high specific strength and low elastic modulus [1,2]. However, the usage of magnesium alloys in more complex applications is limited because of problems associated with ductility, corrosion and creep resistances. Magnesium has poor workability at room temperature due to its crystal structure. It has been demonstrated that ductility enhancement may be achieved in magnesium alloys by refining the grain structure using conventional thermo-mechanical treatment [3,4], powder metallurgy [5,6] or severe plastic deformation [7,8]. Using the addition of alloying element to magnesium, workability was improved by the activation of non-basal plane including c+a slip with the addition of yttrium to magnesium [9]. The workability of magnesium at room temperature was improved by the addition of lithium in order to change the crystal structure from hcp with a high crystal anisotropy to bcc structure with a different crystal symmetry [10]. On the other hand, it is suggested that the extrusion-torsion simultaneous processing is a very new and useful technique for fabricating a rod-shape material with random and fine structures. It has applications for the preliminary working in order to fabricate a high strengthening magnesium alloy screw. However, the effects of extrusion-torsion temperature and torsion speed on a workpiece property are not well-known. In this study, microstructure evolution and hardness change of AZ91D magnesium alloy during extrusion-torsion simultaneous processing is investigated through microstructure observation, X-ray diffraction analysis and micro-Vickers hardness measurement.

Experimental Procedures

The commercial AZ91D magnesium alloy with the dimension of 30 mm diameter was used. The solution treatment was performed at 683 K for 345.6 ks in an argon gas atmosphere. It was extrusion-twisted with 100 t vertical oil pressure press machine. Extrusion ratio is 18 and ram speed is 0.25 mm/s. The extruded material appearing from the die was fixed by chucks, and twisted immediately under the various conditions. The extrusion-twisted sample was removed from the container, and it was water-cooled. The obtained sample was applied to microstructure observation. The sample surface was mechanically polished by a SiC impregnated emery paper from #500 to #2500 using water as the lubricant. The ground sample was then polished using the diamond paste with diameter of 1 μm dipping on a buff. Following the polishing operation, the etching was done using picric acid-ethanol solution. The microstructure was observed using an optical microscope. X-ray diffraction measurement was performed for characterizing the crystal texture. The X-ray diffraction pattern was obtained using Cu-Kα radiation accelerated by the voltage of 40 kV. Vickers hardness was measured by a micro hardness test machine under an indentation load of 0.98 N and the time of 20 s with an average of twelve readings.

Results and Discussion

Effect of torsion

To confirm the effectiveness of torsion, microstructure of samples worked at 573 K was compared with and without torsion. Figure 1 shows the optical micrograph of extruded and extrusion-twisted AZ91D magnesium alloy bar in the sectional center, half and outer parts. Working temperature is 573 K, and torsion speed is 15 rpm. Grain size was decreased through the extrusion comparing with as solution-treated sample. Moreover, it was decreased drastically to 4 μm by the addition of torsion. Extrusion-twisted sample has practically no region of abnormal grain growth. To characterize the evolution of crystal texture, X-ray diffraction analysis was performed. Figure 2 shows the X-ray diffraction pattern of extruded and extrusion-twisted AZ91D magnesium alloy. The specimen surface for XRD analysis is taken parallel to the extruding direction. Basal plane (0002) was detected strongly in the diffraction pattern of the extruded sample. Intensity of prismatic $(10\bar{1}0)$ and pyramidal $(10\bar{1}1)$ planes was increased by the addition of torsion. The crystal texture was changed from basal to pyramidal dominations. Table 1 shows the comparison of diffraction intensity from prismatic, basal and pyramidal planes in the extrusion and extrusion-torsion samples. Diffraction intensity is relative value calculated from pyramidal plane and is presumed to be 100. Intensity of prismatic, basal and pyramidal planes in the extrusion-twisted sample is similar to JCPDS data obtained from AZ91D magnesium alloy powder. The randomizing of crystal orientation was accelerated by the torsion. Hardness distribution of extruded and extrusion-twisted AZ91D magnesium alloy is shown in figure 3. Hardness was increased by the addition of extrusion comparing with as solution-treated sample. Moreover, it was increased to about 85 HV by the addition of torsion.

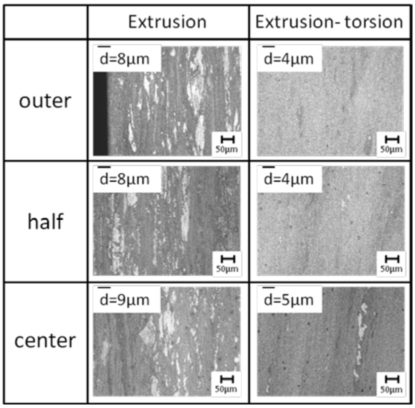

Figure 1. Optical micrograph of extruded and extrusion-twisted AZ91D magnesium alloy bar in the sectional center, half and outer parts.

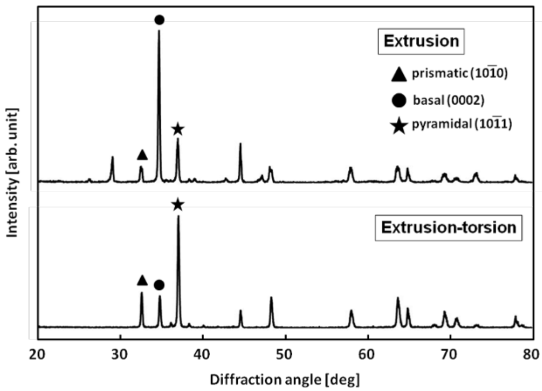

Figure 2. X-ray diffraction pattern of extruded and extrusion-twisted AZ91D magnesium alloy. Working temperature is 573 K, and torsion speed is 15 rpm.

Table 1. Comparison of diffraction intensity from prismatic, basal and pyramidal planes in the extrusion and extrusion-torsion samples.

	prismatic	basal	pyramidal
Extrusion	37	340	100
Extrusion-torsion	32	29	100
JCPDS	25	36	100

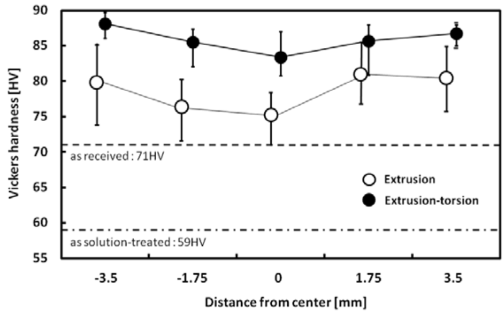

Figure 3. Hardness distribution of extruded and extrusion-twisted AZ91D magnesium alloy. Working temperature is 573 K, and torsion speed is 15 rpm.

<u>Effect of extrusion-torsion temperature</u>

Figure 4 shows the optical micrograph of AZ91D magnesium alloy extrusion-twisted at various temperatures. The torsion speed is 15 rpm. Average grain size was decreased by the dynamic recrystallization during processing with falling extrusion-torsion temperature. Precipitate β-$Mg_{17}Al_{12}$ phase was clearly found in the sample extrusion-twisted at lower temperature, and it suppressed grain growth. Grain refinement under 2 μm was achieved at the lowest extrusion-torsion temperature of 523 K. On the other hand, the second phase did not exist in the sample extrusion-twisted at 678 K. From the equilibrium diagram in Mg-Al-Zn system [11], it was found that 678 K corresponds to α-Mg single phase, 573 K and 623 K correspond to α+β duplex phase.

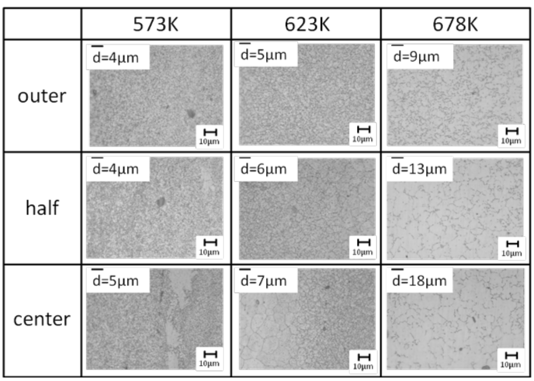

Figure 4. Optical micrograph of AZ91D magnesium alloy extrusion-twisted at various temperatures.

Hardness distribution of AZ91D magnesium alloy extrusion-twisted at various temperatures is shown in figure 5. The torsion speed is 15 rpm. Micro-Vickers hardness increased with falling extrusion-torsion temperature. It seemed that hardness difference between outer and center parts decreased with falling extrusion-torsion temperature.

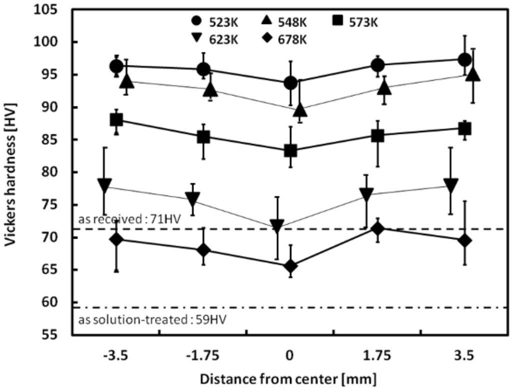

Figure 5. Hardness distribution of AZ91D magnesium alloy extrusion-twisted at various temperatures.

<u>Effect of torsion speed</u>

Figure 6 shows the optical micrograph of AZ91D magnesium alloy extrusion-twisted at various torsion speeds. The working temperature is 678 K. It seemed that the grain size was smallest in the condition of 20 rpm. Torsion speed had a slight influence on the microstructure evolution and hardness distribution compared with extrusion-torsion temperature.

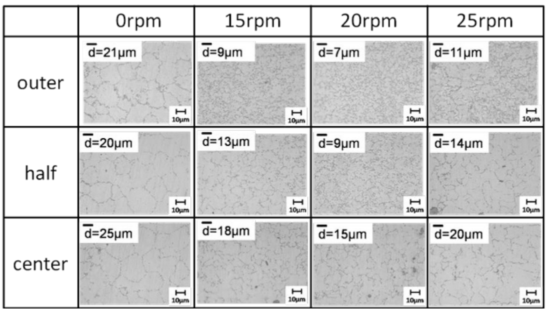

Figure 6. Optical micrograph of AZ91D magnesium alloy extrusion-twisted at various torsion speeds.

Conclusions

In the present study, microstructure evolution and hardness change of AD91D magnesium alloy during extrusion-torsion simultaneous processing is investigated through microstructure observation, X-ray diffraction analysis and micro-Vickers hardness measurement. From the results of the investigations, the following conclusions were obtained.

(1) By the addition of torsion from 10 rpm to 25 rpm, the randomizing of the crystal orientation in AZ91D magnesium alloy was drastically accelerated.

(2) Crystal grain which occurred through the dynamic recrystallization tended to coarsen with the increase of extrusion-torsion temperature.

(3) Torsion speed had a slight influence on the microstructure evolution and hardness distribution compared with the extrusion-torsion temperature.

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