Effect of hot working on the damping capacity and mechanical properties of AZ31 magnesium alloy

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Abstract. Magnesium alloys have received much attention for their lightweight and other excellent properties, such as low density, high specific strength, and good castability, for use in several industrial and commercial applications. However, both magnesium and its alloys show limited room-temperature formability owing to the limited number of slip systems associated with their hexagonal close-packed crystal structure. It is well known that crystallographic texture plays an important role in both plastic deformation and macroscopic anisotropy of magnesium alloys. Many authors have concentrated on improving the room-temperature formability of Mg alloys. However, despite having a lot of excellent properties in magnesium alloy, the study for various properties of magnesium alloy have not been clarified enough yet.

Mg alloys are known to have a good damping capacity compared to other known metals and their alloys. Also, the damping properties of metals are generally recognized to be dependent on microstructural factors such as grain size and texture. However, there are very few studies on the relationship between the damping capacity and texture of Magnesium alloys. Therefore, in this study, specimens of the AZ31 magnesium alloy, were processed by hot working, and their texture and damping property investigated. A 60 mm × 60 mm × 40 mm rectangular plate was cut out by machining an ingot of AZ31 magnesium alloy (Mg-3Al-1Zn in mass%), and rolling was carried out at 673 K to a rolling reduction of 30%. Then, heat treatment was carried out at temperatures in the range of 573–723 K for durations in the range of 30–180 min. The samples were immediately quenched in oil after heat treatment to prevent any change in the microstructure. Texture was evaluated on the compression planes by the Schulz reflection method using nickel-filtered Cu Kα radiation. Electron backscatter diffraction measurements were conducted to observe the spatial distribution of various orientations. Specimens for damping capacity measurements were machined from the rolled specimen, to have a length of 120 mm, width of 20 mm, and thickness of 1 mm. The damping capacity was measured with a flexural internal friction measurement machine at room temperature. It was found that the damping capacity increases with both increasing heat-treatment temperature and time, due to grain growth and the increased pole densities of textures.

1. Introduction

There has been a growing interest in using magnesium alloys for various industrial and commercial applications, including electronics and automotive components parts, owing to their low density and high specific strength. However, magnesium alloys have poor formability at room temperature because of the limited number of slip systems available, given their hexagonal close-packed structure [1]. To extend their applicability, their room-temperature formability obviously needs to be improved, and ways to achieve which, including microstructure refinement and texture control, have been studied by various researchers [2]. However, excluding study for such formability improvement, other characteristics of magnesium alloys have not been clarified enough yet.

Magnesium alloys are known to have higher damping capacities compared to other metals and their alloys [3]. The damping capacity of commercial magnesium alloys is lower than...
that of pure magnesium [4]. In general, the mechanical properties and damping capacity of materials are known to depend on grain size, presence of precipitates, and texture among a host of attributes. In a previous study, the authors studied the effect of heat treatment on the damping capacity of ductile cast iron and found that the mechanical properties and damping capacity varied depending on the heat treatment conditions such as temperature and time [5]. It is therefore believed that similar trends can be expected of magnesium alloys.

In this study, the magnesium alloy, AZ31, subjected to hot-rolling was experimentally investigated under various heat-treatment conditions. Especially, the effect of texture on the mechanical properties and damping capacity of AZ31 was investigated.

2. Experimental procedure

Specimens for evaluation were prepared from commercial cast AZ31 magnesium alloy ingots. A rectangular plate of dimensions 60mm (width) × 60mm (length) × 40mm (thickness) was machined out from an ingot and was hot-rolled at 673 K to a rolling reduction of 30%. Figure 1 is the inverse pole figure showing the axis density distribution. The mean axis density is used as a unit. The maximum axis density and its position are shown at the bottom of the figure. The position is expressed as (α, β), with α being the angle between (0001) and the position of the maximum axis density, and β being the rotation angle around [0001] from the [0001]-[1010] line to the position of the maximum axis density. The maximum axis density is 4.8 times the mean axis density, and the position of the maximum axis density is (0, 0); (0, 0) implies [0001] (basal) texture [6].

In order to investigate the effect of heat treatment on damping capacity, the specimens were annealed at temperatures between 573 K and 773 K for durations in the range of 30–180 min. The specimens were quenched in oil immediately after annealing to prevent any change in microstructure. The mid-plane section of specimens was prepared by mechanical polishing for microstructure observation.

Tensile tests were conducted at room temperature with a cross head speed of 2 mm/min, and the damping capacity was measured with a flexural internal friction measurement machine at room temperature. The vibration amplitude of the specimens was measured by means of an optical sensor throughout the vibration attenuation process. The damping, denoted by the logarithmic decrement (δ), is defined as follows:

\[ \delta = \frac{1}{n} \ln \left( \frac{A_0}{A_n} \right), \]  

(1)
where $n$ is the vibration cycle, while $A_0$ and $A_n$ represent the vibration amplitudes of the initial and $n^{th}$ cycles, respectively. The damping capacity was calculated from the decay of the vibration [5].

Texture measurement was carried out by the Schulz reflection method using nickel-filtered Cu Kα radiation. Based on five pole figures, the crystal orientation distribution function (ODF) was determined by the Dahms and Bunge method [7]. Electron backscatter diffraction (EBSD) measurements were performed after electrolytic polishing of the mechanically polished samples.

3. Results and discussion

Figure 2 shows the optical micrographs of the specimens before and after heat treatment. As shown in Fig. 1(a), dendrites were observed along the grain boundaries, these were composed of Mg$_{17}$Al$_{12}$ [8]. Upon heat treatment, this intermetallic, which had formed before heat treatment disappeared, as shown in Fig. 2(b).

Figure 3 shows the effect of heat treatment time on the tensile strength and hardness of Mg alloys heat-treated at 673 K. As can be seen, both the hardness and tensile strength are inversely proportional to heat treatment time. Additionally, both these properties exhibited a similar relationship with the heat treatment temperature.

Grain size is known to increase with increasing heat-treatment temperature and time; the same was observed in this study. It is believed that the changes in tensile strength are effected by grain growth, and a reduction in the number of defects such as dislocations.

Figure 4 shows the relationship between the heat treatment time and the maximum axis density in the inverse pole figure for heat treatment at 623 K. It is known that a basal

![Hot-rolled AZ31](image1.png)

Fig. 3 Effect of heat treatment time on tensile strength and hardness for heat treatment at 673K.

![Hot-rolled AZ31](image2.png)

Fig. 4 The relationship between heat treatment time and maximum axis density of (0001) for heat treatment at 623 K.
texture is formed in magnesium alloys upon hot-rolling [9]. In this study, a basal texture was formed in all specimens despite annealing at different times and temperatures, and the maximum axis density of the basal texture was found to decrease with increasing heat-treatment time and temperature, as seen in Fig. 4.

At higher temperatures and longer durations, the damping capacity was gradually increased by the reduction in the number of defects such as dislocations in Fig. 5. Consequently, the grain size and texture are affected by the hot-working conditions, and that the changes in grain size and texture influence mechanical the properties (strength and hardness) and damping capacity of magnesium and its alloys.

4. Summary

In order to clarify effect of texture on the mechanical properties and damping capacity of magnesium and its alloys, specimens of AZ31 magnesium alloy were hot-rolled and experimentally investigated after being subjected to various heat-treatment conditions. It was found that with increasing heat-treatment temperature and time, the grain size of the specimens increased and the basal texture progressively weakened. Consequently, the mechanical properties (strength and hardness) deteriorated and the damping capacity decreased.

Acknowledgement

This work was supported by a Research Grant of Pukyong National University (2014).

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