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Effect of Ca and Ce on Wear Behavior of Hot-Rolled AZ31 Mg Alloys

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In this study, Ca and Ce added AZ31 Mg alloys were produced by low pressure die casting method and the following materials were rolled at 400 °C. The wear properties of materials were investigated by wear test method according to ASTM-G133 in a dry condition at room temperature. The microstructure of samples investigated by light optical microscopy and scanning electron microscopy both before and after corrosion tests. The twins and dynamic recrystallization (DRX) and the alloying elements play an important role to impart the final wear resistance of investigated materials.

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1. Introduction

Magnesium alloys are light materials due to their low density of 1.74 g/cm^3 which gives them an important advantage for using as a material for structure, especially to build parts for automotive and airspace vehicles [1, 2]. Moreover, the properties of Mg alloys include excellent damping capacity, good machinability, and high thermal conductivity. However, the wear resistance is a weak property of Mg alloys that needs to be developed in dry or corrosive conditions [3, 4]. To improve the wear resistance of Mg alloys, alloying, coating, and heat treatment were utilized [5]. Rare earth elements can be used as an effective alloying method to enhance many properties of Mg alloys [6, 7]. Ca has excellent mechanical properties, good corrosion resistance and superior thermal stability [8]. As for Ce, it leads to excellent corrosion resistance and good formability to Mg alloys [9]. Although many studies investigating rare earth elements on wear behaviour of Mg alloys are generally limited on as-cast or composite materials, the wrought Mg alloys added with rare-earth elements are still under discussion [1, 5]. This study aims to examine the effect of Ca and Ce on wear behaviour of hot-rolled AZ31 Mg alloys. Moreover, the nature of change of rolling speed affecting the wear resistance was investigated.

2. Experimental studies

AZ31 Mg alloys containing 1 wt% Ca and 0.5 wt% Ce were produced by using low pressure die casting method. Chemical analysis of produced alloys is shown in Table I (XRF-Machine: Rigaku ZSX Primus II). In argon gas protected environment, pure Mg alloys were allowed to melt at 750 °C for 1 h and then the alloying process was accomplished by addition of Ca–Mg and Ce–Mg master alloys to melted pure Mg alloy. In SF_6-CO_2 protective atmosphere, the alloy was transferred to a stainless steel $36 \times 36 \times 200$ mm^3 mold heated at 350 °C by applying 2 atm pressure. The billets of $36 \times 12 \times 80$ mm^3 dimensions were cut from the alloys left to cool in the moulds. The billets were then used in the homogenization process before rolling. The surfaces of the billets which were homogenized for 24 h at 400 °C were sanded with 800 sanding sheets and made ready for rolling. Pre-rolling occurred at 400 °C for 30 min. The samples were reduced at 400 °C rolling temperature from 12 mm wall thickness to 2 mm wall thickness in 5 passes and allowed to cool in air after the last pass. In this study, the rolling parameters were 30% cross-sectional reduction per pass and the rolling speed was 1.5 m/min and 10 m/min. The rollers of the rolling machine used were made of stainless steel with a diameter of 110 mm. No lubricant was used in the rolling process. 2 mm sheet materials were exposed to wear along 120 m under load 20 N (2 kg) with 0.5 mm/s wear speed at 25 °C according to ASTM-G133 which was conducted in a tribometer. The counterbody component was steel AISI 52100 (analog ShKh15) with a hardness of 61 HRC. Before the wear test, the samples were cut to 50×50 mm^2 pieces from the sheet materials and their surfaces were first sanded with 1200 grit and dried with alcohol before the abrasion test. After the wear test, microstructure images of the samples were taken by optical microscope (Nikon Eclipse MA200 + Clemex software) and scanning electron microscope (SEM, Carl Zeiss Ultra Plus Gemini Fesem). Wear behavior in terms of metal loss was examined. Hardness of samples was measured by micro-vickers (HV) of 0.5 HV load.

TABLE I

Chemical composition of alloys (wt%)

Alloys	Al	Zn	Mn	Ca	Ce	Mg
AZ31-1Ca	2.69	0.92	0.14	0.80	–	bal.
AZ31-1Ca-0.5Ce	2.99	0.90	0.24	0.96	0.43	bal.

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3. Results

3.1. Microstructure examinations

Figure 1 shows the light optical microscopy (LOM) images of investigated alloys. As seen in Fig. 1, the grains of all samples mainly were formed as equiaxed after the rolling process. However, the average grain size of samples is different based on the rolling speeds. As the LOM images of AZ31-1Ca alloy show, lower rolling speed gives rise to larger grains and besides more black points are distributed mainly inside of grains when the rolling speed is 1.5 m/min (see Fig. 1a). On the other hand, the twins that are activated during rolling occupied the microstructure more at a higher rolling speed of AZ31-1Ca alloy (see Fig. 1b). Regarding the Ce addition to AZ31-1Ca alloy, larger grains were formed. Moreover, Ce-added alloy that is deformed at 10 m/min shows larger grains and also contains more twins. The twins calculations of investigated samples illustrate that the higher rolling speeds activate more twins formations for both alloy groups (see Fig. 1).

The SEM images of investigated alloys are shown in Fig. 2. The formation and distribution of secondary phases were examined by using these micrographs. As seen in Fig. 2, the secondary phases of 1Ca that deformed at 1.5 m/min rolling speed is finer and homogeneously distributed inside grains and grain boundaries for both surface and cross-section. However, the size of secondary phases was enlarged when the rolling speed was 10 m/min, where the distribution of larger secondary phases was placed on grains boundaries (see Fig. 2). AZ31-1Ca-0.5Ce alloy contains more homogeneously distributed equiaxed grains at both 1.5 m/min and 10 m/min rolling speeds, although the secondary phases of rolled at 1.5 m/min formed with larger size which was placed on grain boundaries.

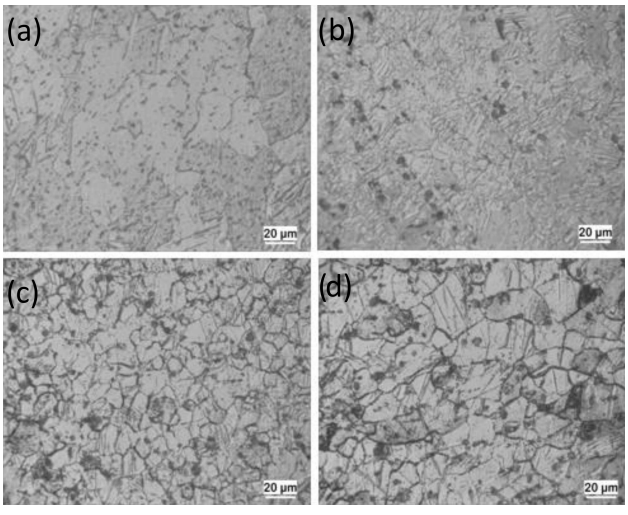

Fig. 1. LOM images of AZ31-1Ca alloys deformed with (a) 1.5 m/min and (b) 10 m/min and AZ31-1Ca-0.5Ce alloys deformed with (c) 1.5 m/min, and (d) 10 m/min rolling speeds.

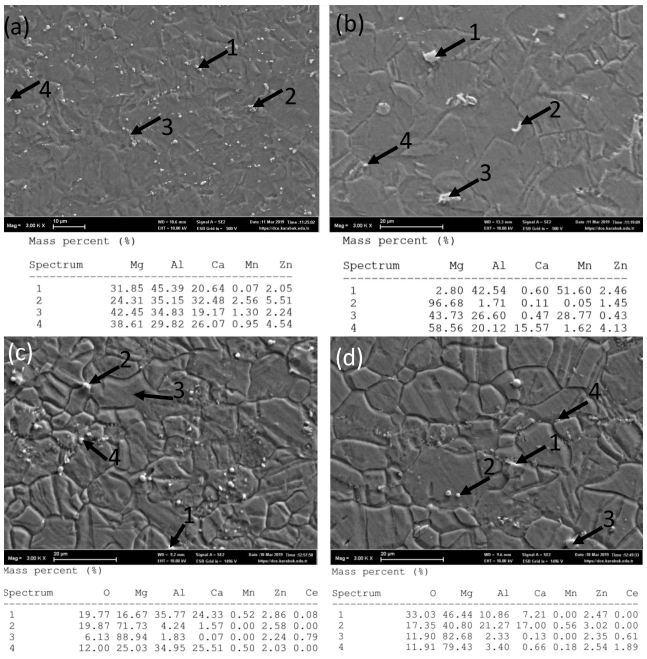

Fig. 2. SEM images and energy dispersive X-ray (EDX) results of AZ31-1Ca alloys deformed with (a) 1.5 m/min and (b) 10 m/min and AZ31-1Ca-0.5Ce alloys deformed with (c) 1.5 m/min and (d) 10 m/min rolling speeds.

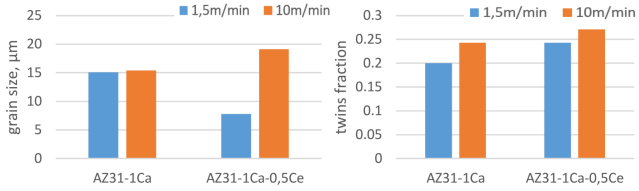

Fig. 3. Average grain sizes and twins fractions of investigated alloys.

The EDX examination shows that the secondary phases of Ca-added alloy deformed at 1.5 m/min rolling speed were formed with a small spherical shapes which were dominantly Al-Ca rich. However, increasing rolling speed to 10 m/min solved generally smaller sized secondary phases in the matrix where Al-Mn rich secondary phases that were introduced mostly on grain boundaries have a larger size and complex or rectangular shapes. However, a small number of the finer and spherical shaped secondary phases were detected on twins boundaries. When we examined Ce added AZ31-1Ca alloys, the Ce mostly were solved in the matrix of 1Ca-0.5Ce alloy deformed at 1.5 m/min rolling speed as the chemical composition of secondary phases does not include Ce element or trace amount. However, the same alloy contained spherical shaped secondary phases containing Ce elements, where the rolling speed was 10 m/min, more than the speed of 1.5 m/min.

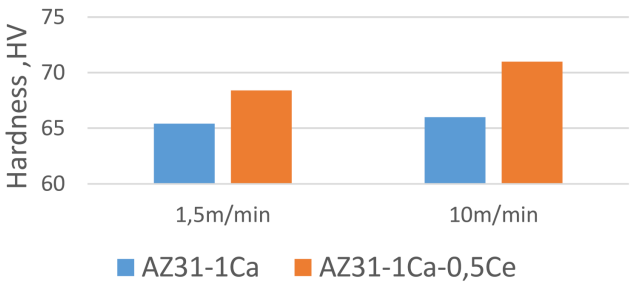

Fig. 4. Hardness (HV) test results of investigated alloys.

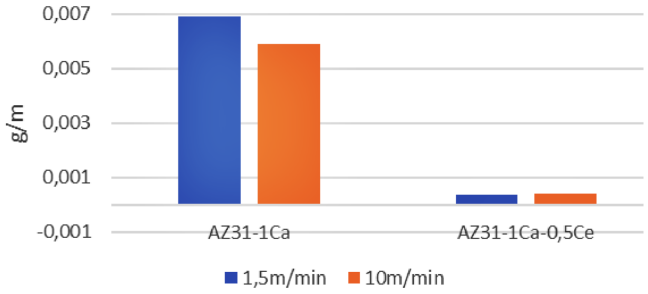

Fig. 5. Metal loss (g/m) after wear test of investigated alloys during 120 m of 2 kg load.

The average grain size results show that the finer grains of 7.8 μm were obtained for 1Ca alloy deformed at 10 m/min rolling speed. The higher rolling speed imparts finer grains to 1Ca added alloys, although the finer grains are obtained were 1Ca-0.5Ce added alloys after 10 m/min rolling speed. As for the twins, both alloys show an increasing twins fraction along with the increase in rolling speed. Moreover, more highly twins density is introduced by 1Ca-0.5Ce added alloy deformed at 10 m/min rolling speed.

3.2. Hardness test results

Figure 4 shows the microhardness test results of investigated samples. As seen in Fig. 4, the hardness of AZ31-1Ca and AZ31-1Ca-0.5Ce alloys was changed positively by the increase in rolling speed. Moreover, the highest hardness was obtained with 0.5Ce added material which deformed at 10 m/min rolling speed. The hardness could be increased with the formed smaller grains or more twins formation that gives rise to hindering of dislocation motion freely along slip direction [10–14]. However, twins boundaries cause more blocking effect on the dislocation motion than grain boundaries, as seen in Fig. 3.

3.3. Wear test results

The wear test results of investigated alloys are shown in Fig. 5. As one can see, metal loss of AZ31-1Ca alloy is higher when the material is deformed with lower rolling speed. For AZ31-1Ca, the wear result is confirmed with the hardness results, where the higher hardness gives rise to lower metal loss during wear test [15, 16]. The wear resistance of AZ31-1Ca alloy was improved with the addition of Ce which is extremely low when we compare it with AZ31-1Ca, as seen in Fig. 5. However, the effect of rolling speed on the wear resistance of AZ31-1Ca-0.5Ce alloy is not proportional to the hardness results in which the 10 m/min rolling speed has higher metal loss than 1.5 m/min. The secondary phase distribution was more homogeneous and bigger in size for the matrix of AZ31-1Ca-0.5Ce alloy deformed at 1.5 m/min than 10 m/min rolling speed. The resistance of secondary phases could be responsible for the wear behaviour of AZ31-1Ca-0.5Ce alloy with 1.5 m/min rolling speed.

4. Conclusions

In this study, the effect of Ce and rolling speed on the wear resistance of AZ31-1Ca alloys was studied by microstructure analysis. The solid solution of Ce element in a matrix played an important role as a dominant determiner to more stable it in wear test. Moreover, the rolling speed has changed the distribution and size of secondary phases which affected approximately minor scale to the wear resistance of investigated alloys which have the bigger size of secondary phases, the more it resists to wear.

Acknowledgments

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