EFFECT OF TI ADDITION ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF AS-CAST AND HOT-ROLLED AZ31 MAGNESIUM ALLOYS

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Abstract- This study investigated the effect of Ti addition on microstructure and mechanical properties of AZ31 magnesium alloys. Ti additions were made by 0.5 and 1 wt%. Alloys were produced by conventional gravity casting in a steel mould preheated to 250 °C. A homogenization treatment at 350 °C for 24 h was performed after the casting processes. Homogenized samples were hot-rolled by 40% thickness reduction at 1 pass at 350 °C. The results showed that Ti addition above 0.5 wt% effectively decreased the grain size of both as-cast and hot-rolled AZ31 alloys. Ti addition did not led to formation of any second phases but decreased the amount of β-$Mg_{17}Al_{12}$ intermetallic phases. Tensile properties were improved by Ti addition. In the as-cast alloys, the AZ31 alloy containing 1 wt% Ti showed the best mechanical properties. However, in the hot-rolled alloys, the alloys with 0.5 wt% and 1 wt% Ti addition showed similar mechanical properties which were higher than AZ31 alloy.

Index Terms- AZ31 Magnesium alloys; Ti modification; microstructure; mechanical properties

I. INTRODUCTION

In recent years, magnesium alloys have been considered as candidate to replace aluminum alloys in automotive and aerospace industries to provide fuel efficiency and high performance since they have a unique specific strength, excellent machinability and castability [1]. However, magnesium alloys suffer from low mechanical properties at both ambient and elevated temperatures which can make them unsuitable in commercial use [2]. AZ31 is one of the most used wrought magnesium alloys having a good combition of strength, ductility and formability [1-2]. In order to improve the mechanical properties of AZ31 alloys, different alloying additions and processing routes have been applied so far. Masoudpanah et al. [3] showed that rare earth element (RE) and Ca additions enhanced the mechanical properties of ECAPed AZ31 alloy. Zhang et al. [4] reported that 1 wt% Nd addition increased the tensile properties of as-cast AZ31 alloy above which the strength of AZ31 alloy decreased. Some researchers investigated different hot forming routes in order to improve the mechanical properties of AZ31 alloy [5-6]. The studies investigating the effect of Ti addition on mechanical properties of magnesium alloys are scarce. Candan et al. [7] showed that Ti addition from 0 to 0.5 wt% gradually increased the strength and the corrosion resistance of as-cast AZ91 magnesium alloys. Choi et al. [8,9] reported that trace amount of Ti addition can improve the strength and the corrosion resistance of AZ31 and AZ61 magnesium alloys. Most of the studies have been conducted about the corrosion resistance of Ti-modified magnesium alloys at their as-cast states. Furthermore, in these studies, mostly trace amounts of Ti additions were made. Therefore, this study investigated the effect of 0.5 wt% and 1 wt %Ti additions on microsctructure and mechanical properties of as-cast and hot-rolled AZ31 magnesium alloy.

II. EXPERIMENTAL PROCEDURE

The Mg-3wt%Al-1wt%Zn alloys with different Ti additions (0, 0.5, 1 wt%) were produced by gravity casting. The chemical compositions of the alloys were measured by wave-length dispersion X-ray fluorescence (XRF) and listed in Table 1. High purity Mg (99.9%), Al (99.9%), Al-10Mn and Al-10Ti master alloys were used to prepare the alloys. The alloys were melted in stainless steel crucible placed in an electric resistance furnace under controlled Ar gas flow. After holding the melt at 750 °C for 45 minutes and stirring for 15 minutes, the melt was poured into a steel mould preheated to 250 °C. A homogenization treatment at 350 °C for 24 h was performed after the casting processes. Homogenized samples were hot-rolled by 40% thickness reduction at 1 pass at 350 °C.

Table I Chemical compositions of the alloys.

Alloy	Al	Zn	Ti	Mn	Mg
AZ31	3.17	1.05	-	0.25	Bal.
AZ31+0.5Ti	2.99	1.12	0.45	0.25	Bal.
AZ31+1Ti	3.05	0.98	1.18	0.28	Bal.

For the microstructure analysis, all the samples were mechanically ground with 240, 400, 600, 800, 1000, 1200 and 2000 grit emery papers followed by polishing with 6 μm and 1 μm diamond paste. The polished samples were etched with 6 gr picric acid, 5 ml glacial acetic acid, 10 ml distilled water and 100 ml ethanol. The microstructure images of the samples were taken by optical microscope and scanning electron microscope. According to EN ISO 6892-1, the tensile specimens with a gauge section of 40 mm x 9 mm x 2 mm were machined from the as-cast and hot-rolled alloys. Tensile tests were performed with a strain rate of 0.00167 1/s at room temperature and each test condition was repeated three times.

III. RESULTS AND DISCUSSION

Fig.1 shows the optical microstructures of the as-cast and hot-rolled AZ31 magnesium alloy with Ti additions of 0, 0.5 and 1 wt%. The as-cast AZ31 alloy consisted of primary α-Mg and low amount of β-$Mg_{17}Al_{12}$ intermetallic phase. The maximum solid solubility of Al in α-Mg is around 12 wt%. β-$Mg_{17}Al_{12}$ eutectic phase can form in Mg-Al system under non-equilibrium cooling conditions during casting as little as 2 wt% Al addition [10].

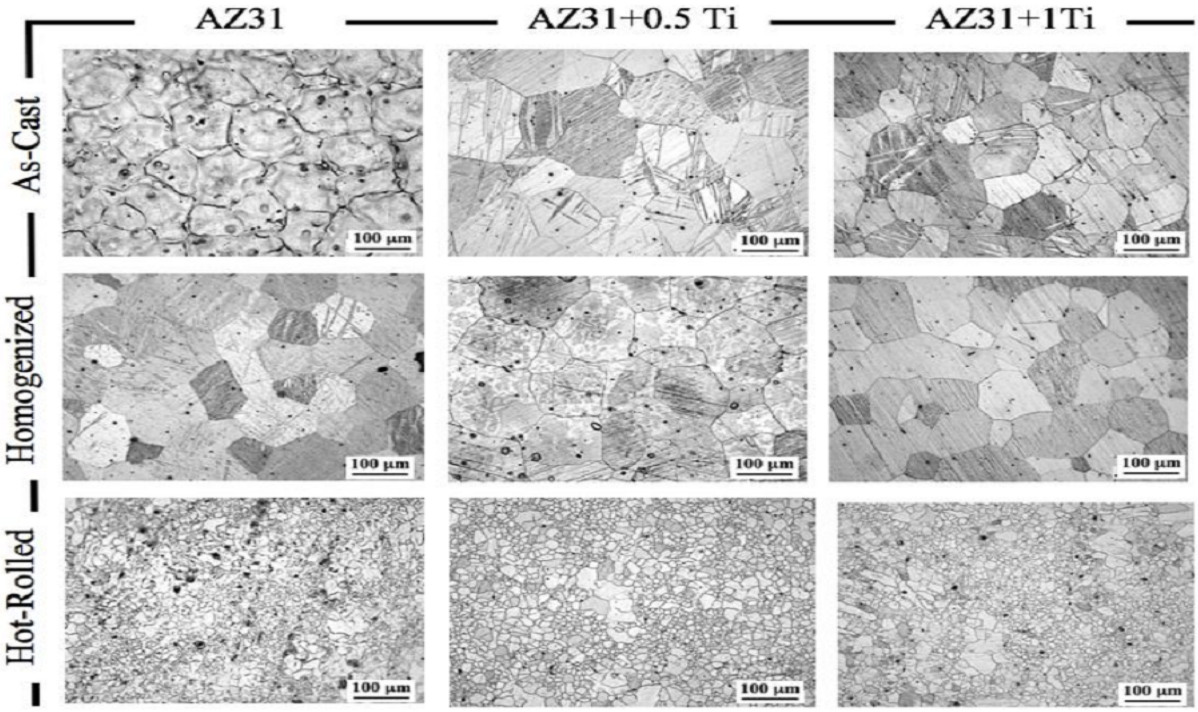
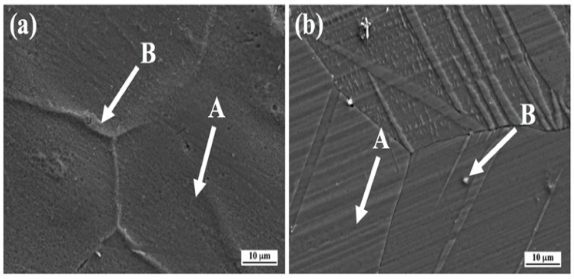


Fig. 1 Optical microstructures of as-cast, homogenized and hot-rolled AZ31 magnesium alloys with 0 wt%, 0.5 wt% and 1 wt% Ti additions.

In the as-cast alloys, Ti addition decreased the formation of β-$Mg_{17}Al_{12}$ intermetallic phase. In Fig.2, SEM images of the as-cast AZ31 and AZ31+1Ti alloys with corresponding energy-dispersive spectroscopy (EDS) results were presented. It can be seen that almost all Al were in α-Mg solution which explains the low amount of β-$Mg_{17}Al_{12}$ phase. After 1 wt% Ti addition, low amount of Ti was also present in α-Mg solution with nearly same Al composition. Mg and Ti do not form intermetallic compounds and Ti has a maximum solid solubility in Mg by 0.24 wt% [11]. The average grain size of the as-cast AZ31, AZ31+0.5Ti and AZ31+1Ti alloys were measured as 120.5 μm, 131.48 μm and 101 μm respectively. This indicates that Ti addition can effectively refine the α-Mg grains above 0.5 wt%. Homogenized samples also showed the similar trend of grain sizes. Furthermore, homogenization treatment resulted in more homogenous microstructure showing no eutectic phases in the microstructures. After hot-rolling process, all alloys showed much finer grains due to dynamic recrystallization (DRX). In hot-rolled alloy, DRXed grain sizes were measured as 13.51 μm, 16.93 μm and 9.90 μm for the AZ31, AZ31+0.5Ti and AZ31+1Ti alloys respectively. This was attributed to the presence of Ti particles which possibly pinned the grain growth during dynamic recrystallization.

The tensile test results of the as-cast and hot-rolled alloys were illustrated in Fig.3 and Fig.4 respectively. It can be seen in Fig. 3 that 1 wt% Ti addition showed the best tensile properties among the as-cast alloys with a yield strength of 149.6 MPa, an ultimate tensile strength of 173.2 MPa and an elongation of 12.6. This improvement was due to refinement of α-Mg grains with 1 wt% Ti addition. After hot-rolling process, the yield strength, ultimate tensile strength and elongation were considerably improved. The hot-rolling process provided much finer microstructure and much less dislocation density by DRX mechanism. The yield strength and the ultimate tensile strength of the alloys with 0.5 wt% and 1 wt% Ti additions were the same with 134 MPa and 255 MPa respectively. However, the elongation decreased when 1 wt% Ti addition was made. This was because of the premature fracture caused by crack initiation at Ti particles. Nevertheless, in hot-rolled states, Ti addition led to an improvement in strength of AZ31 magnesium alloys even though a decrease in elongation was observed with increasing amount of Ti addition.



Sample	Point	Mg	Al	Mn	Ti
AZ31	A	96.57	3.35	0.08	-
	B	97.32	2.58	0.1	-
AZ31 + 1Ti	A	96.46	3.04	0.05	0.45
	B	94.18	5.56	0.02	0.24

Fig. 2. SEM images of as-cast (a) AZ31 and (b) AZ31+1Ti with corresponding energy-dispersive spectroscopy (EDS) results.

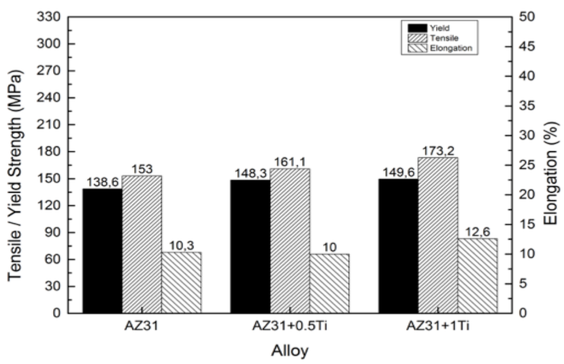


Fig. 3. Tensile test results of the as-cast alloys.

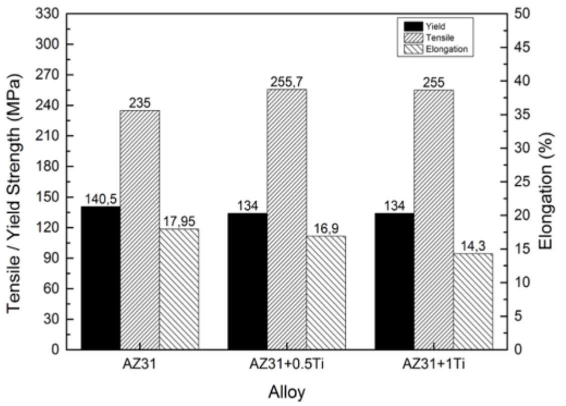


Fig. 4. Tensile test results of the hot-rolled alloys.

CONCLUSION

Following conclusions can be drawn:

- The as-cast AZ31 alloy consisted of primary α-Mg and low amount of β-$Mg_{17}Al_{12}$ intermetallic phase and Ti addition decreased the formation of β-$Mg_{17}Al_{12}$ intermetallic phase.
- Homogenization treatment resulted in more homogenous microstructure showing no eutectic phases in the microstructures. After hot-rolling process, all alloys showed much finer grains due to dynamic recrystallization (DRX).
- Tensile properties were improved by Ti addition. In the as-cast alloys, the AZ31 alloy containing 1 wt% Ti showed the best mechanical properties. However, in the hot-rolled alloys, the alloys with 0.5 wt% and 1 wt% Ti addition showed similar mechanical properties which were higher than AZ31 alloy.

ACKNOWLEDGMENTS

This research is supported by the Scientific research projects (BAP) with project no. KBÜBAP-17-YD-213

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