EFFECT OF Y ADDITION ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF AS-CAST MG-ZN-ZR-LA MAGNESIUM ALLOYS

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Abstract: The microstructure and mechanical properties of as-cast Mg-Zn-Zr-La-Y alloys were investigated. The alloys were produced by low pressure die casting method. Microstructure investigations revealed that Y addition resulted in a formation of Mg-Zn-Y phases generally expressed as three forms I-phase (Mg3Zn6Y), W-phase (Mg3Zn3Y2) and X-phase (Mg12ZnY). After Y addition, the coarse Mg-Zn-La second phases were replaced by semi-continuous net-like second phase structure, which coarsened with increasing Y addition. A considerable increase in the yield strength was observed after Y addition but elongation to fracture was deteriorated due to the increased amount of second phases that may cause premature crack propagation.

Keywords: Magnesium Alloy, ZK60, Casting, Microstructure, MechanicalProperties.

I. INTRODUCTION

Recently, considerable efforts have been made in order to reduce vehicle weights in automotive and aerospace industries because fuel savings and reduced emissions are economic and environmentally friendly [1,2]. In respect to this, magnesium alloys have attracted considerable attention due to their uniquely high specific strength compared to other structural metals. However, magnesium alloys have low strength at room and elevated temperatures which can restrict their widespread applications [2]. Alloying is considered as one of the typical way to enhance the mechanical properties of magnesium alloys by reducing the grain size and forming second phase particles [3].

ZK60 magnesium alloys (Mg-6 wt%Zn-0.5 wt%Zr), have a good combination of strength and ductility. Rare earth (RE) additions to magnesium alloys have been extensively made by numerous researchers and it has been agreed that RE additions formed thermally stable second phases and improved mechanical properties [3–5]. Ma et al. [4] showed that Ce-rich RE additions to ZK60 alloy up to 3 wt% improved the mechanical properties by refining the microstructure and increased extrusion texture. Zhou et al. showed that Nd and Y additions resulted in an improvement of strength of ZK60 alloy by significant grain refining during dynamic recrystallization process. Fang et al. [5] studied the influence of RE addition on mechanical properties of Mg-Zn-Y-Zr and showed that grain size was gradually refined the volume fraction of second phases increased with increasing additions of RE.

Although many studies have focused on the effects of different RE additions on the microstructure and mechanical properties of ZK60 magnesium alloys, there is no study in the literature investigating the combined effect of La and Y additions on ZK60 magnesium alloys. Thus, this study aims for understanding the effects of La and Y additions on the microstructure and mechanical properties of as-cast ZK60 magnesium alloy and clarifying their relationship.

II. DETAILS EXPERIMENTAL

The alloys with nominal compositions (wt%) of Mg-6Zn-1La-0.5Zr, Mg-6Zn-1La-0.5Y-0.5Zr and Mg-6Zn-1La-1Y-0.5Zr were produced by low pressure die casting. Pure Mg ingots (99.9 wt%) were melted at 750 °C under a argon gas flow. After that, pure Zn (99.9 wt%), Mg-30 wt% Y, Mg-30 wt% La and Mg-30 wt% Zr master alloys were added into the crucible. The mixture was held at this temperature for 30 min and stirred for 15 mi. After obtaining a compositional homogeneity, a pressure of 2 bar was applied and the cylindrical steel moulds that were preheated to 250 °C were filled by a steel pipe. The chemical compositions of the produced alloys were measured by wave-length dispersion X-ray fluorescence (XRF-Rigaku ZSX Primus II) and listed in **Table 1**.

Table 1: Chemical compositions of the alloys.

Alloy	Zn	Zr	La	Y	Mg
ZK60-1RE	6.22	0.55	1.12	-	Bal.
ZK60-1RE-0.5Y	6.16	0.58	1.04	0.55	Bal.
ZK60-1RE-1Y	6.29	0.52	1.14	1.1	Bal.

Microstructure images were taken by a Nikon optical microscope (OM) and a Carl Zeiss Ultra Plus field emission scanning electron microscope (SEM) equipped with an energy dispersive X-ray spectroscopy (EDX). The alloys were ground, polished and etched with a mixture of 6 g picric acid, 5 ml acetic acid, 10 ml distilled water and 100 ml ethanol. The constituent phase analyses were carried

out by means of Rigaku Ultima IV X-ray diffractometer (XRD) using a Cu target with a scanning angle from 10 ° to 90 ° and a scanning speed of 3 °/min. Tensile tests were carried out on a Zwick/Roell Z600 universal testing machine at a strain rate of 0.00167 1/s at room temperature. Each test condition was repeated at least three times.

III. RESULTS AND DISCUSSION

3.1. Microstructure

Fig.1. illustrates the XRD results of the as-cast alloys. It can be seen that the as-cast microstructure of ZK60-1RE alloy consisted of α-Mg, Mg-Zn-La ternary phase and Mg-Zn binary phases. In fact, Mg-Zn-Re ternary phase cannot be discerned based on the XRD standards. But according to previous studies [10–12], the same peaks at ~25° and ~52° were detected and proposed that the peaks referred to Mg-Zn-RE ternary phases. Y addition led to a formation of Mg-Zn-Y phases as it was expressed as three different forms: I-phase (Mg_3Zn_6Y), W-phase ($Mg_3Zn_3Y_2$) and X-phase ($Mg_{12}ZnY$) [5,7]. Thefraction of these Mg-Zn-Y phasesshowed an increasewithincreasing Y addition.

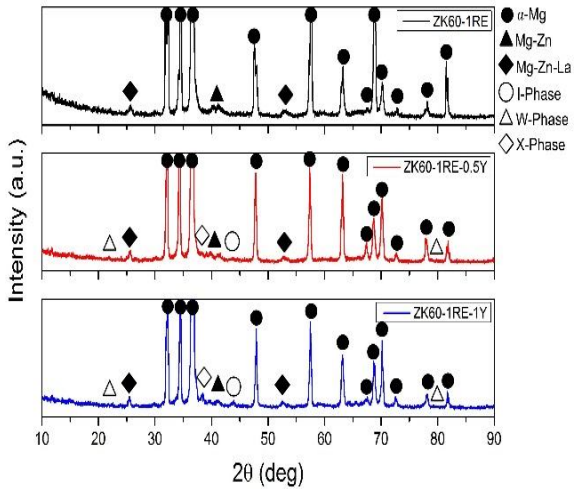


Fig.1. XRD patterns of the ZK60-1RE, ZK60-1RE-0.5Y and ZK60-1RE-1Y alloys.

Fig.2. shows the optical and SEM microstructures of the studied alloys. Without Y addition, ZK60-1RE alloy microstructure consisted of large α-Mg grains and coarse second phase particles mostly located along grain boundaries. After 0.5 wt% Y addition, the coarse second phases were replaced by semi-continuous net-like second phase particles throughout the microstructure.

These net-like structure coarsened after further Y addition to 1 wt%. The volume fraction of the second phases increased by 2 % and 2.5 % after and Y additions of 0.5 wt% and 1 wt% respectively. Y addition also refined the α-Mg grains and resulted in a more uniform distribution of second phase particles. A grain refinement of 42 % was achieved by 2 wt% Y addition.

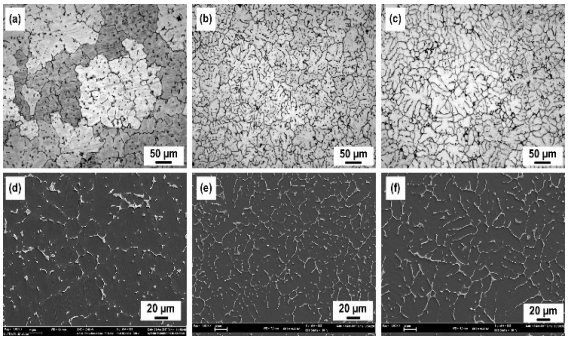


Fig.2. Optical (a-c) and SEM (d-f) micrographs of (a),(d) ZK60-1RE, (b),(e) ZK60-1RE-0.5Y and (c),(f) ZK60-1RE-1Y alloys.

3.2. Mechanical Properties

The tensile test results of the alloys are shown in **Fig.3**. It can be seen that Y addition gave rise to a considerable increase in the yield strength of ZK60-1RE alloy. The alloy containing 0.5 wt% Y addition gave the best yield and tensile strengths, in which improvements of 25 % and 5 % were obtained, respectively. The improvement in the mechanical properties by Y addition can primarily be attributed to the grain boundary strengthening. According to Hall-Petch theory, yield strength increases with a reduction in the grain size due to the increased grain boundaries that can oppose to the dislocation motion. It is also worth noting that Y addition above 0.5 wt% led to a deterioration in the mechanical properties. As stated earlier, with increasing Y addition, the net-like structure of second phases coarsened. This coarsening of second phases after 1 wt% Y addition might lead to premature crack propagation around these particles and decrease in both strength and elongation to fracture.

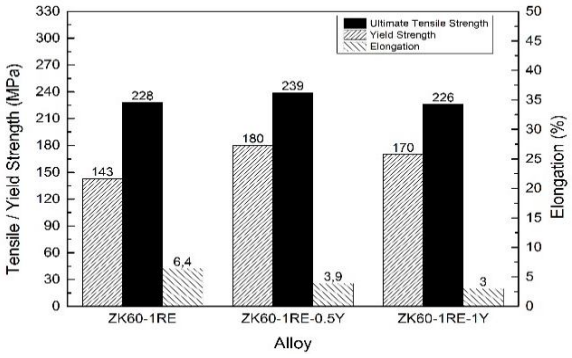


Fig.3. Tensile test results of the ZK60-1RE, ZK60-1RE-0.5Y and ZK60-1RE-1Y alloys.

Fig.4. shows SEM fractography of the alloys. It is observed that the fracture surfaces of the as-cast alloys were composed of many cleavages and tearing edges that resulted in low ductility. Furthermore, many broken second phase particles were seen on the broken surfaces. Second phase particles can act as barriers to dislocations movement and improve the strength. However, they may also cause formation of crack initiation sites during plastic deformation and decrease the ductility.

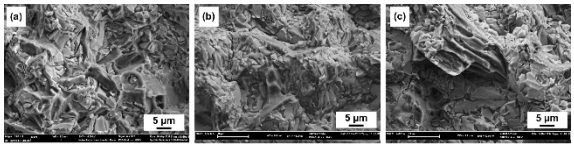


Fig.4. SEM fractographs of the (a) ZK60-1RE, (b) ZK60-1RE-0.5Y and (c) ZK60-1RE-1Y alloys.

CONCLUSIONS

Thermal The following conclusions can be drawn:

1. Y addition led to a formation of Mg-Zn-Y phases as it was expressed as three different forms: I-phase (Mg_3Zn_6Y), W-phase ($Mg_3Zn_3Y_2$) and X-phase ($Mg_{12}ZnY$).
2. After Y addition, the coarse second phases were replaced by semi-continuous net-like second phase particles throughout the microstructure.
3. Y additionresulted in a considerableincrease in theyieldstrength but deterioratedelongationtofractureduetotheincreasedamount of secondphasesthatmaycauseprematurecrackpropagation.

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