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Review of The Effect of Neodymium and Ytterbium on Microstructure and Mechanical Properties of Magnesium Alloy

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Abstract: The impact of the rare earth elements neodymium (Nd) and ytterbium (Yb) on the microstructure and mechanical characteristics of the magnesium alloy was examined. The studies were carried out using optical microscopy (OM) and scanning electron microscopy (SEM) with electron dispersive spectroscopy (EDS), which revealed that neodymium and ytterbium changed the grain size of the alloys. Optical microscopy revealed the grain size of the alloys, indicating grain refinement. The addition of Nd and Yb caused a new development of intermetallic phases at grain boundaries, which dissolved into the magnesium matrix, according to SEM/EDS measurements. Both additions increased the Mg-Zn-Zr base alloys' ultimate tensile strength (UTS) and hardness value.

Keywords: Magnesium Alloy, Neodymium, Ytterbium, Microstructure, Mechanical Properties

1. Introduction

Magnesium alloys are widely used in modern industry. High strength properties combined with relatively low density make them very attractive as structural materials in applications where weight saving is of great importance. Such areas are, first, aircraft and space machinery, but ground transport, including automobiles, has applications for such alloys, too. The application of magnesium alloys in machines enables a decrease in fuel consumption and improvements in their dynamic and other technical characteristics, making them more profitable. There are also other vital applications of magnesium alloys as light structural materials. Besides, they are used as materials with physical or chemical properties.

As well known, Mg-Zn-Zr system alloys are the commonly used wrought magnesium alloys with high tensile strength and excellent plasticity. The wider solidification temperature range, lower eutectic temperature, serious microscopy segregation, obvious shrinkage cavity, bad castability and so on restrict it to be used extensively. Rare earth metals (Y, Sm, La, Ce, and Gd) are commonly used as

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alloying elements to improve and reduce the texture of microstructures and enhance the strength of ZK60 via the formation of a hard Mg–Zn-RE ternary phase [1].

The addition of other RE to the Mg-Zn-Zr system, on the other hand, has variable microstructure and mechanical properties. As a result, the RE addition's real nature and composition. When accrediting the influence of RE addition on alloy characteristics, it is required. The microstructure and mechanical properties of Mg-Zn-Zr base alloy or ZK60 alloy with neodymium and ytterbium additions are investigated in this research.

2. Materials and Methods

The case study technique was applied in this study, with references to previous research and papers. The references were chosen based on their objectives being similar to those of this work, as well as other factors such as the year of publication, the types of alloys utilised, and the sort of experimental approach used. The type of alloys used were mostly prioritised on the Mg-Zn-Zr system alloys with the addition of Nd and Yb as the scope of the study was pointed on. All of the publications for the selected references were taken for the past twenty (20) years from present, and the type of alloys used were mostly prioritised on the Mg-Zn-Zr system alloys with the addition of Nd and Yb as the scope of the study was pointed on. The case study review was primarily focused on the microstructure and mechanical properties of the specimens with proper testing and laboratory analysis utilising the appropriate instruments for the type of experimental approach.

2.1 Materials

In this investigation, magnesium alloys with the Mg-Zn-Zr alloy system were selected because they were similar to the ZK60 alloy. Other magnesium alloys were possible as long as the magnesium (Mg), zinc (Zn), and zirconium (Zr) elements were included in the major composition of the base alloy [1]. The experimental technique with the inclusion of RE into the base alloy was organised by the element of rare earth employed, such as neodymium (Nd) and ytterbium (Yb), with varied numbers of specimens and weight percentages based on the collected references wt%.

2.3 Methods

The case study analysis was directly related to the study's goals of analysing the base alloy's microstructure and mechanical properties after adding RE [2.3]. A tensile test and a hardness test were also used to assess the specimen's mechanical qualities. This test reveals if the basic alloy's mechanical properties have improved or not after Er and Nd have been added. The microstructure investigation was carried out using optical microscopy and SEM/EDS to collect qualitative and quantitative data such as grain size measurement and phase formation along grain boundaries with their compositions [4,5].

3. Results and Discussion

3.1 Microstructure

The analysis began with Nd addition to ZK60 alloy. From measurements on SEM images in Figure 1, the average grain size of ZK60 and ZNdK620 alloys are 65 µm and 42 µm, respectively, which indicates that Nd addition into ZK60 alloy results in good grain refinement. This is probably attributed to that additional Nd addition generates greater constitutional undercooling in a diffusion layer ahead of the advancing solid/liquid interface [6,7]. In addition, it should be noted that the intermetallic phases were significantly changed after Nd addition. In the ZK60 alloy, coarse intermetallic phase with irregular morphologies and fine intermetallic phase can be observed while mainly coarse intermetallic phase with lamellae or network-shaped morphology in the ZndK620 alloy.

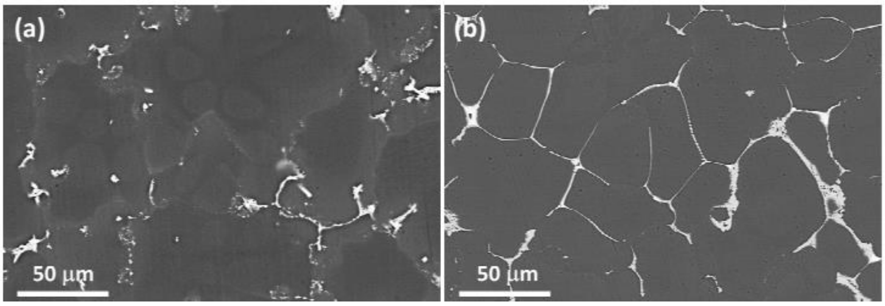

Figure 1: SEM images of the as-cast (a) ZK60 and (b) ZNdK620 alloys

While for Yb addition, Figure 2 shows the as-cast microstructures of ZK60–Yb alloys containing 0, 1 and 2 wt.% Yb, respectively. As shown in Figure 2(a), the microstructure of as-cast ZK60 alloy is comprised of coarse equiaxed grains and a small amount of thin network compounds, $MgZn_2$ and MgZn, at grain boundaries as well as a few Zr-rich particles inside grains. With the addition of Yb and the increase of Yb contents, the grain sizes are decreased and the amount of compounds increased apparently, as shown in Figure 2(a–c) and Table 2. It suggests that Yb has the effects of grain refinement and of intermetallic formation on as-cast ZK60–Yb alloys.

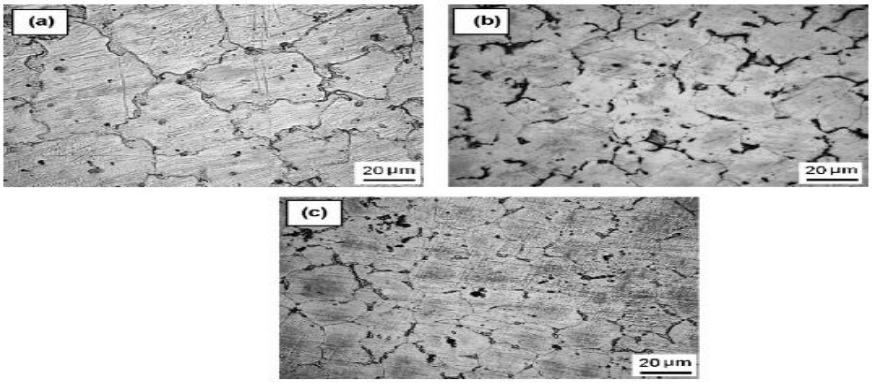

Figure 2: Microstructure of as-cast ZK60 (a), ZK60–1Yb (b) and ZK60–2Yb (c) alloys

Table 2: Grain sizes and quantity of compounds at grain boundaries for the experimental alloys

Alloys	Grain size (μm)	Quantity of compounds (vol.%)
ZK60	38.8	2.3
ZK60–1Yb	26.2	3.1
ZK60–2Yb	17.6	3.6

3.2 Mechanical Properties

Figure 3 shows the representative tensile and compressive curves at room temperature for both as-extruded ZK60 and ZNdK620 alloys. Nd addition significantly improves the strength of ZK60 alloy, although slightly reducing the tensile ductility and having no obvious influence on the strain hardening. Table 3 lists the mechanical properties of the studied two alloys. The TYS and CYS of ZK60 alloy were improved by approximately 19% and 26%, respectively, after Nd addition. Additionally, the as-extruded ZK60 alloy exhibits significant tension-compression yield asymmetry (0.66), which was not improved after Nd addition (0.68).

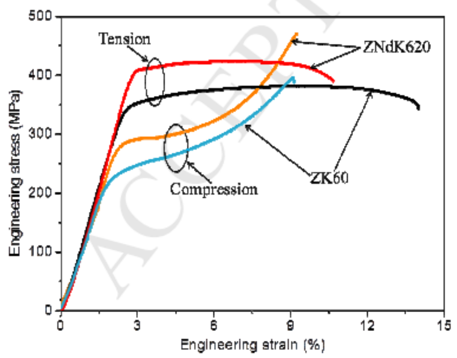

Figure 3: Representative tensile and compressive curves at room temperature for both as-extruded ZK60 and ZNdK620 alloys

Table 3: Mechanical properties of the as-extruded ZK60 and ZNdK620 alloys at room temperature, UTS (MPa): ultimate tensile strength, UCS (MPa): ultimate compressive strength, TYS (MPa): tensile yield strength, CYS (MPa): compressive yield strength, ε_T (%): elongation to failure in tension, ε_C (%): elongation to failure in compression

Alloy	UTS	TYS	ε_T	UCS	CYS	ε_C	CYS/TYS
ZK60	382	342	14.0	395	221	9.2	0.65
ZNdK620	424	408	10.6	470	278	9.2	0.68

Figure 4(a) shows the tensile test results of the as-extruded ZK60–Yb alloys extruded at 370 ◦C with extrusion ratio 20:1. It is apparent that the tensile strengths and yield strengths of the alloys increase, and the elongations decrease with the increase of Yb contents, respectively. The maximum tensile strength is obtained from ZK60–2Yb alloy that is about 420MPa, as shown in Figure 5, higher than that of ZK60 alloy about 70MPa, but the elongation drops to about 3% from 16.4% of ZK60 alloy. After aging at 200 ◦C for 4 hours with and without mentioned solution heat treatment, nominated T6 and T5 states, respectively, the ultimate and yield tensile strengths of ZK60–Yb alloy are reduced moderately and the elongations are increased substantially, as shown in Figure 4(b and c).

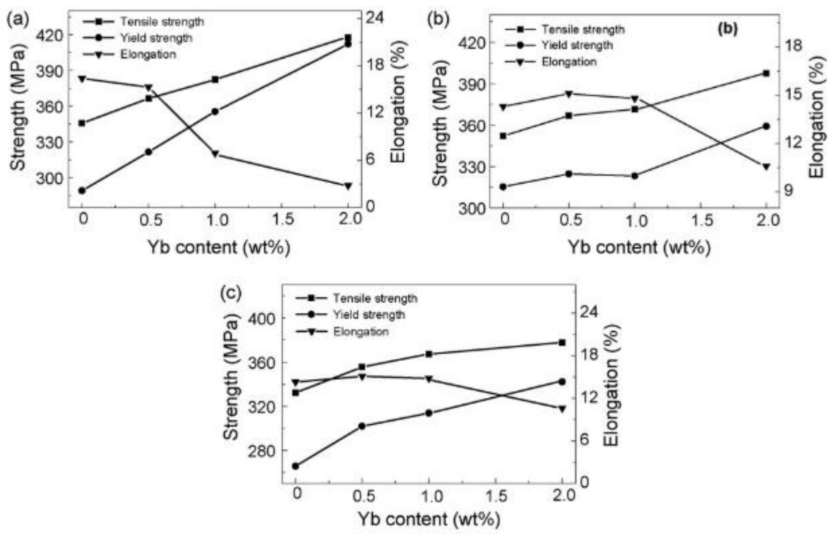

Figure 4: Tensile properties of ZK60–Yb alloys at as-extruded (a), as-T5 (b) and as-T6 (c) states alloys

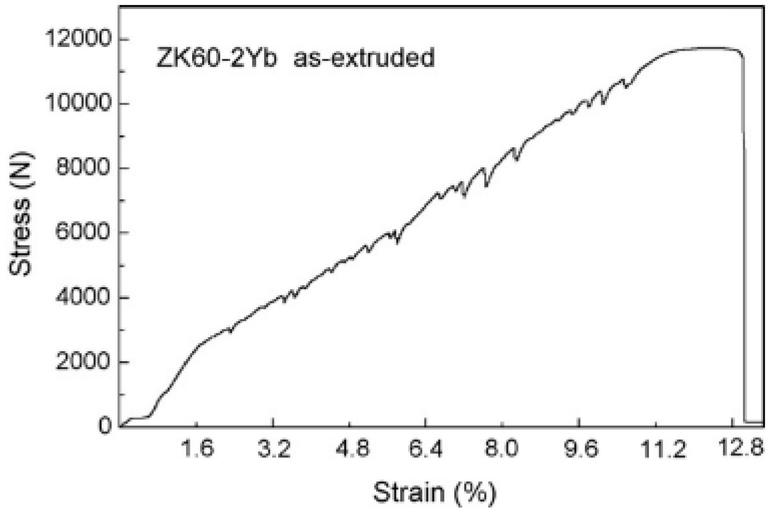

Figure 5: Tensile test curve of as-extruded ZK60–2Yb alloy

4. Conclusion

The effect of the addition of Er and Nd on microstructure and mechanical properties of Mg-Zn base alloy was investigated. From the case study analysis, the follows can be summarized:

a) The microstructure of Mg-Zn-Zr alloy with the addition of Nd or Yb is refined obviously and the eutectic phase containing Nd or Yb is formed at dendrite boundaries and distributed nearby dendrite boundaries. However, the eutectic phases containing Nd and Yb are formed and distributed in the shape of a network in Mg-Zn-Zr with combination addition of Nd and Yb, and the rod-shaped eutectic phases are somehow thickened.
b) After T4 solution treatment, the eutectic structure of Mg-Zn-Zr alloy is fully dissolved into the matrix while there are still some undissolved compounds at grain boundaries in Mg-Zn-Zr-Nd, Mg-Zn-Zr-Yb and Mg-Zn-Zr-Nd-Yb alloy. Particularly in Mg-Zn-Zr-Yb alloy, the Mg-Zn-Yb spherical particle phase is formed and helpful to improve the comprehensive mechanical properties, i.e., the tensile strength, the yield strength and the elongation. At the elevated temperature, the alloy with combination addition of Nd and Yb has good performance in thermal stability, but inferiority in elongation.

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