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Effect of La and Nd on microstructures and mechanical properties of AZ61 wrought magnesium alloy ①

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Abstract: Effects of La and Nd addition on the microstructure and mechanical properties of the AZ61 alloy have been investigated. The results show that when La and Nd are added into the AZ61 alloy respectively, the β($Mg_{17}Al_{12}$) phase is refined and granulated, and new phases are formed in the form of small rod-like shape, which are verified as La_3Al_{11} and Nd_3Al_{11} phase by X-ray diffraction and TEM observation. Microstructure observations show that the effective efficiency of La addition is higher than that of Nd addition, thus the sizes of β($Mg_{17}Al_{12}$) and La_3Al_{11} phase are relatively smaller than those of β($Mg_{17}Al_{12}$) and Nd_3Al_{11} phases in both AZ61 alloy and Nd-containing alloy. The increase of the tensile strength and elongation of AZ61 alloy refers to the existence of small rod-like La_3Al_{11} and Nd_3Al_{11} phases, and fine granulated β($Mg_{17}Al_{12}$) phase.

Key words: AZ61 alloy; RE; microstructure; mechanical properties
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1 INTRODUCTION

Mg alloys are the lightest metallic structural materials with characteristics of incomparable ratio of strength to mass, high elastic modulus and maximum absorption of vibration. In recent years, research and development of Mg alloys have been greatly promoted by the lightweight requirement in automotive, railway and aerospace industries[1, 2]. However, their strengths are limited not to satisfy the criteria of some structural components frequently fractured due to low strength. In order to improve the strength of Mg alloys without affecting other properties, rare earth (RE) elements have been added to Mg alloys since 1960s[3, 4]. Recently, WANG et al[5] reported that RE increases tensile strength and yield strength in cast Mg alloys, and Luo et al[4] has studied the strengthening effects of rare earths on wrought Mg-Zn-Zr-RE alloys. However, there are few studies of the effects of pure rare earth metals on microstructure and mechanical properties of Mg-Al-Zn wrought alloys. Therefore, pure La and Nd are added to the AZ61 wrought alloy for investigating the changes of microstructures and properties in this study.

2 EXPERIMENTAL

Two alloys with compositions of containing 0.7% La and 0.6% Nd based on AZ61 alloy were made into ingots of 220 mm × 180 mm × 25 mm. The ingots were solutionized at 400 ℃ for 15 h. The standard tensile specimens were made from them and tested at room temperature in Zwick/Roell testing machine. The microstructures of specimens were analyzed by a light microscope (OM, LEICA MEF4M), scanning electron microscopes. Phase analysis was performed by means of a D/MAS-ⅢA X-ray diffraction meter (XRD). TEM analysis was conducted in an H-800 transmission electron microscope at 200 kV.

3 RESULTS

3.1 Effect of La and Nd on microstructure

Fig. 1 shows the cast microstructures. It is found that the cast microstructure of AZ61 alloy is composed of primary α(Mg) solid solution and eutectic β($Mg_{17}Al_{12}$) phases.[6] β($Mg_{17}Al_{12}$) phase shows discontinuous network distributed both in grains and at grain boundaries. In La-containing alloy, new phase and β($Mg_{17}Al_{12}$) phase are uniformly distributed in the matrix, and the new phase exhibits mostly small rod-like shape. In Nd-containing alloy the new phase exhibits relatively big rods-like shape, and distributes in the matrix heterogeneously. It is obvious that La and Nd addition reduces the size of β($Mg_{17}Al_{12}$) phases, illustrating that La and Nd restrict the formation of β($Mg_{17}Al_{12}$) phase, and promote the formation of other compounds[7]. The new phases are

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verified as La_3Al_{11} and Nd_3A_{11}[5] by X-ray diffraction, as shown in Fig. 2.

After solution treatment, β($Mg_{17}Al_{12}$) phases of the three alloys are almost dissolved into the matrix. The grain boundaries can be seen clearly, and the mean grain size is about 40 μm, as shown in Fig. 3. This suggests that La and Nd do not refine the grains of the cast AZ61 alloy, and RE-containing alloys only exhibit La_3Al_{11} and Nd_3Al_{11} phases on the matrix. The La_3Al_{11} and Nd_3Al_{11} phases do not dissolute into the matrix. This is because the diffusion of the solutes in these phases is slow, and the decomposition of them is difficult due to their high melting point (1 246 ℃).

3.2 Distributions of La and Nd and morphology of second phase

Fig. 4 shows the line or surface distributions of La and Nd after solution treatment. It is found that La and Nd exist both in the compounds and in the matrix. Furthermore, a small part of La and Nd solves in the α(Mg) matrix, and most of the La and Nd reacts with Al to form La_3Al_{11} and Nd_3Al_{11} phases. Theses phases exhibit small rod-like shape, and do not dissolve into the α(Mg) matrix, because they are stable at high temperatures[8]. Besides, SEM image proves that the size of La-containing phase is smaller than that of Nd-containing phase. This is possibly due to the difference of electronic positive characteristics.

Fig. 5 shows the images of TEM. It is found that the β ($Mg_{17}Al_{12}$) phase of the AZ61 alloy exhibits rods-like shape, while in RE-containing alloys the β ($Mg_{17}Al_{12}$) phase exhibits granulated shape. However, the size of the second phases in La-containing alloy is smaller than that in both AZ61 alloy and Nd-containing alloy. Based on the results of SEM and XRD, it is considered that the RE-containing phases are La_3Al_{11} and Nd_3Al_{11}[7, 8]. They exhibit rod-like shape, seeing *A* compound in Fig. 5(c). Fig. 5(d) is its diffraction pattern. After analysis of its diffraction

Fig. 1 Microstructures of as cast state (a) AZ61, (b) AZ61+ 0.7La and (c) AZ61+ 0.6Nd

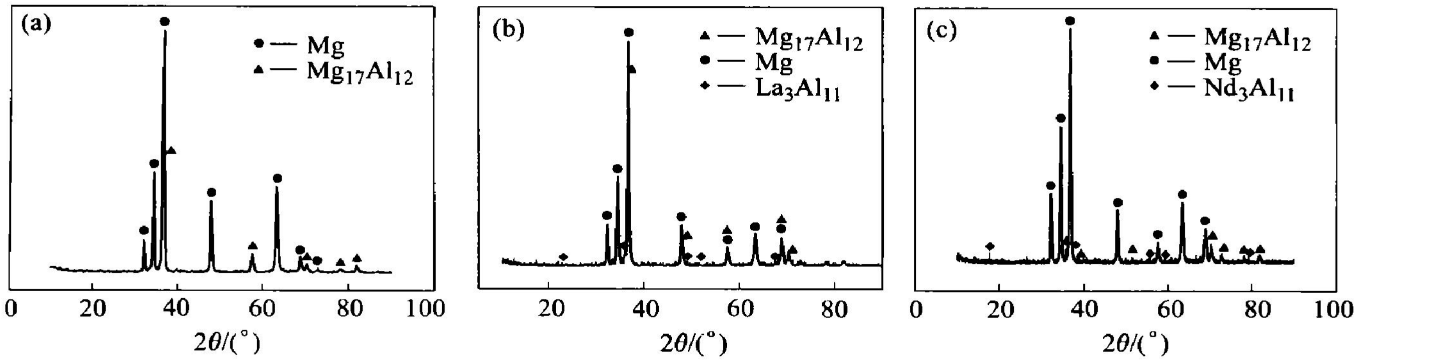

Fig. 2 X-ray diffraction patterns of (a) AZ61 alloy, (b) AZ61+ 0.7La alloy and (c) AZ61+ 0.6Nd alloy

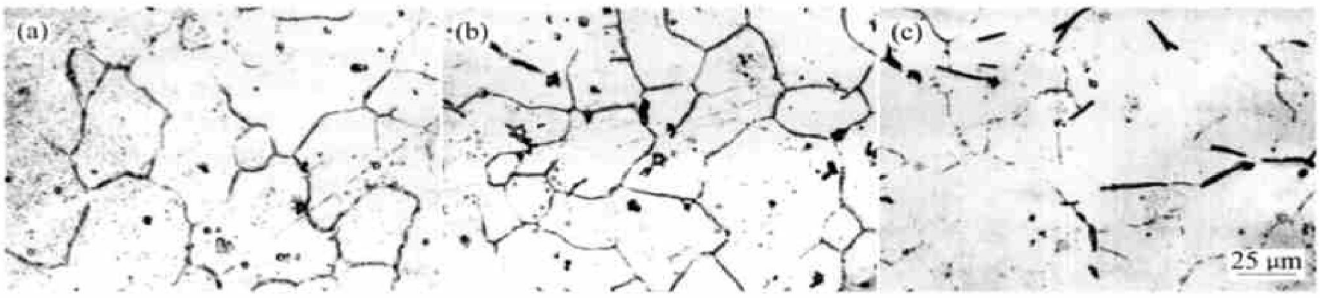

Fig. 3 Microstructures after solution treatment
(a) —AZ61 alloy; (b) —AZ61+ 0.7La alloy; (c) —AZ61+ 0.6Nd alloy

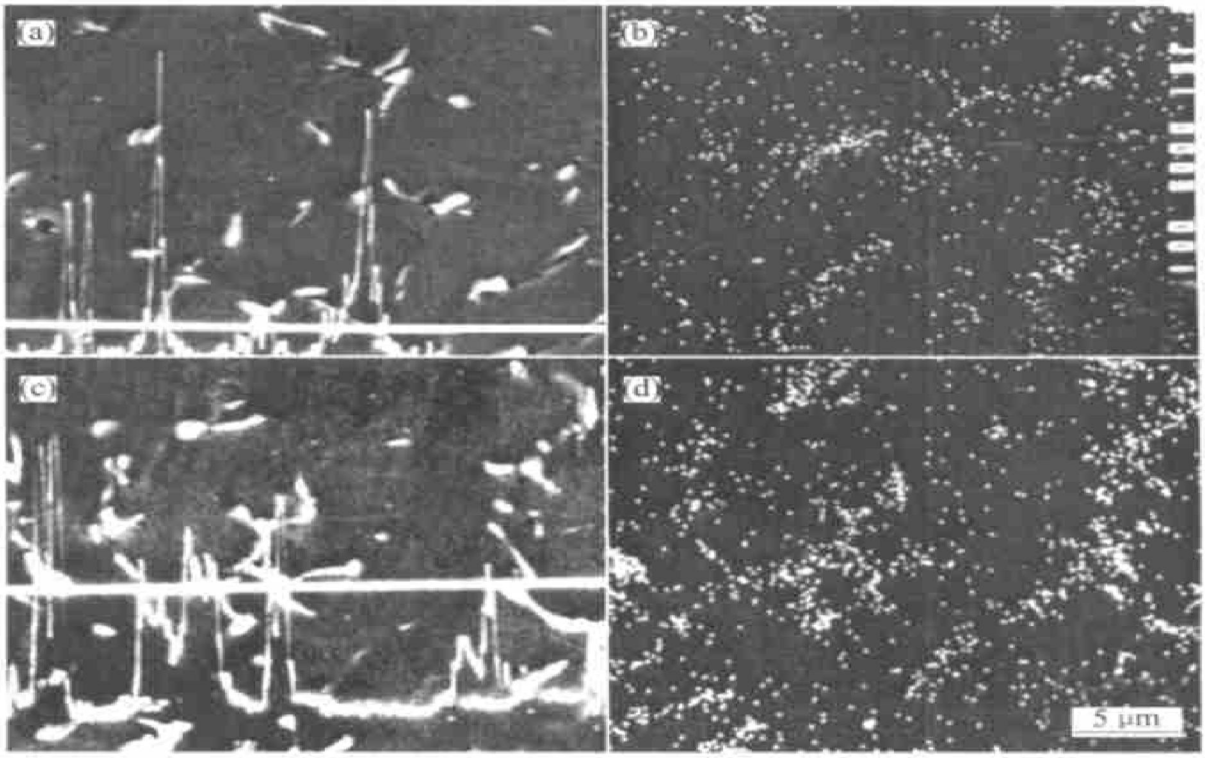

Fig. 4 SEM images after solution treatment
(a) —AZ61+ 0.7La alloy; (b) —AZ61+ 0.6Nd alloy

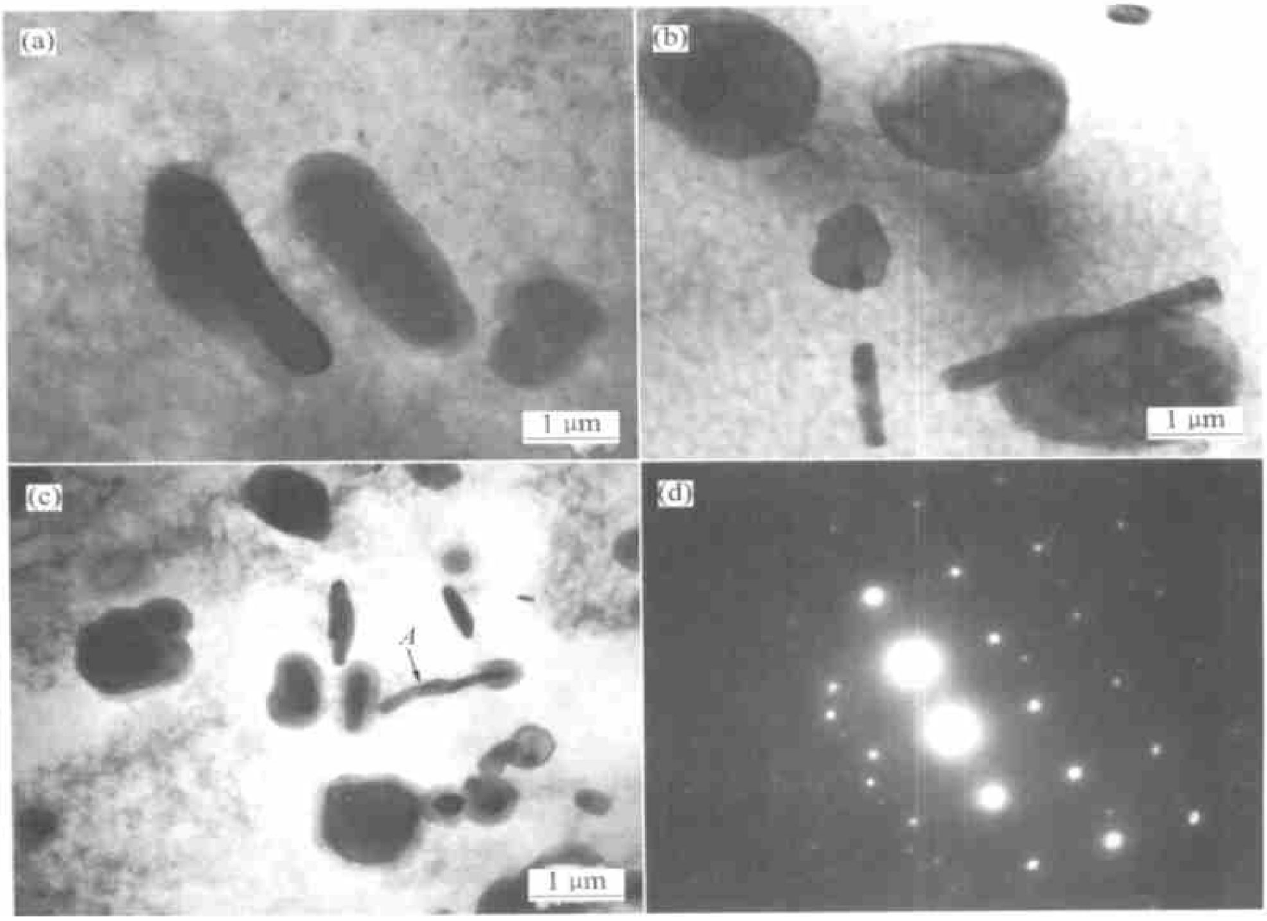

Fig. 5 TEM analysis for second phases of AZ61 alloy(a), AZ61+ 0.6Nd alloy(b), AZ61+ 0.7La alloy(c) and electron diffraction patter of *A* compound(d)

pattern, the compound is verified as La_3Al_{11}.

3.3 Effect of La and Nd additions on mechanical properties

Fig. 6 reveals the effects of La and Nd addition on mechanical properties of the AZ 6 1 alloy at room

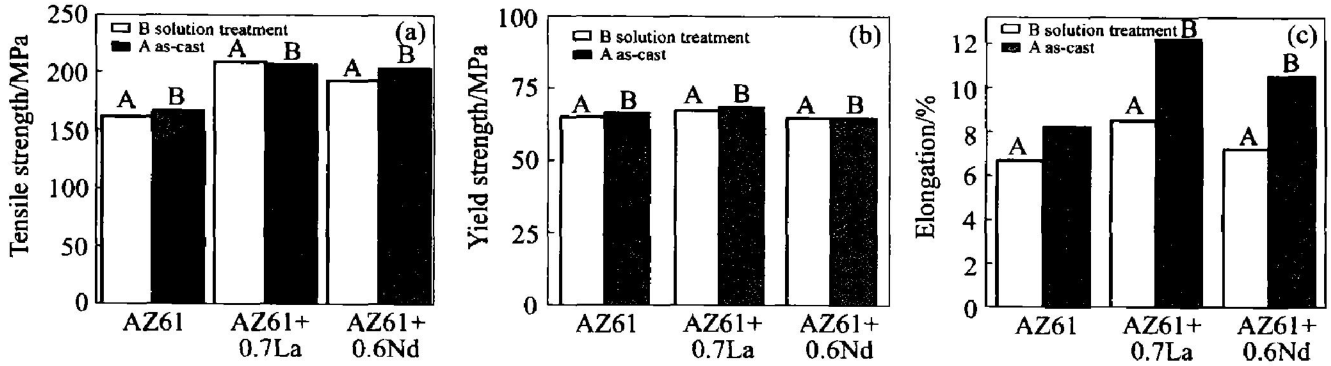

Fig. 6 Mechanical properties of AZ61 alloy, AZ61+ 0. 7La alloy and AZ61+ 0. 6Nd alloy

temperature. It is found that the tensile strength and the elongation increase with the additions of La and Nd, whereas the yield strength almost does not change. This refers to the dispersive strengthening of $Al_{11}La_3$ and Nd_3Al_1. However, the tensile strength and the elongation increase obviously in La-containing alloy. This is possibly due to relatively small β($Mg_{17}Al_{12}$) phase and $Al_{11}La_3$ phases.

4 DISCUSSION

The experimental results show that the tensile strength and the elongation are increased. There are two reasons: first, RE addition refines the β($Mg_{17}Al_{12}$) phase, and makes the β($Mg_{17}Al_{12}$) phase become granulated; second, the new small La_3Al_{11} and Nd_3Al_{11} phases form in the matrix, which promote dispersive strengthening, especially the effective efficiency of fine La_3Al_{11} phase is greatly obvious.

The primary α(Mg) solid solution and the β($Mg_{17}Al_{12}$) phase are composed of the microstructure of AZ61 alloy. No other phase exists[9]. In AZ61 alloy, the β($Mg_{17}Al_{12}$) phase takes discontinuous network distributed both in grains and at grain boundaries. When La and Nd are added to it, second phases change into rod-like or needle shape, which depends cooling condition and the speed of crystal growth. With RE addition, RE enriches in front of consolidation and retards other element diffusing into the α(Mg) solid solution. Therefore, the contents of other elements in the α(Mg) solid solution decrease, and promote more RE-containing phase formation. On the other hand, RE addition and its high chemical activity lead to the increase of supercooling, and then refine the β($Mg_{17}Al_{12}$) phase and make it granulated.

When La and Nd are added into the AZ61 alloy, it is possible to form Al-La, Al-Nd, Mg-La and Mg-Nd compounds. According to their electronic positive characteristics with Al or Mg, La and Nd take firstly to react with Al. Based on the Al-La and Al-Nd binary phase diagrams[6], La_3Al_{11} and Nd_3Al_{11} phases are first formed when RE content is less than 60%. In addition, RE enriches in the front of consolidation and retards the diffusion of Al, and leads to the increase of Al content in front of consolidation. When RE content surpasses the solvability in Al, RE-containing phases appear. These phases are La_3Al_{11} and Nd_3Al_1, and mostly exist in the form of small rod-like shape, as shown in Figs. 4 and 5.

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