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Refinement of LPSO structure in Mg-Ni-Y alloys by ultrasonic treatment

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ABSTRACT

Effect of ultrasonic treatment (UT) on the microstructures and mechanical properties of $Mg_{99.0-x}Ni_xY_{1.0}$ (x = 0.5, 1.0, 1.5, at.%) alloys was investigated. With the increase of Ni content, the amount of eutectic structure, consisting of Mg, Mg_2Ni phase and LPSO structure, increased while the mechanical properties decreased in as-cast alloys. After introducing UT to the melt, the secondary phases in these alloys were refined significantly and distributed uniformly, especially for long period stacking ordered (LPSO) structure. In $Mg_{98.5}Ni_{0.5}Y_{1.0}$ alloy, the formation of $MgNi_4Y$ phase, which was distributed adjacent to the LPSO structure at the grain boundaries, was stimulated by UT. In $Mg_{97.5}Ni_{1.5}Y_{1.0}$ alloy with UT, not only the width of grain boundaries were reduced, but also both the width of LPSO structure and that of eutectic structure were reduced. The optimal mechanical properties were obtained in $Mg_{98.5}Ni_{0.5}Y_{1.0}$ alloy, which exhibited 206 MPa in ultimate tensile stress and 7.96% in elongation, respectively. After UT, these properties were enhanced to 231 MPa and 14.56%, respectively. The other alloys' mechanical properties were also enhanced significantly by UT.

1. Introduction

Long Period Stacking Ordered (LPSO) structure in magnesium alloys has attracted much attention in the past decade due to its excellent strengthening effect [1–5]. However, the large and inhomogeneous sizes of the LPSO structure are harmful for the mechanical properties of alloys and will weaken the strengthening effect of LPSO structure. In order to improve the mechanical properties of magnesium alloys reinforced with LPSO structure, it is necessary to take measures to control the size and distribution of LPSO structure in magnesium alloys. Itoi et al [6] studied the $Mg_{90.5}Ni_{3.25}Y_{6.25}$ (at.%) alloy subjected to rolling and heat treatment. The ultimate tensile strength and elongation of the alloy reached 520 MPa and 8%, respectively. Such high performance is obtained mainly due to large amount of LPSO structure with a kink deformation, which can hinder the basal slip effectively. Therefore, the morphology of LPSO structure has great influence on the alloys' properties. Lu et al [7] applied ECAP (Equal Channel Angular Pressing) method to Mg-Gd-Zn-Zr alloy. The results showed that the formation of LPSO structure was stimulated by ECAP process and the shape of the LPSO structure was changed from fine lamellar structure to microcell particles, which consisted of extremely tiny 14H-type LPSO structure and α-Mg slices. The random distribution of micro LPSO structure with regular shape is conducive to strengthening the matrix, leading to enhancement of mechanical properties. In addition, the heat treatment process, as a common process used for improving microstructures and properties, is also able to take effects on LPSO structure. In $Mg_{97}Zn_1Gd_2$ alloy, the LPSO structure could not be found in the as-cast alloy while the 14H-type LPSO structure precipitated out during aging treatment [8]. Besides this change, type of LPSO structure can be modified through suitable heat treatment process. In Liu' study [9], after solution treatment at 773 K for 8 h, the bulk 18R-type LPSO structure disappeared partly and the lamellar 14H-type LPSO precipitated out in α-Mg grains. The lamellar 14H-type LPSO structure is more conducive to the ductility than 18R-LPSO.

According to previous studies, the shape, amount, distribution and type of LPSO structure can be modified by many methods and these changes have great influences on the properties of magnesium alloys. It is worth to note that previous studies always paid attentions to the LPSO structure which had been synthesized in the alloys and then applied some process to modify the existed LPSO structure, such as plastic deformation. However, the application of these processes is always restricted due to the expensive equipment and time consuming. Consequently, it is necessary to seek more convenient means for refining LPSO structure. Ultrasonic treatment (UT) may be an appropriate one. The grain size of primary α-Mg phase decreased significantly by applying ultrasonic to the solidifying AZ91 alloy [10,11]. Lin et al [12] introduced ultrasonic vibration treatment into Al-Si alloys. The result showed that the bulky primary Si phase was fined significantly. In Wang's study [13], Al_3Ti particles were refined and distributed more uniform after UT. In addition to the primary phases, UT can also take effects on the secondary phases. In Lee' study about Al-Si alloys [14], the UT process could decrease the size of various secondary phases,

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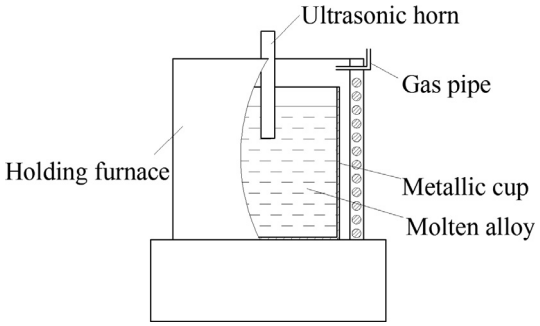

Fig. 1. Schematic of ultrasonic equipment.

including the eutectic Si, due to the increasing nucleation after UT. The coarse Al_2Sm phase in Mg-Al-Zn-Sm alloy could be modified to dispersive fine particles by UT process [15]. According to Zhao's study [16], the strip-like MgAlCeMn phase could be modified to fine globular particles by UT. Therefore, UT process is a potential method in refining LPSO structure and improving the quality of casting. Up to now, the effect of UT on the LPSO structure has never been studied.

In this study, Mg-Ni-Y alloys reinforced with small fraction of LPSO structure are synthesized. And ultrasonic treatment process is firstly applied to modifying LPSO structure.

2. Experimental procedure

$Mg_{99.0-x}Ni_xY_{1.0}$ (x = 0.5, 1.0, 1.5, at.%) alloys (named as alloy I, alloy II and alloy III in turn) were prepared by pure Mg (99.9 wt%), pure Ni (99.9 wt%) and Mg-30 wt.%Y master alloy. These alloys were melted under an atmosphere of 0.1 vol% SF_6 and 99.9 vol% N_2 at 760 °C, and this temperature was held for enough time to ensure the complete dissolution of pure Ni. And then part of the liquid Mg alloys was transited with a cylindrical metallic cup to a holding furnace at 640 °C. The diameter and height of the metallic cup is 60 mm and 85 mm, respectively. UT on alloys melt was carried out by inserting the ultrasonic horn into molten alloy below the surface at 10–15 mm, and turning on the ultrasonic generator. The ultrasonic horn is made of TC4 titanium alloy and is 25 mm in diameter at the tip. The molten alloy after UT was cooled to 640 °C and poured to a metal mold preheated to 200 °C. Alloys without UT process were prepared with the same method except for not turning on the ultrasonic generator. Fig. 1 shows the schematic of the ultrasonic equipment. The molten alloys were protected by high purity argon gas injected through the gas pipe. Time of UT process was maintained at 50–70 s. The power of UT transformed to the ultrasonic horn was 1.2 kW and the power density of ultrasonic was

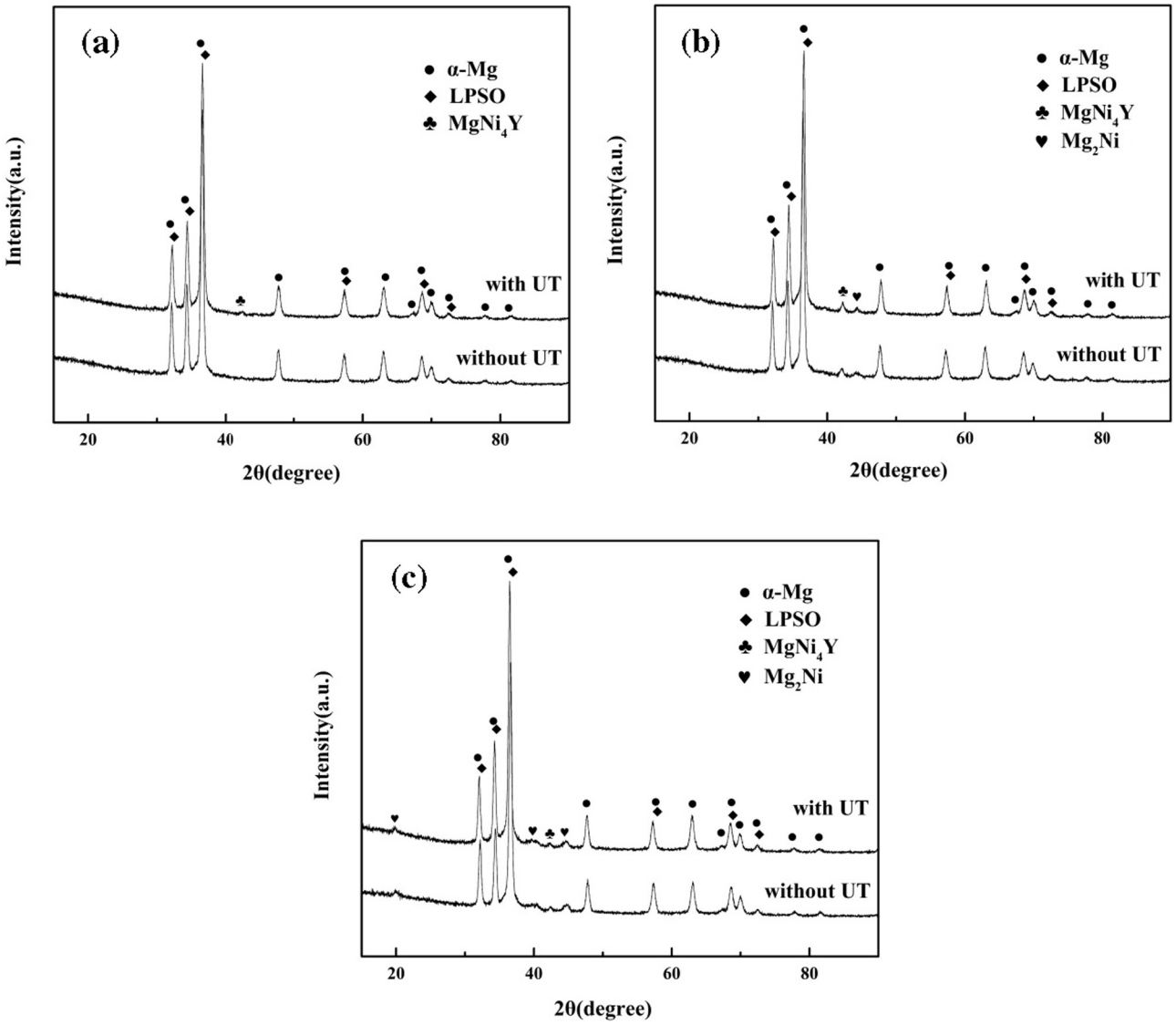

Fig. 2. XRD results of $Mg_{99.0-x}Ni_xY_{1.0}$ alloys without and with UT: (a) Alloy I; (b) Alloy II; (c) Alloy III.