Available online at www.sciencedirect.com
ScienceDirect
Materials Letters 62 (2008) 2872–2875
materials letters
www.elsevier.com/locate/matlet

Grain refinement of AZ91 alloy by introducing ultrasonic vibration during solidification

Xinbao Liu *, Yoshiaki Osawa, Susumu Takamori, Toshiji Mukai

Lightweight Alloys Group, Structural Metals Center, National Institute for Materials Science, Tskuba, Ibaraki 305-0047, Japan

Received 11 July 2007; accepted 22 January 2008
Available online 1 February 2008

Abstract

Ultrasonic vibration was introduced into the solidification of AZ91 alloy. Various microstructures were produced in this alloy using ultrasonic vibrations at different temperatures of the melt. The coarse dendrite microstructures were obtained with ultrasonic vibrations at temperatures below the liquidus temperature. The fine uniform grains were achieved under ultrasonic vibrations during the nucleation stage, which was mainly attributed to the cavitation and the acoustic flow induced by the ultrasonic vibration.

Keywords: Magnesium alloys; Microstructure; Grain refinement; Ultrasonic vibration

1. Introduction

Mg alloys have been widely used due to their comprehensive properties, such as low density, high specific strength and stiffness, improved damping property and electromagnetic shielding capacity, excellent machinability and good castability [1]. During the past decade, the demand for Mg alloys has increased rapidly in automotive, railway and aerospace industries. The most widely and commercially used Mg alloy system is the AZ91 alloy, which contains 9Al-1Zn-0.2Mn (all alloy compositions are in wt.% in this paper). Due to its wide solidification interval, however, the AZ91 alloy has a high susceptibility to solidification defects, such as hot tearing and microporosity. To overcome these defects, the refined microstructure is usually prepared by adding other elements, such as C, Ca, Sr, Sb and RE elements. Although these elements can refine the microstructure, various problems are also encountered. The addition of carbon produces carbide (Al_4C_3, SiC, and CaC_2), hexachloroethane (C_2Cl_6) and hexachlorobenzene (C_6Cl_6) that cause environmental problems [2,3]. The Ca addition promotes hot tearing [4], and the Sr addition reduces the ambient temperature properties [5]. Furthermore, the process control of the Sb or RE addition was difficult due to the formation of rodlike phases, and the addition of RE proved to be expensive [6,7]. Therefore, mechanical approaches for refining the microstructure of the AZ91 alloy without adding any elements are necessary.

Previous experiments on the Al alloys showed a promising effect of ultrasonic vibration on the microstructure refinement of castings [8–10]. When ultrasonic vibrations are coupled to the solidifying melts, microstructural changes occur including grain refinement, increased homogeneity and reduced segregation. Thus, the present attempt at applying ultrasonic vibration to the solidification of AZ91 alloy is made in this work, and the effect of ultrasonic vibrations at different temperatures of the melt on the microstructure is investigated.

2. Experimental procedure

A commercial ingot of an AZ91D Mg alloy with a nominal composition of Mg-9.08Al-0.62Zn-0.26Mn was used as the principal alloy. The melting process was carried out in an electrical resistance furnace under an atmosphere containing a gas mixture of CO_2/SF_6. An alumina crucible containing approximately 150 g

* Corresponding author.
E-mail address: liu.xinbao@nims.go.jp (X. Liu).

0167-577X/$ - see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.matlet.2008.01.063

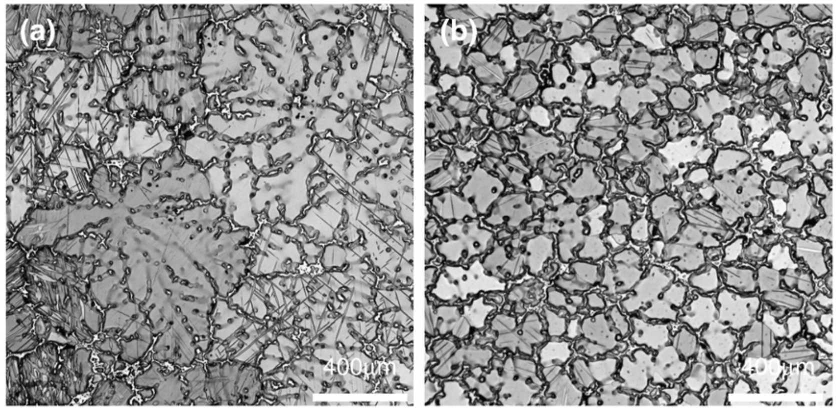

Fig. 1. Microstructures of the AZ91D alloy, (a) without ultrasonic vibration and (b) with ultrasonic vibration at temperatures from 615 °C to 580 °C.

of liquid magnesium was employed, and a thermocouple was inserted near the middle of the melt to acquire the temperature during solidification. The ultrasonic vibration system consisted of an acoustic generator with a maximum power of 1.2 kW. A detailed description of the ultrasonic vibration system has already been reported elsewhere [11]. When the melt was superheated to 720 °C, the furnace descended and the ultrasonic horn was quickly immersed into the melt to be preheated. The vibration process was not able to function until the pre-determined temperature was achieved. Then the ultrasonic horn was quickly removed, and the melt was cooled to room temperature.

Several experiments were conducted to study the effect of ultrasonic vibration on the microstructure of the AZ91 alloy. Because the liquidus and solidus temperatures of the AZ91D alloy were 598 °C and 468 °C [12], different temperature ranges of the melt were chosen to carry out the ultrasonic vibration. They were from 615 °C to 580 °C, from 615 °C to 595 °C, from 595 °C to 590 °C and from 590 °C to 580 °C, respectively. Microstructure characterization was conducted on an optical microscope. The specimens were cut from the longitudinal section of each sample. These specimens were polished and then etched by a solution of 10 mL acetic acid, 4.2 g picric acid, 10 mL H_2O, and 70 mL ethanol.

3. Results

Fig. 1 shows the microstructures of the AZ91D alloy with and without ultrasonic vibrations. In the alloy that did not receive any ultrasonic vibration, the coarse dendrites of the primary phase (α-Mg) are present throughout the sample demonstrating the normal dendrite growth mode, as shown in Fig. 1(a). A length of the branch of dendrites was about 500 µm. On the other hand, the fine uniform grains of the primary α-Mg phase were universally distributed in the sample produced with ultrasonic vibration at temperatures from 615 °C to 580 °C, which can be seen in Fig. 1(b).

Fig. 2 gives the microstructures of the AZ91D alloy under ultrasonic vibrations at different temperatures. The morphology of the primary α-Mg phase changed considerably with a decrease in the temperatures of ultrasonic vibration. With the ultrasonic vibration at temperatures from 615 °C to 595 °C, fine uniform grains of the primary α-Mg phase shown in Fig. 2(a) were formed, which was the same as that in Fig. 1(b). However, the microstructures at temperatures below the liquidus temperature (598 °C) from 595 °C to 590 °C and from 590 °C to 580 °C consisted of dendritic grains of the primary α-Mg phase, as shown in Fig. 2(b) and (c). Furthermore, the dendrite branches of the primary α-Mg phase in Fig. 2(c) were coarser compared to the microstructure in Fig. 2(b) but were slightly finer than that without the ultrasonic vibration as shown in Fig. 1(a).

Fig. 3 shows the cooling curves for above microstructures of the AZ91D alloy as shown in Figs. 1 and 2. It is clear that by decreasing the

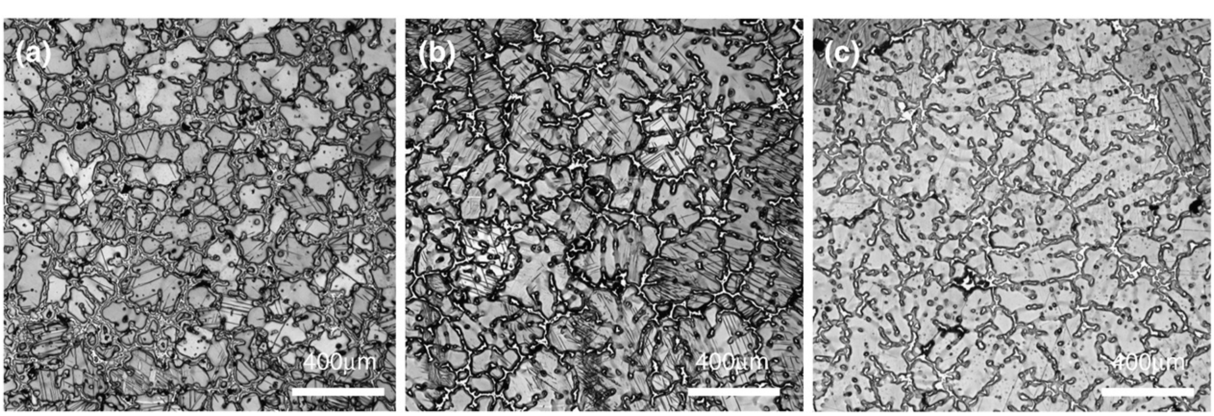

Fig. 2. Microstructures of the AZ91D alloy under ultrasonic vibrations at temperatures, (a) from 615 °C to 595 °C, (b) from 595 °C to 590 °C and (c) from 590 °C to 580 °C.