Journal of Alloys and Compounds 497 (2010) 147–154

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: www.elsevier.com/locate/jallcom

Microstructural evolution and phase transformations during partial remelting of AZ91D magnesium alloy refined by SiC

T.J. Chen*, X.D. Jiang, Y. Ma, Y.D. Li, Y. Hao

Key Laboratory of Gansu Advanced Nonferrous Materials, Lanzhou University of Technology, Lanzhou 730050, China

ARTICLE INFO

Article history:
Received 15 January 2010
Received in revised form 9 March 2010
Accepted 9 March 2010
Available online 15 March 2010

Keywords:
AZ91D alloy
Thixoforming
Microstructural evolution
Partial remelting
Phase transformation

ABSTRACT

The microstructural evolution and phase transformations have been investigated during partial remelting of AZ91D magnesium alloy refined by SiC particles. Simultaneously, the effect of heating temperature on semisolid microstructure has also been discussed. The results indicate that a semisolid microstructure with small and spheroidal particles can be obtained after the AZ91D alloy being partially remelted. The microstructural evolution can be divided into four stages, the initial coarsening, structural separation, spheroidization and final coarsening, which are attributed to the phase transformations of $\beta \rightarrow \alpha$, $\alpha + \beta \rightarrow L$ and $\alpha \rightarrow L$, $\alpha \rightarrow L$, and $\alpha \rightarrow L$ and $L \rightarrow \alpha$, respectively. Proper rising heating temperature is beneficial for achieving good semisolid microstructure available for thixoforming. For most of the primary particles in the semisolid microstructure, one particle originates from one original dendrite in the as-cast microstructure.

1. Introduction

Magnesium alloys are attractive for lightweight structural applications in transportation industry because of their low density and high specific strength and stiffness [1]. However, AZ91D alloy, the most commonly used magnesium alloy, suffers from the challenge in meeting the requirements of strength, ductility, fatigue and creep resistance. In order to improve these properties, thixoforming is a promising way by decreasing grain size and shrinkage porosities [2].

For the thixoforming technology, the key procedure is the production of semisolid ingots with small and spheroidal primary particles uniformly suspended in liquid phase [2,3]. There are several methods to fabricate this kind of nondendritic semisolid ingots, such as magnetohydrodynamic or mechanical stirring, spray casting, chemical grain refining, near-liquidus pouring and strain-induced melt activation [2–8]. Alternatively, the grain refining process produces the desired microstructures by adding grain refiner during traditional casting and a following heat treatment in mushy zone, and is a relatively simple method because it does not need some special treating procedures, such as stirring, spraying and deformation [2,3]. The key of this method is to obtain cast ingots with fine equiaxed grains. Unfortunately, for AZ91D alloy, a magnesium alloy containing aluminum, there is still no a commercially-used grain refining technique although several approaches have been developed [9,10]. Among these approaches, carbon inoculation has significant refining effect and good adaptability for the aluminum bearing alloys with different compositions and impurity contents, and thus is a promising way for commercial use if the introduction of carbon can be well resolved [10,11]. The authors investigated the grain refinement of AZ91D alloy by SiC particles and a technique with good maneuverability and reliability has been developed [12]. The grain size can be decreased from 311 μm of the not refined alloy to 71 μm of the refined alloy by 0.2 wt.% SiC particles.

In addition, the microstructural evolution during partial remelting is another key topic for thixoforming because this process has large effect on the resultant semisolid microstructure. The existing references have extensively investigated the microstructural evolution processes of Al alloys with different initial microstructures, such as fine grains, developed dendrites, nondendritic microstructure, deformed microstructure and spray cast microstructure [2–8]. Comparatively, the investigations about Mg alloys are quite limited and most of them have been focused on the previously deformed alloys [2,3,13–18]. Only a few papers have involved the as-cast magnesium alloys, but emphasized on the morphology change and coarsening behavior of the primary particles or the Mg_2Si particles in Si containing alloys in semisolid sate [19–25]. However, the microstructural evolution prior to liquid forming is very important for the final semisolid microstructure [26]. Furthermore, the relationship between the as-cast microstructure and semisolid microstructure is still unclear. Finally, it can be expected that the microstructural evolution is essentially resulted from phase transformations occurring during partial remelting and study on the

* Corresponding author. Tel.: +86 931 2976573; fax: +86 931 2976578.
E-mail addresses: chentj1971@126.com, chentj@lut.cn (T.J. Chen).

0925-8388/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.jallcom.2010.03.090

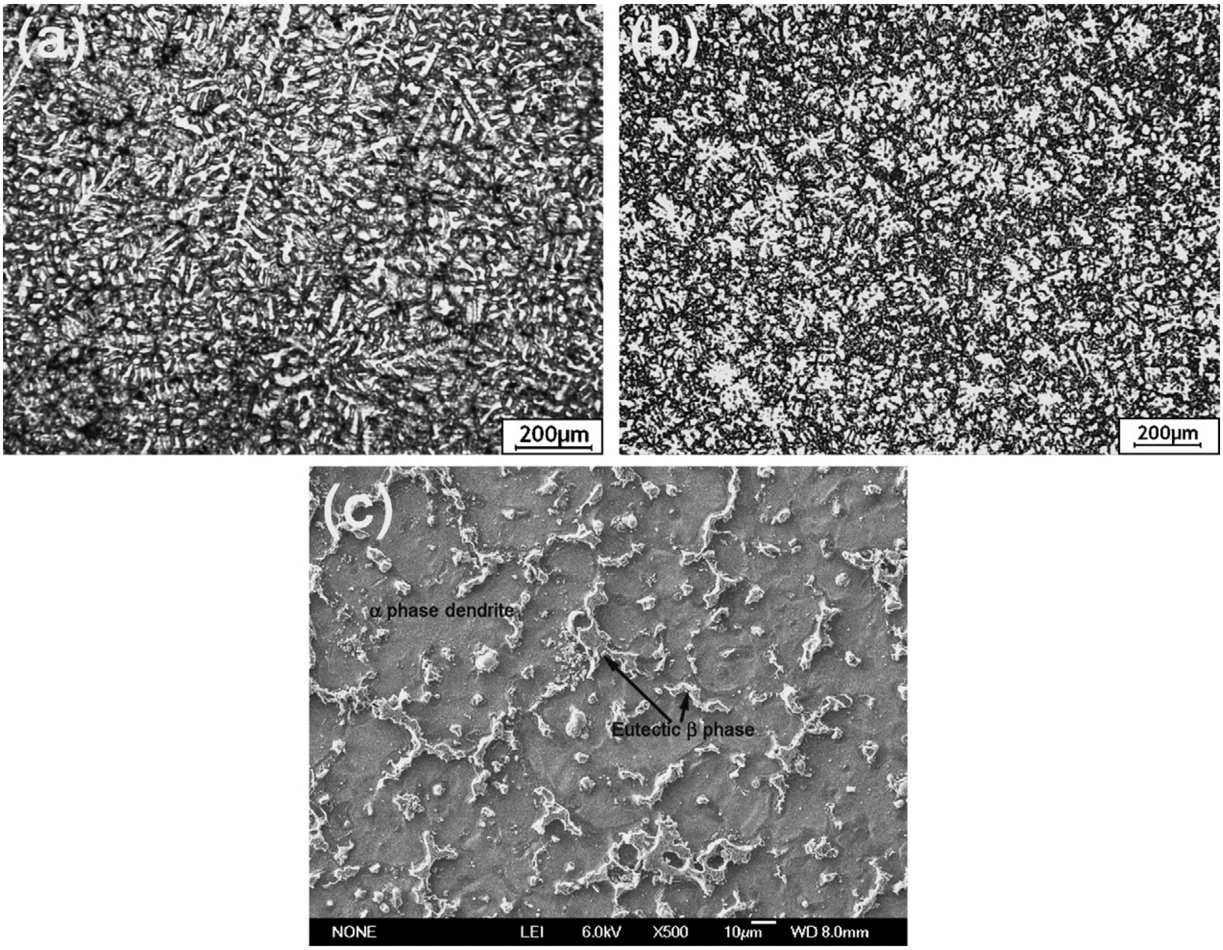

Fig. 1. (a) OM micrograph of the not grain-refined AZ91D alloy, (b) OM and (c) SEM micrographs of the refined AZ91D alloy by 0.2% SiC.

phase transformations can offer some important information to further verify the microstructural evolution process. But the existing investigations almost have not involved this aspect.

Therefore, in this paper, the microstructural evolution has been investigated during partial remelting of the AZ91D alloy refined by SiC particles, especially the evolution process prior to liquid forming. Simultaneously, the phase transformations occurring during partial remelting has been discussed. In addition, the effect of heating temperature on the semisolid microstructure has also been examined.

2. Experimental

The alloy used in the work is commercial AZ91D alloy and its composition is Mg–9.04Al–0.6Zn–0.31Mn (in wt.%). The details about grain refinement and preparation of cast alloy rods can be found in reference [12]. The rods (Φ 16 mm) refined by 0.2 wt.% SiC particles and having fine equiaxed grains with size of 71 μm were cut into small specimens (Φ 16 mm × 10 mm). Some of the specimens were heated for different durations (0–120 min) at 580 °C to investigate the microstructural evolution and phase transformations. The other specimens were heated for 20 min at different temperatures (550 °C, 560 °C, 570 °C, 580 °C and 590 °C) to study the effect of heating temperature on semisolid microstructure. In order to examine the temperature change of the specimen during partial remelting, one hole was drilled along the center axis of a specimen and a thermocouple was mounted in it.

All of the heated specimens were water-quenched quickly. One cross-section of each specimen was finished and polished by standard metallographic techniques, and then studied by scanning electron microscope (SEM) using back-scattered imaging mode and examined by energy disperse spectroscopy (EDS). Subsequently, they were etched by aqueous solution containing glycerol, nitric acid, hydrochloric acid and acetic acid and then observed on an optical microscope (OM). To determine the size and shape factor of the primary particles in the semisolid microstructures, the microstructures of some of typical specimens were quantitatively examined. The areas A_i and perimeters P_i of each primary particle were obtained and the average particle size D was calculated from the formula:

$$D = [\sum 2(A_i/\pi)^{1/2}]/N \quad (1)$$

where N is the total grain numbers. The shape factor F was calculated from the formula:

$$F = (\sum P_i^2/4\pi A_i)/N \quad (2)$$

if the particles are perfectly spherical, the shape factor has a value of 1; it increases for less spheroidal particles [27]. On each sample, three images with magnification of 200 times were examined.

X-ray diffractometer (XRD) was used to identify the phase constituents of the specimens heated for different durations at 580 °C in order to deduce the phase transformations occurring during partial remelting.

3. Results and discussion

3.1. As-cast microstructure

The solidification process and the resulting as-cast microstructure of the AZ91D should be first clarified in order to verify its microstructural evolution during partial remelting. Fig. 1 presents the microstructures of the not refined alloy and the alloy refined by 0.2 wt.% SiC particles. It shows that the primary dendrites of the not refined alloy are in equiaxed grain morphologies, but their secondary dendrite arms are quite long, i.e., the dendrites are quite developed (Fig. 1(a)). After being treated by 0.2 wt.% SiC particles, the primary dendrites become into fine and uniform equiaxed grains (Fig. 1(b)), which implies that SiC particles is an effective grain refiner for AZ91D alloy