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Effect of cooling condition on microstructure of semi-solid AZ91 slurry produced via ultrasonic vibration process

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Abstract: The effects of cooling conditions on the microstructure of semi-solid AZ91 slurry produced via ultrasonic vibration process were investigated. AZ91 melts were subjected to ultrasonic vibration in different temperature ranges under different cooling rates. The results show that fine and spherical *α*-Mg particles are obtained under ultrasonic vibration at the nucleation stage, which is mainly attributed to the cavitation and acoustic streaming induced by the ultrasonic vibration. The reduction of lower limit of ultrasonic vibration temperature between the liquidus and solidus increases the solid volume fraction and average particle size. Increasing cooling rate increases the solid volume fraction and reduces the average shape factor of particles. The appropriate temperature range for ultrasonic vibration is from 605 °C to 595 °C or 590 °C, and the suitable cooling rate is 2−3 °C/min.

Key words: AZ91 alloy; semi-solid; ultrasonic vibration; microstructure; cooling condition

1 Introduction

The semi-solid metal (SSM) processing, including thixoforming and rheocasting, is an effective net-shape forming process which combines the elements of both casting and forging, showing many advantages over the conventional process [1−3]. In recent years, more and more researches have been focused on rheocasting because of its low cost and high productivity [4,5]. Rheocasting involves stirring the solidifying alloy to prepare non-dendritic semi-solid slurry, then shaping the slurry directly. The transportation and storage of semi-solid slurry are the major difficulties during rheocasting, so the control of cooling conditions is very important during the preparation of semi-solid slurry.

A number of processes have been developed to prepare semi-solid slurry. Alternatively, the ultrasonic vibration is a simple and effective process to produce semi-solid metal slurry [6]. During the ultrasonic vibration process, an ultrasound field is imposed to the solidifying melt resulting in grain refinement, increased homogeneity, reduced microsegregation as well as degassing [7−9]. Currently, the ultrasonic vibration process is mainly used in producing the semi-solid slurry of aluminum alloys. LÜ et al [10,11] prepared semi-solid aluminum alloy slurry with direct and indirect ultrasonic vibration process. Their results indicated that good semi-solid slurry of aluminum alloy could be obtained in a short time by applying ultrasonic vibration near its liquidus temperature, and a considerable improvement in the mechanical properties was achieved after rheocasting. There are not as many published researches on ultrasonic treatment of magnesium alloys as on aluminium alloys. LIU et al [12] and GAO et al [13] studied the effect of ultrasonic power on the microstructure and mechanical properties of AZ91 magnesium alloy. These investigations showed that ultrasonic treatment resulted in formation of fine non-dendritic grains in the solidified microstructures, and the tensile and compressive strengths as well as the fracture strains of the castings were improved by ultrasonic treatment. ZHANG et al [14,15] investigated the effects of ultrasonic treatment on the microstructure and mechanical properties of Mg−9.0%Al binary and AZ80 magnesium alloys and reported the effects of ultrasonic treatment on the size

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and morphology of $Mg_{17}Al_{12}$ phase. They showed that $Mg_{17}Al_{12}$ phase in the entire cross section of the castings was significantly refined and also lost its continuity along the grain boundaries. LAN et al [16] used ultrasonic treatment for dispersion of nano-sized SiC particles in molten AZ91D magnesium alloy to produce metal matrix nanocomposites. They showed a nearly uniform distribution and good dispersion of SiC nano-particles within the matrix. Most researches on ultrasonic treatment of magnesium alloys were focused on grain refinement, and studies on the semi-solid slurry preparation of magnesium alloy via ultrasonic vibration process were limited.

In this work, semi-solid slurry of AZ91 magnesium alloy was prepared by ultrasonic vibration process and the effects of cooling conditions on the microstructure of semi-solid AZ91 slurry were investigated.

2 Experimental

A commercial ingot of the AZ91D alloy with a measured composition of Mg−8.45Al−0.56Zn−0.19Mn was used as the principal alloy. In each experiment, about 1.2 kg of the alloy was melted in an electrical resistance furnace under a protective gas of CO_2+SF_6. When the melt temperature was stabilized at 680 °C, the crucible with melt was transferred to another furnace for ultrasonic treatment. This furnace was pre-heated to different temperatures below 580 °C in order to get different cooling rates. The schematic of ultrasonic vibration device is shown in Fig. 1. It consists of an ultrasonic generator and transducer with a maximum power of 2.0 kW and fixed frequency of about 20 kHz, a ultrasonic horn and a moveable platform. In each experiment, as soon as the melt temperature decreased from 680 to 660 °C, the ultrasonic vibration device was lowered and 7 cm of the tip of its horn which had been pre-heated to 660 °C was immersed into the melt.

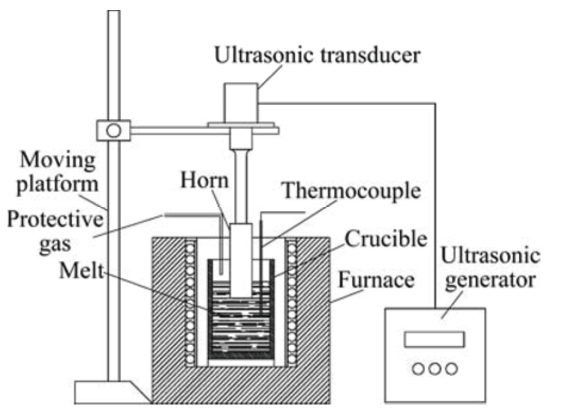

Fig. 1 Schematic of ultrasonic vibration device used in this study

Several experiments were conducted to study the effects of cooling conditions on the microstructure of semi-solid AZ91 slurry. Because the liquidus and solidus temperatures of the alloy used in this study are about 598 °C and 431 °C (determined by the cooling curve in Fig. 2), respectively, different temperature ranges of the melt were chosen to carry out the ultrasonic vibration. They were from 605 °C to 595 °C, from 605 °C to 590 °C and from 605 °C to 585 °C, respectively. After being vibrated with different cooling rates (1.56, 2.82 and 8.04 °C/min) in different temperature ranges, some slurries were extracted out by a steel tube with an inner diameter of 10 mm and quenched in water immediately.

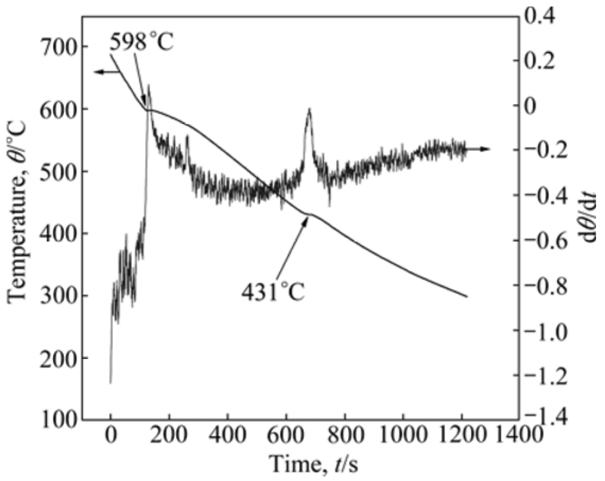

Fig. 2 Cooling curve of AZ91 alloy with its first derivative curve

Specimens for the metallographic examination were cut from the quenched rods, then polished and etched by 4% (volume fraction) nitric acid ethanol solution. The microstructures were examined using an optical microscope and micrographs of the samples were analyzed by a quantitative metallographic analysis software, including the solid volume fraction, the average size and shape factor of solid particles. At least five representative areas with the total surface of 80 mm^2 in each sample were studied through metallographic evaluations. The solid volume fraction was calculated by the ratio of all particles area in the total area of the photomicrograph. For the shape of solid particle is irregular, the average diameter measured in one particle was defined as the size of that particle. The shape factor (S_F) was defined as $S_F=4\pi A/P^2$, where A and P are the area and the perimeter of the primary particles, respectively. S_F varies from 0 to 1, and when the value of S_F is close to 1, the sectional shape of the particle approaches a circle. More than 100 particles in each sample were measured in order to obtain the average size and shape factor of solid particles.