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Preparation and theoretic study of semi-solid Al_2Y/AZ91 magnesium matrix composites slurry by ultrasonic vibration

HUANG Wenxian (黄文先)[1,2,3], YAN Hong (闫 洪)[1,2,*]

(1. Department of Materials Processing Engineering, School of Mechanical Electrical Engineering, Nanchang University, Nanchang 330031, China; 2. Key Laboratory of Light Alloy Preparation & Processing in Nanchang City, Nanchang 330031, China; 3. Department of Civil Engineering, School of Architectural Engineering, Jinggangshan University, Ji'an 343009, China)

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Abstract: Semi-solid Al_2Y/AZ91 magnesium matrix composites slurry was prepared by ultrasonic vibration, effect of ultrasonic vibration temperature and time on microstructure of semi-solid slurry was investigated. The results showed that with the ultrasonic vibration temperature decreasing the solid volume fraction of semi-solid slurry increased. The best ultrasonic vibration temperature was 600 ºC. With the increase of ultrasonic vibration time, the average grain diameter of primary a-Mg particles decreased firstly, then increased, the average shape factor increased gradually and decreased slightly after 90 s, and a few rosette dendrites were observed after 120 s. The best semi-solid slurry with average grain diameter of 75 μm and shape factor of 0.7 were gained after the melt was treated by ultrasonic vibration for about 60 s at near liquidus temperature (600 ºC). At last, the microstructure evolution mechanism of semi-solid magnesium matrix composites slurry was analyzed by the theories of thermodynamics and kinetics.

Keywords: ultrasonic vibration; magnesium matrix composites; semi-solid slurry; microstructure; rare earths

Semi-solid forming technology as a new process for metal forming in the 21th century, including thixoforming and rheocasting, has attracted increasingly more people's attention because of various advantages[1–4]. In contrast with thixoforming, rheocasting has many advantages such as simple process, energy preservation, little environmental contamination and low production cost, the preparation methods of slurry mainly include mechanical stirring, electromagnetic stirring, ultrasonic vibration and low superheatpouring process with a shear field process[5,6]. The ultrasonic vibration is a simple and effective process to produce semi-solid slurry, the surface of melt will not be broken during ultrasonic vibration process, which has the advantages of refining grains and improving uniformity of melt. At present, the method is mainly applied in preparation of semi-solid aluminum alloy slurry. Lü et al. prepared semi-solid aluminum alloy slurry by ultrasonic vibration, the fine non-dendritic primary α-Al grains with average grain diameter of 60 μm were obtained[7]. Dai et al. prepared semi-solid Zl201 aluminum alloy slurry by indirectultrasonic vibration method, and studied the effect of ultrasonic technological parameters on the average grain diameter and shape factor[8]. Some researchers studied the evolution mechanism of non- dendritic grains of aluminum alloy during the during solidification via ultrasonic vibration, their results indicated that the effect of ultrasonic streaming and cavitation was closely related to technological parameters, the variation of technological parameters caused changes of microstructure[9,10]. By now, there are not as many researches on ultrasonic treatment of magnesium alloys as on aluminium alloys[11,12], especially few on magnesium matrix composites. Due to the existence of reinforced phase in magnesium matrix composites, certain properties such as the viscosity of metal melt of magnesium matrix composites are different from the viscosity of matrix material, the small reinforced particles may increase the rate of nucleation of primary α-Mg particles, which will result in variety of the acting law of ultrasonic vibration on microstructure of magnesium matrix composites. Currently, there are few studies on the semi-solid slurry preparation of magnesium matrix composites via ultrasonic vibration. The evolution mechanism of semi-solid magnesium matrix composites slurry is poorly understood, which limits the application of ultrasonic vibration on semi-solid forming of magnesium matrix composites.

In this work, semi-solid slurry of Al_2Y/AZ91 magnesium matrix composites was prepared by ultrasonic vi-

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* **Corresponding author:** YAN Hong (**E-mail:** yanhong_wh@163.com; **Tel:** +86-791-83968873)

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bration, and the effects of different ultrasonic technological parameters on the microstructure of Al_2Y/AZ91 magnesium matrix composites were investigated, the evolution mechanism of semi-solid Al_2Y/AZ91 magnesium matrix composites slurry during ultrasonic vibration process was analyzed as well, which provided the bases of theory and experiment for thorough research and application of magnesium matrix composites.

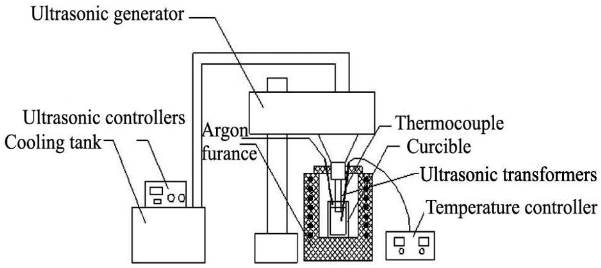

Fig. 1 Schematic of ultrasonic vibration device

1 Experimental

The schematic of ultrasonic vibration device used in this work is shown in Fig. 1. It mainly consists of ultrasonic generator and transducer with fixed frequency, ultrasonic controllers, ultrasonic transformers, furance and temperature controller. The experimental material consists of AZ91 alloy (Al 9.163, Zn 0.538, Mn 0.218, Si 0.042, Fe 0.0028, Cu 0.0053, Be 0.0007, Ni 0.0056 and Mg balance, wt.%) and Mg-30 wt.%Y master alloys. Mg-30 wt.%Y master alloys broken into particles were preheated to 300 ºC, the melted AZ91 alloys were heated to 850 ºC, then the Mg-30 wt.%Y master alloys wrapped aluminium foil were pressed into the melt of AZ91 alloys, the addition of yttrium was 2 wt.%, the ultrasonic transformers were immersed into the melt, then ultrasonic generation system was turned on, after 2 min, the melt was poured into metal mould, Al_2Y/AZ91 magnesium matrix composites were gained.

Al_2Y/AZ91 magnesium matrix composites were placed in a crucible, furance temperature were set at 750 ºC, during the process of melting the metal melt was protected by self-made covering powder and argon. When the temperature of melt reached 750 ºC, the metal melt was rested for 10 min. In order to study the effect of ultrasonic vibration temperature on the microstructure of Al_2Y/AZ91 magnesium matrix composites semi-solid slurry, when the melt temperature decreased from 750 to 608, 605, 600, 597 °C, respectively, the crucible filled with melt was removed into the furance of ultrasonic vibration device, the ultrasonic transformers preheated to 580 °C was immersed into the melt about 10 mm in depth, then the ultrasonic generation system was turned on. After being vibrated for 30, 60, 90 and 120 s, some slurry was extracted out by a quartz tube and quenched in water immediately. Specimens for the metallographic examination were cut from the quenched rods, then polished and etched by 4% (volume fraction) nitric acid ethanol solution.

Phase identification was performed by an X-ray diffractometer using Cu Kα radiation made by Bede Company. The microstructures were examined using a Nican M300 optical microscope and micrographs of the samples were analyzed by a metallographic analysis software. The distribution of intermetallic phases were examimed by a scanning electron microscope (SEM) (Model JSM-6703 JEOL Japan) equipped with an energy diffraction spectrum (EDS). Due to irregular shapes and different sizes of the grains, the average diameter was defined as the size of primary α-Mg grain, the roundness of grain was indicated by shape factor S, which was defined as $S=4\pi A/P^2$, where A and P are the area and the perimeter of the primary α-Mg grain, respectively.

2 Results

2.1 Phase components

In order to identify the phases in the Al_2Y/AZ91 magnesium matrix composites, X-ray diffraction was used to determine the phase components of the as-prepared specimens and AZ91 alloy. Fig. 2 shows XRD result of matrix of AZ91 (a) and Al_2Y/AZ91 magnesium matrix composite (b). As shown in Fig. 2, the phase components of AZ91 alloy include α-Mg and $Mg_{17}Al_{12}$ phase, the phase components of magnesium matrix composite consist of Al_2Y phase besides α-Mg and $Mg_{17}Al_{12}$ phases, which indicates that there is a strong interaction

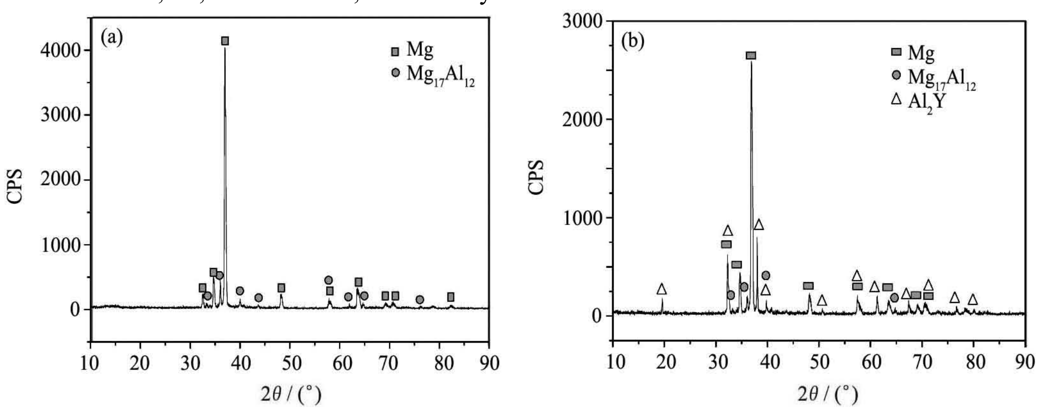

Fig. 2 XRD results of matrix of AZ91 (a) and Al_2Y/AZ91 magnesium matrix composite (b)