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Effect of ultrasonic on morphology of primary Mg_2Si in in-situ Mg_2Si/Al composite

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Abstract: Effects of ultrasonic on morphologies of primary Mg_2Si crystals in in-situ Mg_2Si/Al composite were investigated by metallographic microscopy and field emission scanning electron microscopy. The results show that the mean grain size of primary Mg_2Si crystals is refined from 150 to 20 μm by high intensity ultrasonic, and the morphologies of primary Mg_2Si crystals are changed as well. Optical microscopy reveals that primary Mg_2Si crystals without ultrasonic vibration exhibit coarse particles with cavities, in which eutectic structures grow. However, primary Mg_2Si crystals with ultrasonic vibration appear fine grains without any cavity. Three-dimensional morphologies of primary Mg_2Si without ultrasonic vibration display octahedron and tetrakaidecahedron with hopper-like hole in the crystals. After ultrasonic vibration, primary Mg_2Si particles become solid crystals with rounded corners and edges.

Key words: ultrasonic; Mg_2Si/Al composite; Mg_2Si; morphology; grain refinement

1 Introduction

Particulate reinforced aluminum metal matrix composites (MMCs) have significant implication potentiality in aircraft and automobile industries and attract worldwide increasing attention due to their improved properties, such as low density, excellent castability, good wear resistance and fine physical properties [1−3]. Magnesium silicide (Mg_2Si intermetallic compound), as a type of in-situ reinforcement phase, exhibits high melting temperature (1085 °C), low density (1.99×10^3 kg/m^3), high hardness (4.5×10^9 N/m^2), low thermal expansion coefficient (7.5×10^{-6} K^{-1}) and high elastic modulus (120 GPa) [1]. In-situ Mg_2Si particulates reinforced aluminum MMCs are excellent materials for producing auto pistons and brake discs due to their low density, high specific tensile strength and wear resistance [1,3,4]. However, Mg_2Si crystal often grows into coarse dendrite or grain during conventional solidification procedure [5], resulting in the decrease of mechanical properties of the composites.

For the purpose of refining primary Mg_2Si grains, many processing technologies have been developed, including modifier material addition, such as P [1], Sr [1], Y [5] and Sn [6], and rapid cooling casting [2]. In recent years, high-intensive ultrasonic shows large potential in refining solidification structure of light alloy. ZHANG et al [7] fabricated in situ (Mg_2Si+MgO)/Mg composite with assistance of the high-energy ultrasonic and found that the morphologies of in situ Mg_2Si particles were changed to smooth olive-shape or spherical shape. KO et al [8] used ultrasound to refine the primary Mg_2Si in Al−Mg−Si alloys and found that the morphology of primary Mg_2Si was also changed to polygonal from irregular shape. However, CHEN and LIN [9] revealed that high intensity ultrasonic vibration had no essentially influence on morphology of the primary Mg_2Si in Mg_2Si/Mg composite.

Despite extensive previous studies have been aiming at refinement of primary Mg_2Si, whether and how the morphologies of primary Mg_2Si would be changed by high energy ultrasonic is still wanting. This work attempts to reveal how high energy ultrasonic influences the morphologies of primary Mg_2Si by comparing the features of the section and the three-dimensional morphologies of primary Mg_2Si in Mg_2Si/Al composites with and without high energy ultrasonic vibration.

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2 Experimental

Commercial Al−20%Si (mass fraction) master alloy ingot and pure Mg ingot were used to prepare 20%Mg_2Si/Al composite. About 180 g of Al−Si alloy was melted in an alumina crucible in a 3 kW electric furnace. Then, about 19 g of pure Mg, wrapped by aluminum foil and preheated at 300 °C, was added into the melt protected by argon atmosphere. After holding at 780 °C for 10 min, the composite melt was poured into a steel crucible preheated at 600 °C and bolted with the horn. The schematic diagram of ultrasonic devices is shown in Fig. 1. The ultrasonic system with frequency of 20 kHz and whole power of 1 kW was started immediately to treat the melt until the solidification process was finished. Then the resulting composite with ultrasonic vibration was stripped away from the steel crucible. For comparison, the Mg_2Si/Al composite without ultrasonic vibration was fabricated.

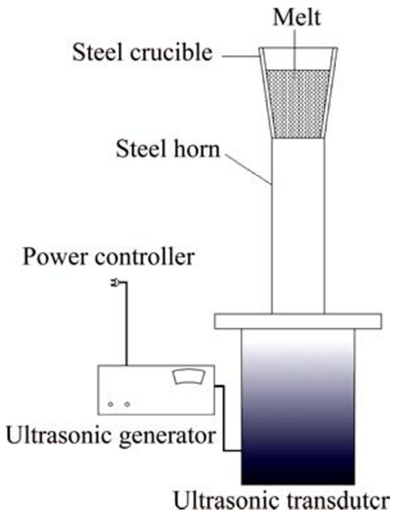

Fig. 1 Schematic diagram of ultrasonic devices

Specimens for optical microscopy analysis were cut from each resulting composite. The sections were polished through standard routines and etched by hydrofluoric acid (HF) water solution (0.5%) for 180 s. Characterization of the microstructure and the qualitative analysis were carried out on an OLYMPUSBX-60 metallographic microscopy with an image collection and analysis system. For observing the three-dimensional morphologies of primary Mg_2Si, one small piece of material was cut off from the center part of every resulting composite and cleaned with ultrasonic cleaner. NaOH water solution (25%) was used as etchant to extract primary Mg_2Si particulates. The extracted particulates were cleaned repeatedly and alternatively with an ultrasonic cleaner by water and alcohol to break up eutectic structures connected to primary Mg_2Si particles. The detailed 3D features of primary Mg_2Si were characterized by field emission scanning electron microscopy (FESEM, JSM-6700F).

3 Results and discussion

3.1 Grain refinement of primary Mg_2Si by ultrasonic

Figure 2 shows the optical microscopy microstructures of the composites and planar characters (polishing section of primary Mg_2Si grain) of primary Mg_2Si particles. Primary Mg_2Si crystals in the composite without ultrasonic vibration grow into coarse grains with the mean size of 150 μm, while primary Mg_2Si particles in composite with ultrasonic vibration grow into fine grains with the mean size of 20 μm.

For grain refinement during solidification procedure, increasing the solidification rate is an effective method. It is explicit that high intensive ultrasonic has great potential in grain refinement for primary phases precipitated during solidification procedure in light metals [10]. Ultrasonic cavitation can produce transient (in the order of nanoseconds) micro hot spots with temperatures of about 5000 °C, pressures above 101 MPa, and heating and cooling rates above 10^{10} K/s [11]. The velocity of acoustic streaming with a maximum speed of 1.37 m/s, produced by ultrasonic vibration [12], can break weak embryos into micro crystal fragments, which are turned into new nucleus for primary Mg_2Si grains. The nucleation rate can be increased by ultrasonic via this way.

It is well known that some impurities particulates in the melt can work as nucleus of heterogeneous nucleation during solidification. However, not all impurity particulates can act as the nucleus effectively. RAMIREZ et al [10] indicated that the high-intensive ultrasonic vibration could improve the nucleation potency of the nucleus. Therefore, those impurity particulates which have qualification as heterogeneous nucleation nucleus can work as nucleus of primary Mg_2Si effectively, and this results in the enhancement of nucleation rate. According to the Clapeyron equation, $\Delta T_m = T\Delta P\Delta V/\Delta H$, the elevation of pressure in the melt, induced by cavitation in a lot of small liquid volume, results in the increase of T_m, which is equivalent to increase of the undercooling and the nucleation rate.

3.2 Effect of ultrasonic on morphology of primary Mg_2Si

As shown in Fig. 2(a), primary Mg_2Si grains, in composite without ultrasonic vibration, have incomplete polygonal planar character with long straight edges and sharp corners. Inside the primary Mg_2Si crystal, cavities are formed during solidification procedure, as shown by the marked sign *A* in Fig. 2(a). It can be seen clearly that