



Effects of melt treatment temperature and isothermal holding parameter on water-quenched microstructures of A356 aluminum alloy semisolid slurry



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Abstract: The semisolid slurry of the A356 aluminum alloy was prepared by self-inoculation method (SIM), the effects of melt treatment temperatures and isothermal holding parameters on water-quenched microstructures of A356 aluminum alloy semisolid slurry were investigated, and the solidification behavior of the remaining liquid phase (secondary solidification) was analyzed. The results indicate that the melt treatment temperature has significant effects on the final semisolid microstructures. The semisolid slurry which is suitable for the rheological forming can be produced when the melt treatment temperature is between 680 and 690 °C. During the isothermal holding process, the growth rate of the primary particles conforms to the dynamic equation of $D_t^3 - D_0^3 = Kt$, and the coarsening rate of the primary particles is the fastest when the isothermal holding temperature is 600 °C. Additionally, the isothermal holding time also has obvious effect on the secondary solidification microstructures. The secondary particles are the smallest and roundest when the isothermal holding time is 3 min. The amount of the secondary particles gradually increases with the increase of isothermal holding temperature, and the eutectic reaction therefore is confined into small intergranular areas, contributing to the compactness of the final solidified eutectic structures.

Key words: aluminum alloy; semisolid; self-inoculation method; secondary solidification; primary particles; eutectic structure

1 Introduction

As the demands for high performance, high reliability and lightweight components are more and more urgent due to the increasing pressure of energy saving and emission reduction during the environmental protecting, the development of advanced forming theory, method and technology with proprietary intellectual property rights has been paid much attention to the automotive industry and the new technology fields [1]. Compared with high pressure casting, vacuum die casting and squeeze casting, semisolid rheological forming technology is a more promising technology capable of producing high-integrity components, and the utilization rate of material property is higher than that of the same kind of casting parts. The quality utilization rates of rheological forming materials are close to those of high pressure casting materials. Meanwhile, semisolid

rheological forming technology can not only form complex-shaped components, but also reduce the forming equipment tonnage and energy consumption [2–6]. Therefore, rheological forming is regarded as one of the most promising forming technologies of metal materials in the 21st century.

Slurry preparation process is a key step in the development of the rheological forming technology. In recent years, a variety of semisolid slurry preparation technologies have been proposed, such as the twin-screw slurry maker [7], GISS (gas induced semisolid) [8], SCP (serpentine pouring channel) [9], WSP (wavelike sloping plate) [10], SSR (semi-solid rheocasting) [11], CRP (continuous rheoconversion process) [12], NRC (new rheocasting process) [13], and SEED (swirled enthalpy equilibration device) [14].

The solidification process of semisolid metal forming can be divided into two stages: the stage of slurry preparation (solid particles crystallize from the

liquid alloy) is called primary solidification, and the solidification stage of slurry in the forming process (solidification of the remaining liquid) is called secondary solidification [15]. Although the primary solidification has been extensively investigated and comprehensively understood, not much attention has been paid to the solidification of the remaining liquid. Theoretically, the secondary solidification including the crystallization of the secondary primary phase and eutectic reaction, accompanied with the volume shrinkage and segregation problems, results in some defects such as shrinkage, hot cracking and nonuniform microstructure. FAN et al [16–18], REISI and NIROUMAND et al [19], ZANLER et al [20], GUAN et al [21,22] and CHEN et al [23] studied the solidification microstructures of the remaining liquid phase of different alloys using different methods, and indicated that the slurry preparation process, solid phase fraction and cooling rate have significant effects on the solidification behavior of the remaining liquid and its microstructures.

Hence, in order to promote the application of semisolid rheological forming technology, it is necessary to study the influence of processing parameters and solid fraction during the process of slurry preparation on the solidification behavior of the remaining liquid phase. In the present work, semisolid slurry of the A356 aluminum alloy was prepared by self-inoculation method (SIM) [24]. The effects of melt treatment temperature and isothermal holding parameters on microstructures of the A356 aluminum alloy (microstructures of primary solidification and secondary solidification) were studied to provide a theoretic basis for the optimization of processing parameters and its application.

2 Experimental

Figure 1 shows the schematic diagram of slurry preparation by SIM [15]. The fluid director was inclined at 45° with a length of 500 mm. The commercial A356 alloy (composition as shown in Table 1) was melted in a pit-type electric resistance furnace and degassed by C_2Cl_6 (1% of the alloy mass) when the melt temperature reached 720 °C, the melt temperature was adjusted to 700, 690, 680 and 670 °C, respectively, and then self-inoculants (5% of alloy mass, with the size of 5 mm×5 mm×5 mm) were added into the melt and stirred with iron bars quickly. After that, the mixed melt was collected through fluid director to the slurry collector to gain semisolid slurry, and directly poured into cold water to obtain water-quenched specimens without isothermal holding. Finally, the prepared slurry was isothermally held for a certain time (3, 5 and 10 min) at different holding temperatures (610, 600 and

590 °C), and then directly poured into cold water to obtain water-quenched specimens with different isothermal holding parameters.

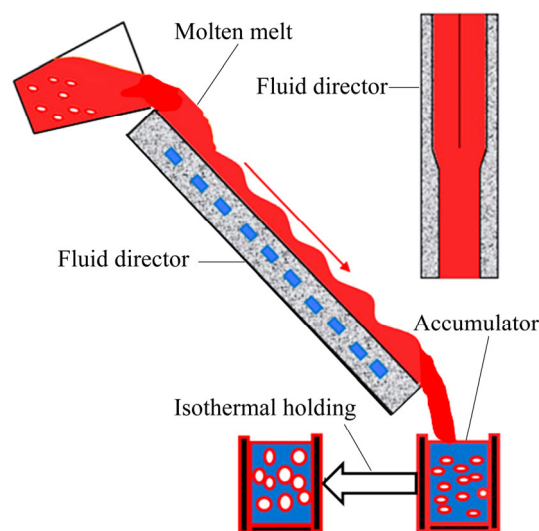


Fig. 1 Schematic diagram of slurry preparation by SIM [15]

Table 1 Chemical composition of commercial A356 alloy (mass fraction, %) [15]

Si	Mg	Fe	Ti	Cu	Zn	Al
7.06	0.27	0.115	0.097	0.001	0.01	Bal.

Specimens were prepared by the standard technique of grinding with SiC abrasive paper and polishing with an Al_2O_3 suspension solution, followed by etching in saturated NaOH aqueous solution. The microstructures of the specimens were observed by an MEF-3 optical microscopy (OM). The average particle size ($D=(4A/\pi)^{1/2}$, where A is the area of the particle) and shape factor ($F=P^2/(4\pi A)$, where P is the perimeter of particle) of the primary particles, were measured using image analysis software Image-Pro Plus 5.0. The FEG450 scanning electron microscopy (SEM) observation was carried out in an energy dispersive spectroscopy (EDS) facility and was operated at an accelerating voltage of 3–20 kV to observe the morphologies of the secondary particles and eutectic structures [15].

Figure 2 shows the schematic diagram of the temperature change in the SIM process. When the melt temperature reaches T_1 , the self-inoculants are added and the temperature is reduced to T_2 . And then the temperature is reduced to T_3 after the melt flows through the fluid director, and there is an isothermal holding process for a specific time at temperature of T_3 . Finally, the forming process is carried out. In this experiment, the average temperature reduction (T_2-T_1) after adding self-inoculants is about 50 °C, and the temperature drops about 30 °C (T_3-T_2) after the melt flows through the fluid director. Thus, the mean temperature change in the

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