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Influence of rheo-diecasting processing parameters on microstructure and mechanical properties of hypereutectic Al−30%Si alloy

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Abstract: The effects of pouring temperature, vibration frequency, and the number of curves in a serpentine channel, on the microstructure and mechanical properties of Al−30%Si alloy processed by rheo-diecasting (RDC) were investigated. The semisolid Al−30%Si alloy slurry was prepared by vibration serpentine channel pouring (VSCP) process in the RDC process. The results show that the pouring temperature, the vibration frequency, and the number of the curves strongly affect the microstructure and mechanical properties of Al−30%Si alloy. Under experimental conditions of a pouring temperature of 850 °C, a twelve-curve copper channel and a vibration frequency of 80 Hz, the primary Si grains are refined into fine compact grains with average grain size of about 24.6 μm in the RDC samples assisted with VSCP. Moreover, the ultimate tensile strength (UTS), elongation and hardness of the RDC sample are 296 MPa, 0.87% and HB 155, respectively. It is concluded that the VSCP process can effectively refine the primary Si grains. The refinement of primary Si grains is the major cause for the improvement of the mechanical properties of the RDC sample.

Key words: hypereutectic Al−Si alloy; primary Si; vibration serpentine channel; pouring process; rheo-diecasting; microstructure; mechanical properties

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1 Introduction

High silicon (w(Si)>22%) aluminium alloys are widely used for making heat-resistant parts such as pistons of high speed engines, engine blocks, aircraft components and military applications due to the superior performances of high specific strength, excellent wear resistance and corrosion resistance, as well as low coefficient of thermal expansion [1−4]. In general, the mechanical properties of hypereutectic Al−Si alloys largely depend on the morphology and size of the primary Si grains. However, the morphology of primary Si grains is mainly star-like, or plate-like, or penniform and the Si grain size is very large after traditional solidification. So, it is difficult to improve the morphology of primary Si grains and refine the Si grain size through the conventional casting process. If the size and morphology of primary Si grains can be refined, the properties of hypereutectic Al−Si alloys with high Si content will be greatly improved [5,6].

The present investigations mainly focus on the microstructure and phase morphology of hypereutectic Al−Si alloys. However, the mechanical properties of high silicon (w(Si)>22%) Al−Si alloys are rarely reported. Diecasting is an efficient and economical process offering a broader range of shapes and components than any other manufacturing technique. However, the traditional diecasting process will produce a great amount of entrapped gas during the two first filling stages of die casting process. The presence of gas porosity in castings is harmful because the mechanical properties and pressure tightness are adversely affected [7,8]. Rheo-diecasting (RDC) can produce high quality components with high integrity and improved the performance [9,10]. The RDC process has a lot of advantages such as extremely low porosity, fine and uniform microstructure and improved mechanical properties. More importantly, the resulting RDC products have close-to-zero porosity and therefore can be heat-treated [11]. In the rheo-forming process, molten alloy is stirred as the temperature is decreased in order to create semi-solid slurry with a controlled grain size, which is then injected into a die and formed with a press, as

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reported by JIN et al [12]. There have been many new developed techniques to prepare semisolid alloy slurry. Among these new techniques, serpentine channel pouring (SCP) process is an environmentally safe technology with simple process and low cost [13−15]. In this study, we propose a novel method to prepare semi-solid Al−30%Si alloy slurry through a vibrated serpentine channel pouring (VSCP) process and investigate the mechanical properties of the Al−30%Si alloy processed by rheo-diecasting (RDC).

In recent years, the rheological forming process of semi-solid slurry has attracted more and more attention for its merits, such as simple process and low cost. The A356 alloy formed directly by rheo-squeeze casting of semi-solid slurry made with rotating magnetic field method showed excellent mechanical properties, as reported by ZHANG et al [16]. Recently, LIN et al [17] have used ultrasonic vibration (USV) to make semi-solid slurry, and it has significant effects on refining the primary Si grains of hypereutectic Al−Si alloy and modifying the intermetallic compounds such as Fe-containing phase. CAO et al [18] reported that heat treatment and P modifier could be used to prepare hypereutectic Al−50%Si alloy, and it could make the size of primary Si grains reduce to 48 μm. ZHENG et al [19] prepared semi-solid A390 alloy slurry through serpentine channel pouring (SCP) process near the liquidus temperature, and the fine primary Si grains with average grain size of about 20 μm were obtained in the A390 alloy.

The object of this paper is to investigate the effects of different process parameters on the microstructure and mechanical properties of Al−30%Si alloy. Different process parameters (i.e., the pouring temperature, the number of curves in the serpentine channel, and the vibration frequency of the channel) were varied to obtain a favorable as-cast microstructure and better mechanical properties. In addition, the refinement mechanism of the primary Si grains in the Al−30%Si alloy samples processed by RDC assisted with the vibration serpentine channel pouring (VSCP) process was also studied.

2 Experimental

2.1 Materials and equipments

The schematic diagram of VSCP system is shown in Fig. 1. It consists of melting stage (A) and pouring stage (B). All experimental materials were melted in a 5 kW resistance furnace. The melt and isothermal holding temperatures were controlled by a PID temperature controller. The Al−30%Si alloy was melted in a clay-bonded graphite crucible. The vibration frequency and amplitude of the vibration table could be adjusted by the control cabinet. The collection crucible, with a diameter of 80 mm and a height of 150 mm, was made of red copper. The pouring temperatures and the temperature of the melt in the copper collection crucible were measured with a K-model handset thermocouple. The applied mechanical vibration power in this study was 3 kW, and the amplitude was 150 μm [20].

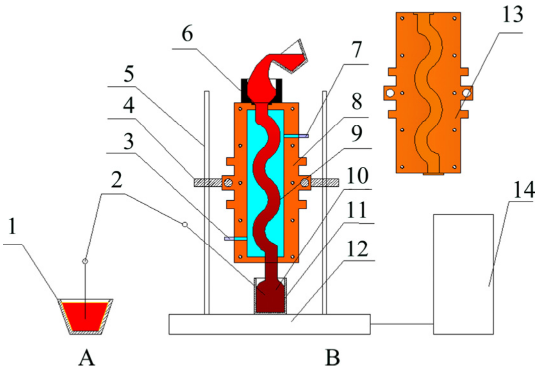

Fig. 1 Schematic diagram of VSCP system (A—Melting stage; B—Pouring stage; 1—Graphite clay melting crucible; 2—K-type thermocouple; 3—Water inlet; 4—Studdle; 5—Bracket; 6—Pouring cup; 7—Water outlet; 8—Water jacket; 9—Serpentine channel; 10—Slurry; 11—Copper collection crucible; 12—Vibration table; 13—Copper serpentine channel; 14—Control cabinet)

The newly produced cast alloy investigated had the composition shown in Table 1 and was prepared with commercial A390 aluminum alloy and Al−43%Si (mass fraction, the same in the following) master alloy, commercial pure Al (99.8%), pure Cu (99.99%) and pure Mg (99.9%). Differential scanning calorimetry (DSC) (NETZSCHSTA 409C/CD) was employed to determine the liquidus and solidus temperatures of the Al−30%Si alloy. The liquidus and the solidus temperatures of the alloy are 801 °C and 488 °C, respectively. The DSC curve of the alloy is shown in Fig. 2.

Table 1 Chemical composition of Al−30%Si alloy (mass fraction, %)

Si	Cu	Mg	Zn	Mn	Cr	Ni	Fe	Al
30	4.5	0.55	0.02	0.01	0.02	0.01	0.17	Bal.

2.2 Methods

The experimental parameters are listed in Table 2. Firstly, the materials were melted in a graphite crucible at 920−950 °C. And the melt was degassed for 15 min with argon gas introduced through a graphite lance. The melt was allowed to cool down to a chosen pouring temperature near liquidus after degassing. The collection crucible was preheated to 430−450 °C by the heating furnace. Subsequently, the alloy melt was poured through a vibration serpentine channel that was continuously cooled with cooling water flow of 500 L/h and was