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Forced convection rheoforming process for preparation of 7075 aluminum alloy semisolid slurry and its numerical simulation

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Abstract: A self-developed forced convection rheoforming (FCR) machine for the preparation of light alloy semisolid slurry was introduced. The microstructure characteristics of 7075 aluminium alloy semisolid slurry at different stirring speeds prepared by the FCR process were analyzed. The experimental results suggest that with the increase of the stirring speed, the mean grain size of the semisolid decreases and the shape factor as well as the number of primary grains increase. Meanwhile, the preparation process of semisolid slurry was numerically simulated. The flow characteristics of the melt in the device and the effect of the stirring speed on temperature field and solid fraction of the melt were investigated. The simulated results show that during the preparation process of semisolid slurry, there is a complex convection within the FCR device that obviously changes the temperature field distribution and solid fraction of the melt. When the convection intensity increases, the scope of the undercooling gradient of the melt is reduced and temperature distribution is improved.

Key words: 7075 aluminum alloy; forced convection rheoforming (FCR); semisolid slurry; preparation; numerical simulation

1 Introduction

7075 wrought aluminum alloy has many good properties such as high strength, high hardness and light mass. It is widely used in aerospace and automotive field [1,2]. Reducing cost is a primary reason to consider the use of casting. This is usually achieved by replacing assemblies of numerous detailed parts or by replacing the parts that require complex machining and fabrication operations. However, the conventional casting process has disadvantages in casting such as pore defects, which lead to lower strength and limit the development and application of high performance aluminium alloy [3−5]. However, an alternative semisolid metal (SSM) process was developed in 1971 [6]. The SSM process combines the advantages of plastic processing and solidification processing. It can make complicated-structure products within one-step forming while refining the crystal structure and reducing defects like hot tears or solidification shrinkage [7−11].

After years of research and practice, process issues still exist in thixoforming such as complex process, high energy consumption, inefficiency and high-cost. Hence, the focus of current studies of SSM process has turned back to the rheoforming research in recent years [12−16]. One of the main research directions of rheoforming process is developing the efficient and reliable equipments and techniques for the preparation of semisolid slurry. So far, many semisolid slurry preparation technologies and forming processes have been proposed such as two-screw rheoforming process (TSR) [17], low superheat pouring with a shear field process (LSPSF) [18], serpentine channel pouring process (SCP) [19], gas induced semisolid process (GISS) [20], continuous rheoconversion process (CRP) [21] and taper barrel rheoforming process (TBR) [22].

A self-developed forced convection rheoforming (FCR) machine was designed for the preparation of light alloy semisolid slurry by KANG et al [23]. It is high efficient, reliable and easy to maintain. It can work all day without clean-up. The stable semisolid slurry with homogeneous and fine microstructure could be obtained by the FCR process. Furthermore, it is convenient to

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combine FCR device with traditional metal forming processes to develop new rheoforming process.

Stirring speed is one of the major factors that affect microstructure in the FCR process. Taking 7075 aluminium alloy as experimental material, the microstructure characteristics and microstructure evolution of the SSM slurry at different stirring speeds were analyzed in this work. Based on heat transfer and hydrodynamics, the flow characteristics and the effect of stirring speed on the distribution of temperature field and solid fraction were investigated with the reliable commercial CFD software Flow-3D.

2 Experimental procedures and numerical simulation

2.1 FCR device

Figure 1 illustrates the structure of FCR machine. The machine consists of a shearing system, a temperature control system and an emptying system, with the advantages of high efficient, reliable and easy to maintain. The shearing system includes the spiral rod equipped with helical blade and mixing chamber with graphite sleeve. The temperature control system contains heating and cooling elements on the wall of the stainless barrel to ensure a constant temperature. The emptying process is achieved through emptying handle connected with graphite blockage. When the SSM slurry is prepared, the graphite blockage blocks the slurry outlet to avoid the leakage of the alloy melt under the action of the strong spring. After SSM slurry being prepared, the SSM slurry flows out by turning round emptying handle and raising the graphite blockage. 5 kg semisolid slurry can be prepared by the machine once according to its bulk. If a large amount of slurry is required once, it could be achieved through continuous pouring without blockage. The temperature control system can assure accurate stable barrel temperature through heating and cooling elements. The device can work continuously and steadily because the feed inlet, discharge port and mixing chamber are all equipped with graphite lining to minimize sticking material.

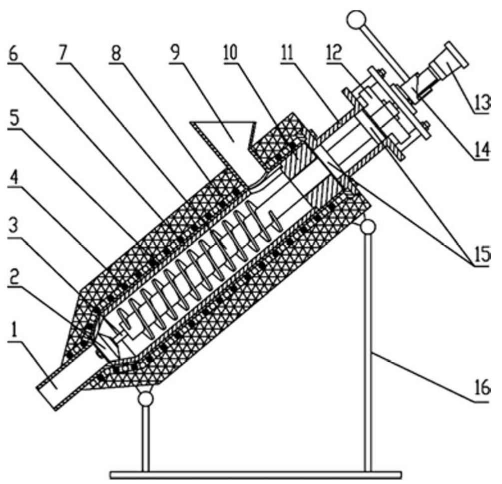

Fig. 1 Schematic diagram of integrated FCR machine: 1—Slurry outlet; 2—Graphite blockage; 3—Emptying core bar; 4—Heating and cooling elements; 5—Stainless barrel; 6—Graphite inner sleeve; 7—Spiral stirring rod; 8—Insulation; 9—Funnel; 10—Graphite insulation ring; 11—Bearing block; 12—Gear; 13—Adjusting handle; 14—Emptying handle; 15—Bearing; 16—Adjustable bracket

The operating principle of FCR machine is as follows: while stirring, the melt in the mixing chamber has complicated convection characteristics. In the meantime, under the cooling effect of the device, the generation environment for dendrites has been destroyed and the grains incline to grow up as nearly spherical. The main factors affecting the preparation of semisolid slurry are pouring temperature, barrel temperature, stirring speed and mixing time.

2.2 Experimental material and procedures

The experimental material is commercial 7075 high strength aluminium alloy with the chemical composition given in Table 1. The solidus and liquids were determined by differential scanning calorimetry (DSC). The samples of about 3 mm in diameter and 1 mm in height were cut, sandpapered, and then put into carbon pans with lids in argon atmosphere. The samples were heated to 700 °C at 5 °C/min and cooled to room temperature at the same rate. The studied alloy has a melting range of 477−640 °C.

Table 1 Chemical composition of 7075 aluminium alloy ingot (mass fraction, %)

Zn	Mg	Cu	Cr	Mn	Fe	Al
5.80	2.41	1.62	0.23	0.01	0.20	Bal.

For SSM processing, the FCR process is shown in Fig. 2. The aluminium alloy ingot was dried and then put into a melting furnace. After refinement and degassing treatment at 710 °C, liquid alloy was set aside for about 15 min and cooled to the pouring temperature (0−30 °C above the liquidus). About 2 kg of the alloy was poured into the FCR machine at 640 °C. The graphite inner sleeve was controlled at temperature of 620−580 °C, stirring speed of 100−500 r/min and stirring time of 10−90 s. The liquid alloy in the device was influenced both by stirring and cooling effect. The prepared slurries were poured into a special stainless barrel and cooled in water.

The samples were ground, polished and etched by Keller reagent. The effects of process parameters on the primary α(Al) particle size and the shape factor were investigated. The shape factor (F) was calculated by