Journal of University of Science and Technology Beijing
Volume 15, Number 1, February 2008, Page 48

Materials

# Filling ability of semi-solid A356 aluminum alloy slurry in rheo-diecasting

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(Received 2007-02-28)

**Abstracts:** The effects of slurry temperature, injection pressure, and piston velocity on the rheo-filling ability of semisolid A356 alloys were studied by the reho-diecasting methods. The results show that the slurry temperature of the semi-solid A356 aluminum alloy has an important effect on the filling ability; the higher the slurry temperature, the better is the filling ability, and the appropriate slurry temperature for rheo-filling is in the range of 585-595°C. The injection pressure also has a great effect on the filling ability, and it is appropriate to the rheo-filling when the injection pressure is in the range of 15-25 MPa. The piston velocity also has a great effect on the filling ability, and it is appropriate to the rheo-filling when the piston velocity is in the range of 0.072-0.12 m/s. The filling ability of the slurry prepared by low superheat pouring with weak electromagnetic stirring is very good and the microstructural distribution in the rheo-formed die castings is homogeneous, which is advantageous to the high quality die casting.


**Key words:** A356 aluminum alloy; rheo-diecasting; filling ability; semi-solid

[*The work was financially supported by the National Nature Science Foundation of China (No.50774007), the National High Technology Research and Development Program of China (No.2006AA03Z115), and the National Key Basic Research Program of China (No.2006CB605203).*]

## 1. Introduction

Ever since semi-solid metal forming was developed by Flemings at MIT in the 1970s, it has attracted considerable attention in overseas and domestic. Several experts have participated in the basic and applied research of these techniques. After developing for over thirty years, these have successfully been applied to manufacturing various kinds of car and aircraft parts [1-3]. However, at present, only the thixo-forming techniques have been used for commercial production and the commercial production scale is small yet. This is mainly because the preparing cost of semi-solid slurry and the energy consumption of billet reheating are higher, and the recycling of bleeding drops, biscuits, gating system, and rejected castings are difficult. When compared with thixo-forming technologies, reho-forming techniques of semi-solid metals have several advantages, such as considerably shorter process, easy recycling of the gating system and waste castings, low production cost, *etc*. Thus, reho-forming techniques are now becoming one of the most important study subjects [4-9]. Low superheat pouring with weak electromagnetic stirring for a short time (LSPWES) is a new method for the preparation of semi-solid alloys slurries [10-11], which requires low energy consumption as compared with the preparation of semi-solid alloys billets using only electromagnetic stirring at a high power [12-13]; and the process control is considerably convenient [14] and the slurry microstructure is better than that prepared by the liquidus casting technology. Therefore, LSPWES can be applied as the key technology of a new semi-solid rehoforming process [15]. In this study, the filling ability of semi-solid A356 alloy slurry prepared by the LSPWES method was investigated and the experimental results can be useful for the development of an advanced reho-forming technology.

## 2. Experimental

The raw materials used in the experiments were

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commercial A356 aluminum alloy. Its composition was Si, 7.49wt%; Mg, 0.46wt%; Fe, 0.16wt%; and balance Al. The liquids temperature and the solids temperature are about 615 and 555°C, respectively.

In the experiments, the slurry of A356 alloy was first prepared by low superheat pouring with weak electromagnetic stirring, and then the slurry was soaked in an induction heater. After the soaking process, the slurry was finally delivered quickly into the injection chamber of the die casting machine and formed.

To investigate the rheo-diecasting filling ability of the above-prepared slurry, the die with a 1300 mm×10 mm×3 mm spiral cavity was used. The schematic diagram and cross section of the die is shown in Fig. 1. The rheo-formed spiral sample length may be used as the standard to evaluate the effects of slurry temperature, injection pressure, and piston velocity on the filling ability. The slurry temperatures used in these experiments were in the range of 585-595°C, the injection pressures were in the range of 5-25 MPa, and the piston velocities were between 0.024 and 0.072 m/s. The preheated die and the injection chamber temperature were 120 and 300°C, respectively.

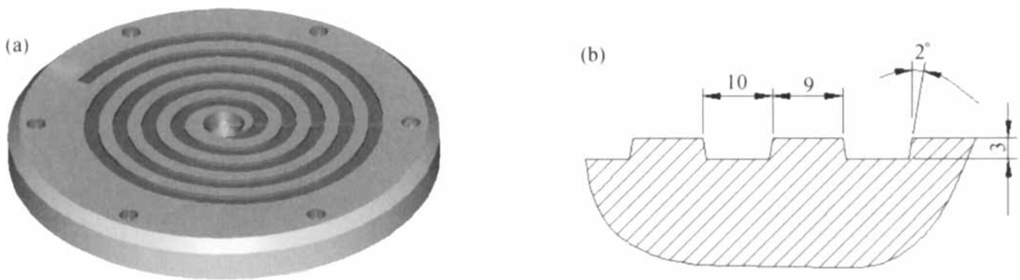


**Fig. 1. Schematic diagram of the die (a) and its cross section (b) (unit: mm).**

The metallographic specimens were cut from the different sites of the spiral samples and roughly ground, finely polished, and etched by an aqueous solution of 0.5vol% HF. The microstructure was observed and analyzed with an optical microscope for analyzing the microstructural distribution.

## 3. Result and discussion

### 3.1. Effect of slurry temperature on the filling ability

The slurry temperature here is the temperature at which the slurry was delivered into the injection chamber. The experiments indicate that the slurry temperature has a great effect on the filling ability of the semi-solid A356 aluminum alloy slurry. The filling lengths of rheo-formed spiral samples at different temperatures are shown in Fig. 2, in which the piston velocity is 0.072 m/s.

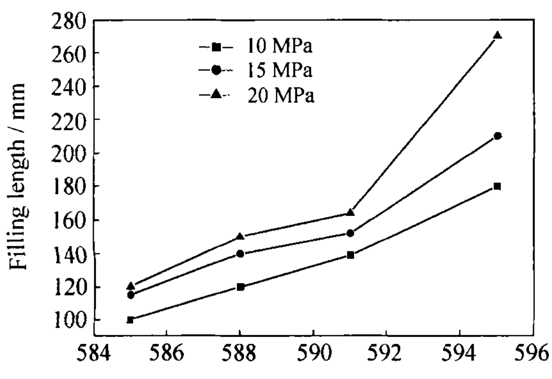


**Fig. 2. Effect of slurry temperature on the filling length of the semi-solid A356 alloy slurry.**

It can be seen from Fig. 2 that the variation trend of filling length with increasing slurry temperature is similar whether the injection pressure is 10, 15, or 20 MPa, and it is obvious that the filling length increases with increasing slurry temperature. Namely, the filling ability of the semi-solid A356 aluminum alloy slurry becomes gradually better with the increasing slurry temperature. This is because the solid fraction and apparent viscosity decrease with the increasing slurry temperature, and therefore, the filling resistance is lower when the slurry flows in the cavity and the filling length increases. On the other hand, the freezing time of the slurry resulting from the higher temperature will be longer, and the filling time may be longer. Thus, the higher the slurry temperature, the longer is the freezing time, and the better is the filling ability. However, if the slurry temperature is considerably higher, the turbulent flow and the gas entrainment may be caused. Therefore, the appropriate slurry temperatures that ensure a completely compacted filling must be adopted.

It can also be seen from Fig. 2 that the filling ability of the slurry prepared by low superheat pouring with weak electromagnetic stirring is very good. Even when the slurry temperature and the reheated die temperature are 585 and 120°C, respectively, the filling length still reaches up to 100 mm, which indicates a good filling ability for the castings with 3 mm thickness and 10 mm width. If the slurry temperature continuously increases to 595°C, the filling length reaches up to more than 180 mm and is in a range of 180-270 mm, namely, the filling length will increase to 270 mm when the forming temperature and the injection pressure are 595°C and 20 MPa, respectively. Thus, the complete filling for any complex die cavity can be ensured by appropriately adjusting the slurry temperature and the injection pressure.

### 3.2. Effect of injection pressure on the filling ability

The injection pressure is the static pressure exerted on the semi-solid A356 aluminum alloy slurry in the injection chamber. It is also an important parameter in the rheo-diecasting process, and the effect of injection pressure on the filling length of the spiral die castings under various injection pressure conditions is shown in Fig. 3, in which the slurry temperature is 585°C.

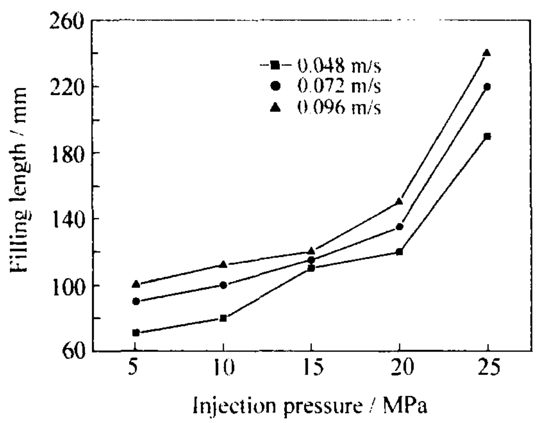


**Fig. 3. Effect of injection pressure on the filling length.**

From Fig. 3, it can be seen that the filling length is shorter when the injection pressure is low; however, the filling length will increase when the injection pressure increases. For example, when the injection pressure is 5 MPa and the piston velocity is 0.048m/s, the filling length is only 71 mm, which indicates a poor filling ability. However, when the injection pressure increases to 15 MPa, the filling length will reach up to 110 mm, which indicates a good filling ability. Moreover, if the injection pressure increases to above 15 MPa, the filling length will increase considerably and will reach up to 120-190 mm. The varying trend of the filling length with the increasing injection pressure may be explained as follows: when the injection pressure is low, the filling power is not enough to overcome the flow resistance of the slurry, therefore, the filling length is short; if the injection pressure increases, the slurry will get larger power to overcome the flow resistance of the slurry. However, if the injection pressure is very high and reaches a critical value, the air in the cavity cannot escape immediately, and the filling length will decrease because of the higher adverse pressure, and the gas entrapment may also be caused [1, 3]; thus, a higher pressure must be adopted if gas entrapment must be prevented.

It can also be seen from Fig. 3 that while the injection pressure increases, the filling length will increase considerably if the piston velocity increases at the same time. For example, when the piston velocity is 0.096 m/s, if the injection pressure increases to 25 MPa, the filling length will reach up to 240 mm, that is to say, the filling ability is considerably better. The main reason may be that the higher filling velocity decreases the heat emission of the slurry and is favorable for the slurry to flow for a longer time before it freezes, and therefore, the filling ability will become considerably better.

The results in Fig. 3 indicate that if the exhaustion of the die is good and gas entrainment cannot appear, a higher injection pressure is favorable to the filling ability, and the filling ability of the slurry prepared by low superheat pouring with weak electromagnetic stirring is also very good.

### 3.3. Effect of piston velocity on the filling ability

The piston velocity is the velocity at which the piston moves forward when the slurry is filled. It is also an important parameter in the rheo-diecasting process. Fig. 4 shows the effect of piston velocity on the filling length, in which the slurry temperature is 585°C.

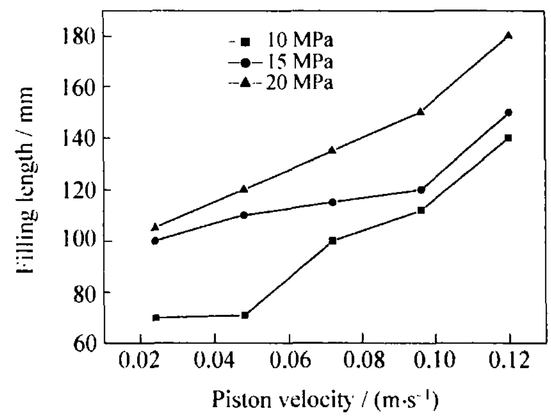


**Fig. 4. Effect of piston velocity on the filling length.**

From Fig. 4, it can be seen that the filling length increases with increasing piston velocity. When the injection pressure is 10 MPa and the piston velocity is 0.024 m/s, the filling length is only 70 mm, which indicates a poor filling ability under this condition. If the piston velocity increases to 0.072 m/s and the injection pressure is also 10 MPa, the filling length increases and reaches up to 100 mm. However, if the piston velocity increases to 0.12 m/s, the filling length will increase and will reach up to140 mm, which indicates a better filling ability at this time. With increasing piston velocity, the slurry filling speed will increase and the filling time in the same die cavity will be shortened; the heat emission also decreases so that the slurry will flow at a higher temperature. As a result, the apparent viscosity of the slurry will be lower and the flow ability will also be good; thus, the filling length gradually becomes longer in the end. It can also be seen from Fig. 4 that if the injection pressure increases, the filling length will considerably increase while the piston velocity will increase simultaneously. For example, when the injection pressure is 20 MPa and the piston velocity is 0.024 m/s, the filling length is only 105 mm, but if the piston velocity increases to 0.12 m/s, the filling length will increase to 180 mm, which indicates that this condition has a good filling ability. Thus, it is favorable for good filling ability when the injection pressure is above 15 MPa and the piston velocity is above 0.096 m/s.

The varying trend of the filling length with increasing piston velocity also shows that the filling ability of the slurry prepared by low superheat pouring and weak electromagnetic stirring is very good.

### 3.4. Microstructural distribution

To get the isotropic and good mechanical properties, it is required in the semi-solid metal forming process that the microstructural distribution is very homogeneous, namely, the spherical primary α-Al grains should be distributed homogeneously in the die casting. Fig. 5 shows the sites at which the metallographic specimens were cut.

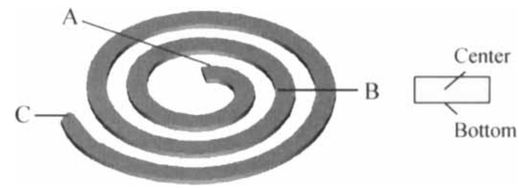


**Fig. 5. Schematic diagram of the sites at which the metallographic specimens were cut.**

Fig. 6 shows the center microstructures and the periphery microstructures at the A, B, and C sites. It can be seen from Fig. 6 that the spherical primary α-Al grains at the center are very homogeneous whether at A, B, or C sites. However, the spherical primary α-Al grains at the periphery are smaller than that in the center to a very limited extent and the obvious microstructural segregation cannot be found, which indicates that the semi-solid slurry filling is stable. It also indicates that the slurry prepared by low superheat pouring with weak electromagnetic stirring is appropriate to the rheo-forming process, which will lay a solid base for die casting with high quality and good mechanical properties.

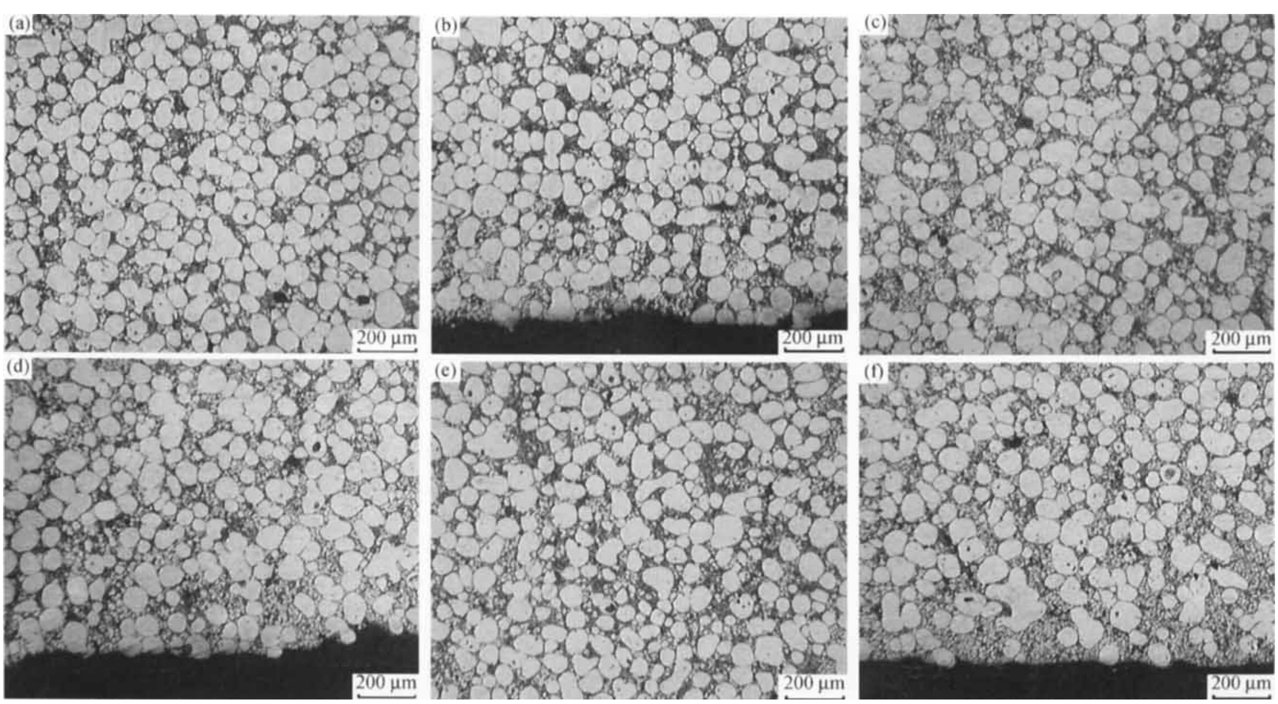


**Fig. 6. Microstructures of the metallographic specimens cut from the semi-solid filled pieces: (a) at the center of site A; (b) in the periphery of site A; (c) at the center of site B; (d) in the periphery of site B; (e) at the center of site C; (f) in he periphery of site C.**

## 4. Conclusions

(1) The slurry temperature of the semi-solid A356 aluminum alloy has an important effect on the filling ability; the higher the slurry temperature, the better is

the filling ability, and the appropriate slurry temperature for rheo-filling is in the range of 585-595°C.

(2) The injection pressure has a great effect on the filling ability, and it is appropriate to the rheo-filling when the injection pressure is in the range of 15-25 MPa.

(3) The piston velocity has a great effect on the filling ability, and it is appropriate to the rheo-filling when the piston velocity is in the range of 0.072-0.12 m/s.

(4) The filling ability of the slurry prepared by low superheat pouring with weak electromagnetic stirring is very good, and the microstructural distribution in the rheo-formed die castings is homogeneous, which is advantageous to the high quality die casting.

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