Method of Fast Forecasting Mold Filling Capacity of Al-Si Alloy by Surface Tension

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Based on the theoretical analysis, a new method for fast forecasting the mold filling capacity of Al-Si alloy by its surface tension has been proposed. Through many experiments and statistical analysis, a specific relation between the mold filling capacity of Al-Si alloy and surface tension has been got. Depending on this relation, the mold filling capacity of Al-Si alloy can be fast forecasted by surface tension before being poured. [doi:10.2320/matertrans.MRP2007215]

(Received September 3, 2007; Accepted November 16, 2007; Published December 12, 2007)

Keywords: mold filling capacity, surface tension, fast forecast, aluminum-silicon alloy

1. Introduction

Castability is not a specific alloy property and is usually considered to be a measure of the mold filling capacity of Al-Si alloy. 1, 2 Poor mold filling capacity will cause many casting defects, such as misrun, cold shut and shrinkage. 3–7 To avoid casting defects and get sound castings, a necessity of having an effective method for fast forecasting the mold filling capacity is rapidly growing. In recent decades, most of the researches on the methods have followed along measurements, and thus effectively guide the industrial production. Therefore, there is a need to develop a new method.

In the present study, a new method has been proposed to fast forecast the mold filling capacity of Al-Si alloy. By experiments on Al-Si alloys, a specific relation between surface tension and the mold filling capacity has also been got.

2. Analysis of Relationship Between Surface Tension and Mold Filling Capacity

Early in 1974, the mechanism of fluid flow during mold filling had been explained by M. C. Flemings, 1, 2 who showed that the flow of the molten metal will cease when local solidification prevents further molten metal from passing to supply the advancing metal front. According to this mechanism, the relation between the fluidity length $X$ of Al-Si alloy and many influence factors can be expressed as: 15

$$X = \frac{\frac{\bar{P}}{V}W + \sqrt{\left(\frac{\bar{P}W}{V}\right)^2 + 4k\beta P(T_L - T_0)R}}{2k\beta(T_L - T_0)} + \frac{1}{\beta} \ln \frac{T_J - T_0}{T_L - T_0}$$

(1)

Where $W$ is the solidification velocity of the molten Al-Si alloy, $V$ is the average flow velocity, which is decided by surface roughness of the mold, $T_J$ is the pouring temperature, $T_L$ is the liquidus temperature, $T_0$ is the mold temperature, $R$ is the effective radius of the cavity, $k$ is the coefficient and constant of the yield stress, and $\bar{P}$ is the effective pressure in the cavity.

When the fluidity length of the Al-Si alloy is measured by using a fixed spiral specimen, these factors, such as $W$, $V$, $\beta$, $T_L$, $T_0$, and $R$, will obviously retain the same. The fluidity length $X$ is therefore affected by the effective pressure $\bar{P}$ and pouring temperature $T_J$, and the effective pressure $\bar{P}$ in the cavity can be expressed as:

$$\bar{P} = P_0 - \frac{2\sigma \cos \theta}{R} - P_a$$

(2)

Where $P_0$ is the static head pressure, $\sigma$ is surface tension of the molten Al-Si alloy, and $P_a$ is the counter-pressure caused by gas in the cavity. From eq. (1) and eq. (2) it can be concluded that there is a relationship between the fluidity length $X$ and surface tension $\sigma$ of the molten Al-Si alloy, and the fluidity length of Al-Si alloy may be fast forecasted by surface tension.

Moreover, the molding materials are not wetted by the molten Al-Si alloy and the advancing front is convex. 16, 17 Accordingly, the additional pressure caused by surface tension of the molten Al-Si alloy will point to the liquid interior, and thus it will hinder the molten Al-Si alloy from filling the cavity, especially the taper angle or the thin sections. 18 The bigger is the surface tension, the smaller is the ability of filling the taper angle. So, the ability of filling the taper angle can be fast forecasted by surface tension as well.

3. Device of Measuring Mold Filling Capacity

In the present study, standard spiral specimen is used to measure the fluidity length of the molten Al-Si alloy, and a special die, shown schematically in Fig. 1, is designed to measure the ability of filling the taper angle. It consists of the sprue and four edge-shaped specimens with 10° taper angle. After the molten Al-Si alloy is poured, four edge-shaped specimens are filled from the bottom of the mold and the gas in every edge-shaped specimen is extruded by the molten Al-Si alloy, so the counter-pressure caused by the gas can be
neglected. At the same time, because the molten Al-Si alloy in the sprue plays role in preheating the taper angle of four edge-shaped specimens, there is enough time to fill the taper angle.

The ability of filling the taper angle can be defined as follows:

$$ F = \frac{1}{r} = -\frac{\rho gh}{2\sigma \cos \theta} $$

Where $F$ is the ability of filling the taper angle, $r$ is the radius of actual taper angle filled by the molten Al-Si alloy, $h$ is the height of the static head, $\rho$ is the density of the molten Al-Si alloy, and $\theta$ is the contact angle.

Originally, a die is adopted to measure the $F$, which is shown in Fig. 2. When the gap between two cylindrical cores is filled by the molten alloy, it’s obvious that the contact angle retains the same (180 degree). In order to simplify the die and facilitate the molding, an edge-shaped specimen with the taper angle derived from this die is used to replace the gap between these two cylindrical cores. For the good $F$, the molten Al-Si alloy can adequately fill the taper angle of the edge-shaped specimen. Therefore, the contact angle can be regarded as a constant. To avoid the influence of the static head pressure, the edge-shaped specimen is cut off at 10 mm distance from the static head, and its vertical projection is shown in Fig. 3. As long as the distance $l_1$ and $l_2$ can be measured precisely, the ability of filling the taper angle of the Al-Si alloy can be calculated according to the eq. (4).

$$ F = \frac{2(l_1 - l_2)}{(10.536 - 0.1317l_2)^2 + (l_1 - l_2)^2} $$

Where $l_1$ is the distance from the arc tip to the bottom of the specimen, and $l_2$ is the distance from the arc transition to the bottom of the specimen.

4. Experimental

Materials for experiments are Al-Si alloys and the composition accords with A413 of ASTM B85-82. They are melted in a resistance heating furnace and the melting process is as follows. Over the 973–993 K temperature range the molten alloys are degassed by the hexachloroethane with 0.3% (mass fraction), and over the 1013–1033 K temperature range they are modified by the sodium modifier (e.g. NaF+NaCl+KCl or NaF+NaCl etc.) from 0.0% to 3.0% with 0.05% step interval. After being modified, at the 993–1003 K temperature range the surface tension of the molten Al-Si alloys is measured by self-developed apparatus. At the same time, the molten Al-Si alloys are poured into the molds to test the fluidity length and the ability of filling the taper angle. Because the initial mold temperature is kept at 298 K, its influence on the mold filling capacity retains the same.

Many experiments on Al-Si alloys have been made to discover the relation between surface tension and the mold filling capacity. According to the experimental results and statistical analysis, a specific relation between the fluidity length, the ability of filling taper angle and surface tension of the molten Al-Si alloy has been got, which is shown in Fig. 4.

When surface tension is below 340 mN/m and above 680 mN/m, it has an unremarkable influence on the fluidity length. But when it is between them, the fluidity length will decrease remarkably with the increase of surface tension. The change rule can be explained as follows. When the molten Al-Si alloy is excessively modified, surface tension is very low and thus the additional pressure is very small. So, the fluidity length is mainly affected by the surface roughness of the cavity, the static head pressure and the gas counter-pressure. But with the increase of the surface tension, it will become a leading factor. As a consequence, the fluidity length will decrease rapidly with the increase of the surface tension. On the contrary, when the molten Al-Si alloy is unmodified, although the surface tension is higher than that
of modification, the fluidity length is principally affected by the shape of grains during solidification. The cavity is prone to be blocked by the coarse dendritic grains. Therefore, the fluidity length will change little with the increase of the surface tension.

The ability of filling the taper angle will decrease linearly with the increase of the surface tension. The bigger is the surface tension, the smaller is the ability of filling the taper angle, which can be seen from Fig. 4. Because the gas in cavity has been extruded entirely by the molten Al-Si alloy, the ability of filling the taper angle is scarcely affected by the gas counter-pressure. In addition, the smaller the taper angle is, the more surface tension plays role in deciding the ability of filling the taper angle. Consequently, during filling the taper angle, surface tension is always one of most decisive factors. When the surface tension is 280 mN/m, the ability of filling the taper angle is as high as 77.3 mm approximately. When the surface tension is about 780 mN/m, the ability of filling the taper angle will fall into 16.7 mm approximately.

Provided that surface tension of the molten Al-Si alloy can be fast forecasted before being poured. According to it, the mold filling capacity has been got. According to it, the mold filling capacity of Al-Si alloy can be fast forecasted by surface tension of the molten Al-Si alloy.

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Provided that surface tension of the molten Al-Si alloy is fast measured, the mold filling capacity will be got instantly. The comparison of the mold filling capacity of Al-Si alloy acquired by two methods is shown in Table 1. It shows that the deviations of the fluidity length and the ability of filling the taper angle are very small. Therefore, the filling mold capacity, including the fluidity length and the ability of filling the taper angle, can be fast forecasted by surface tension of the molten Al-Si alloy before being poured.

### 5. Conclusions

1. Through analyzing the relationship between surface tension and the mold filling capacity, a new method for fast forecasting the mold filling capacity of Al-Si alloy by surface tension has been proposed.

2. A special die has been designed to measure the ability of filling the taper angle of the molten Al-Si alloy. By many experiments on Al-Si alloys, a specific relation between the mold filling capacity and surface tension has been got. According to it, the mold filling capacity of Al-Si alloy can be fast forecasted before being poured.

### Acknowledgements

This work was supported by National Natural Science Foundation of China (Grant No. 50174023) and Heilongjiang Province Key Task Project of Science and Technology (Grant No. G00A12011).

### REFERENCES


### Table 1 Partial comparison of the mold filling capacity of Al-Si alloy between the forecasted and the measured.

<table>
<thead>
<tr>
<th>(\sigma) (mN/m)</th>
<th>(X_{\text{mm}})</th>
<th>Deviation (%)</th>
<th>(F_{\text{mm}^{-1}})</th>
<th>Deviation (%)</th>
</tr>
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<tr>
<td>356</td>
<td>694</td>
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<td>397</td>
<td>598</td>
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<td>45.6</td>
<td>–1.3</td>
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<tr>
<td>455</td>
<td>531</td>
<td>1.1</td>
<td>41.6</td>
<td>–3.4</td>
</tr>
<tr>
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<td>479</td>
<td>2.1</td>
<td>31.5</td>
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</tr>
<tr>
<td>610</td>
<td>436</td>
<td>–4.8</td>
<td>27.8</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Fig. 4 Relation between the fluidity length, the ability of filling the taper angle and surface tension of the molten Al-Si alloy.