Effect of the degassing on surface tension of eutectic Al-Si alloys

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Abstract

According to orthogonal regression method, an experiment is designed to study the influence of the degassing agent, the degassing time and the degassing temperature on surface tension of eutectic Al-Si alloy. A model how surface tension of eutectic Al-Si alloy is affected by the degassing treatment has been obtained by experiments. The surface tension is mainly affected by the quantity of the degassing agent, the degassing time is less important, and the degassing temperature was found to have little influence on the surface tension. Moreover, the influences of the interactive and quadratic terms can be neglected. The further comparative experiments have shown there are very small deviations between the calculated values and the measured values. So the surface tension of eutectic Al-Si alloys can be calculated by the sum of different contributions from the quantity of the degassing agent, the degassing time and the degassing temperature.

Key words: surface tension, degassing, orthogonal regression design, Al-Si alloy

1. Introduction

Surface tension is one of the important physicochemical properties of Al-Si alloys [1, 2]. It is the foundation of studying the interface dynamics of the liquids [3]. In solidification phenomena, surface tension plays very important role in optimizing and simulating the crystal growth parameters [4], generating the electro meniscus phenomenon [5], predicting the graphite shape [6], the modification degree [7], the porosity formation [8], the surface roughness [9] and the mould filling capacity [10]. The degassing treatment is an effective means to enhance the mechanical properties, particularly ductility, of Al-Si alloys [11–13]. So, degassing level monitoring is strongly recommended and there is a need to develop new methods [14]. In recent years, although some researches have shown that there are some relationships between surface tension and the degassing, the modification and the inclusion of Al-Si alloys [15–17], the specific relation has not been established yet. Therefore, to obtain a specific relation and thus to effectively monitor the degree of degassing, it is very necessary to study the influence of the degassing treatment on surface tension of Al-Si alloys. This will provide experimental basis for studying the interface dynamics of the molten Al-Si alloys, and also for developing a new method of forecasting the degree of degassing.

In the present work, the influence of the degassing agent, the degassing time and the degassing temperature on the surface tension of the molten eutectic Al-Si alloys has been studied according to orthogonal regression experiments and the rule has been obtained.

2. Experimental

Materials for experiments are eutectic Al-Si alloys and the composition accords with A413, namely, Si: 11.0–13.0 %, Fe: 1.3 %, Cu: 1.0 %, Mg: 0.1 %, Zn: 0.5 %, Mn: 0.35 %, Ni: 0.5 %.

The melting process is as follows. Over the 250–300 ℃-temperature range, the graphite crucible is thoroughly dehydrated. Then, the eutectic Al-Si alloys are melted in a resistance-heating furnace using this graphite crucible. Over the 700–750 ℃-temperature range, the molten Al-Si alloys are degassed by the hexachloroethane tablets (ø 20×5) to remove hydrogen and the oxide inclusions. The quantity of the hexachloroethane tablets is decided by the experimental

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Table 1. Code of the factors

Factors	w (%)	t (min)	T (℃)
Codes	x_1	x_2	x_3
+1.215	0.60	18	750
−1.215	0.00	6	700
0	0.30	12	725
+1	0.55	17	746
−1	0.05	7	704

scheme. After the dross (most is the oxide inclusions) formed is skimmed out from the melt surface, the molten Al-Si alloys are not modified and the surface tension is directly measured by the RTW-04 Melt Physical Property Analyzer. (It is used to automatically measure the surface tension, the viscosity and the density of the melts over the 0–1600℃-temperature range. The surface tension is measured according to the ring detachment method, the measurement range is at 200–2000 mN m^{-1} and the precision is ±1.5 %.) For the same batch of the molten Al-Si alloy, surface tension is measured five times and their average is regarded as an effective value.

Besides the quantity of the degassing agent, the factors that affect surface tension of the molten Al--Si alloys are the degassing time and the degassing temperature [18, 19]. To establish a specific relation between the quantity of hexachloroethane, the degassing time, the degassing temperature and surface tension, an experiment has been designed according to orthogonal regression design method [20–22]. It is made up of an orthogonal table L_8 (2^7), six experimental points on the orthogonal axes and one central experimental point. The factors which affect the surface tension of the molten Al-Si alloys are defined as follows: the hexachloroethane degassing agent ranges from 0.0–0.6 %, the degassing time ranges from 6–18 minutes, and the degassing temperature ranges from 700–750℃. The codes of the factors are shown in Table 1, and the transformation formulae between the codes and the factors can be expressed by the following equation:

$$\begin{aligned} x_1 &= 3.333 \cdot w - 1.215, \\ x_2 &= 0.167 \cdot t - 2.430, \\ x_3 &= 0.040 \cdot T - 35.235, \end{aligned} \tag{1}$$

where w is the quantity of the hexachloroethane degassing agent, t is the degassing time, T is the degassing temperature, and x_1, x_2, x_3 are the codes of three factors, respectively.

3. Results and discussion

According to the experimental scheme mentioned above, fifteen experiments are performed and the measurement results of surface tension are shown in Table 2. The experimental results are calculated by MATLAB and the orthogonal regression equation is given as:

$$\begin{aligned} \sigma = 795.7 - 45.12x_1 - 9.08x_2 - 2.97x_3 + \\ + 0.03x_2x_3 - 0.01x_1' + 0.09x_2' - 0.01x_3'. \end{aligned} \tag{2}$$

Table 2. Orthogonal experiment design and the calculation of the measurement

No.	x_0	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	x_1'	x_2'	x_3'	σ (mN m^{-1})
1	1	1	1	1	1	1	1	0.27	0.27	0.27	749.5
2	1	1	1	−1	1	−1	−1	0.27	0.27	0.27	748.9
3	1	1	−1	1	−1	1	−1	0.27	0.27	0.27	758.3
4	1	1	−1	−1	−1	−1	1	0.27	0.27	0.27	758.7
5	1	−1	1	1	−1	−1	1	0.27	0.27	0.27	832.1
6	1	−1	1	−1	−1	1	−1	0.27	0.27	0.27	832.4
7	1	−1	−1	1	1	−1	−1	0.27	0.27	0.27	841.8
8	1	−1	−1	−1	1	1	1	0.27	0.27	0.27	841.3
9	1	1.215	0	0	0	0	0	0.746	−0.73	−0.73	729.3
10	1	−1.215	0	0	0	0	0	0.746	−0.73	−0.73	862.6
11	1	0	1.215	0	0	0	0	−0.73	0.746	−0.73	770.5
12	1	0	−1.215	0	0	0	0	−0.73	0.746	−0.73	821.7
13	1	0	0	1.215	0	0	0	−0.73	−0.73	0.746	782.4
14	1	0	0	−1.215	0	0	0	−0.73	−0.73	0.746	809.5
15	1	0	0	0	0	0	0	−0.73	−0.73	−0.73	796.2
A_i	15	10.952	10.952	10.952	8	8	8	4.361	4.361	4.361	–
B_i	11935.20	−494.20	−99.41	−32.53	0.00	0.00	0.20	−0.05	0.39	−0.05	–
a_i	795.7	−45.12	−9.08	−2.97	0.00	0.00	0.03	−0.01	0.09	−0.01	–
S_i	–	22298.30	902.64	96.61	0.00	0.00	0.01	≈ 0	0.04	≈ 0	–

T a b l e 3. Significance test of the regression coefficients

	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	x'_1	x'_2	x'_3
S_i	22298.30	902.64	96.61	0.00	0.00	0.01	≈ 0	0.04	≈ 0
f_i	1	1	1	1	1	1	1	1	1
S_e					234.61				
f_e					5				
F	475.22	19.24	2.06	0.00	0.00	0.0002	0.00	0.0009	0.00
			$F_{0.01}(1, 5) = 16.26$			$F_{0.25}(1, 5) = 1.69$			

T a b l e 4. Comparison of the surface tension between the calculated value and the measured value

No.	w (%)	t (min)	T (℃)	σ (mN m^{-1}) calculated	measured	Deviation (%)
1	0.10	10	730	829.4	834.6	−0.6
2	0.20	8	746	812.7	816.4	−0.5
3	0.30	10	735	792.5	801.2	−1.1
4	0.35	9	721	787.3	784.7	0.3
5	0.40	12	735	770.8	778.1	−0.9
6	0.50	12	738	752.3	746.8	0.7

To ensure Eq. (2) is correctly given, there is a need to carry out the significance test. The F test is used to evaluate the significance of Eq. (2) and it can be calculated according to Eq. (3):

$$F = \frac{S_u/f_u}{S_e/f_e} = 55.2 > F_{0.01}(9, 5) = 10.2, \quad (3)$$

where S_u is the regression square sum, S_e is the residual square sum, f_u and f_e are freedom degrees of S_u and S_e, respectively.

The result of the F test shows that Eq. (2) is significant at 0.01 level.

Similarly, the F test is used to determine whether the regression coefficients of Eq. (2) are significant at 0.01 level. The calculated results of the F test for the regression coefficients, as shown in Table 3, lead to the following conclusions. The simple terms x_1, x_2, x_3 are significant at 0.01 level, and the interactive x_1x_2, x_1x_3, x_2x_3 and the quadratic terms x'_1, x'_2, x'_3 are not significant at 0.01 level. Moreover, the results in Table 3 show that the sequence of the significance of the regression coefficients is $x_1 > x_2 > x_3$. Therefore, according to the orthogonal regression design method and Eq. (1), the sequence that the quantity of the degassing agent, the degassing time and the degassing temperature affect the surface tension of the molten Al-Si alloys can be also concluded. The surface tension is mainly affected by the quantity of the degassing agent, the degassing time is not important, and the degassing temperature has little influence on the surface tension.

In Eq. (2), the constant term ($b_0 = 795.7$) is very close to the result of central experimental point ($a_0 = 796.2$, which is shown in Table 2), which proves that the linearity of Eq. (2) is satisfied.

Therefore, after the quadratic terms $x'_i = x_i^2 - 0.73$ are introduced into Eq. (2) and the insignificant terms are neglected, according to Eq. (1) and Eq. (2), the relation between the surface tension of the molten Al-Si alloys and these three factors can be expressed as follows:

$$\sigma = 967.81 - 180.94 \cdot w - 1.81 \cdot t - 0.14 \cdot T, \quad (4)$$

where σ is the surface tension of the molten Al-Si alloys, w is the quantity of the degassing agent, t is the degassing time, and T is the degassing temperature.

To validate the correctness of Eq. (4), some experiments on the eutectic Al-Si alloys have been performed. When different degassing treatment is adopted, the surface tension of the molten Al-Si alloys will differ, and actual surface tension and the temperature are measured by RTW-04 Melt Physical Property Analyzer. Also, the surface tension of the measured alloys can be calculated according to the quantity of the degassing agent, the degassing time and the degassing temperature. On the condition of different degassing treatment, the measurement results and the deviations between the calculated values and the measured values are shown in Table 4. Small deviations (below

±1.1 %) show that Eq. (4) is satisfied, and thus surface tension of the molten Al-Si alloys can be calculated by the sum of the different contributions from the quantity of the degassing agent, the degassing time and the degassing temperature.

4. Conclusions

In summary, the influence of the degassing agent, the degassing time and the degassing temperature on surface tension of the eutectic Al-Si alloys has been studied and the conclusions are as follows:

1. Surface tension of the eutectic Al-Si alloys is mainly affected by the quantity of the degassing agent, the degassing time is not important, and the degassing temperature has little influence on the surface tension.

2. Surface tension of the eutectic Al-Si alloys can be calculated by the empirical equation $\sigma = 967.81 - 180.94 \cdot w - 1.81 \cdot t - 0.14 \cdot T$ and the comparative experiments show it is satisfied.

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