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Effect of melt pulse electric current and thermal treatment on A356 alloy ①

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Abstract: Effects of the melt pulse electric current and thermal treatment on solidification structures of A356 alloy were investigated. In the experiments, the low temperature melt(953 K and 903 K) treated by pulse electric current was mixed with high temperature melt(1 223 K). By the control experiments, the results show that the solidification structure of A356 alloy is refined apparently by the pulse electric current together with melt thermal treatment process, and the mechanical properties, especially the elongation ratio of the specimen treated is improved greatly. The structure change of the melt by pulse electric current and melt thermal treatment is the main reason for the refinement of the solidification structure of A356 alloy.

Key words: A356 alloy; low temperature melt; solidification structure; pulse electric current; melt thermal treatment
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1 INTRODUCTION

Possessing higher strength-to-mass ratio, better castability, and better wear resistance, being used for automotive and aerospace applications, the hypoeutectic A356 alloy is one of the most important industrial materials. More and more attention has been paid to improving its mechanical properties. Microstructure refining can effectively improve strength, toughness and service life. Various methods, such as adding alternative, low temperature casting, sonic or ultrasonic vibration and electromagnetic treatment, are often employed to refine the solidification structure of the metals or alloys.

Melt thermal treatment(MTT) is such a process in which two kinds of temperature melt, one is lower temperature melt and the other is higher temperature melt, are mixed to produce the castings. The studies[1, 2] showed that the MTT technique can refine the solidification structure of hypereutectic Al-Si alloy significantly. Previous work[3, 4] indicated that the structure of low temperature melt plays an important role in the MTT processing. Meanwhile, pulse electric current(PEC) discharge during the course of solidification is also an effective method to refine the microstructure of Pb-Sn alloys[5-9]. Illuminated by this, it is expected that the cooperation of the MTT and PEC should refine the solidification structure and improve the mechanical properties of commercial hypoeutectic A356 alloy more remarkably and which is the right aim of the present study.

2 EXPERIMENTAL

Commercial A356 alloy was employed as the experimental material, the composition of which is shown in the Table 1. The temperature of its liquidus is 887.5 K.

Table 1 Composition of A356 alloy (mass fraction, %)

Si	Mg	Fe	Cu	Zn	Ti	Al
7.1	0.403	0.096	0.052	0.007	0.134	Balance

The experimental setup used was the same as the previous study[10]. TDS-210 digital real-time oscilloscope was used for data measurement and storage of PEC discharge in the experiments.

The alloy was melted and refined with C_2Cl_6 in the graphite crucible at 1 023 K. Then the melt was divided into two parts. One was cooled with the furnace to desired temperature(such as 953 K and 903 K) and held for 30 min. The other was heated to the higher temperature(1 223 K) and held for 30 min, protected with Ar gas. Tungsten electrodes were preheated to the melt experimental temperature before immersion. In the experiment, the capacitance was charged up to 1 kV and discharged 10 times. A little amount of the treated melt was drawn out

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with a quartz tube(diameter- d 8 mm, not preheated) as soon as the discharge was end to produce the specimen for observation of low temperature melt (LTM) characters. Then the LTM and the HTM(high temperature melt) were mixed and poured into the permanent mold(preheated to 493 K) quickly. The temperature of mixed melt was kept at 993 ±5 K. The resistance between the electrodes was 2. 2 mΩ, which was measured by ZY9858 microresistivity surveyor. The solidification structure of the specimen was observed by LECO-IA32 image analysis system. The cooling curve was measured by ADS thermal system. Control samples were prepared without treatment except C_2Cl_6 refinement.

Fig. 1 and Table 2 show that the maximum voltage drop across the specimen upon discharged of 1 kV of the capacitor bank is about 450 V with oscillating frequency about 6 kHz. The total discharging time is 450 μs. And the maximum peak current of pulse discharge passing through the melt is about 2×10^5 A.

Table 2 Parameters of PEC discharging

Half-wave	Peak voltage / V	Peak current / 10^4 A	Mean voltage / V	Mean current kA	Duration of half-wave/ μs
1	450	20	120	54	60
2	300	13. 6	160	73	100
3	170	7. 7	80	36	110
4	90	4. 1	60	27	120
5	35	1. 6	20	9	60

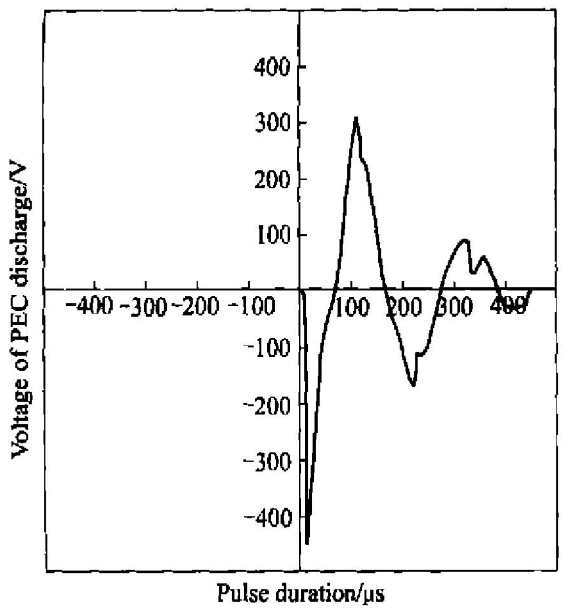

Fig. 1 Voltage drop across specimen during discharge

(The initial capacitor bank voltage was 1 kV.)

3 EXPERIMENTAL RESULTS

3. 1 Structure of LTM treated by PEC

Fig. 2 and Fig. 3 show the typical optical solidification microstructures of A356 alloy without and with PEC treatment at 953 K and 903 K, respectively, the light phases in which correspond to the primary α-Al phase and the dark regions to eutectic. From the figures, the solidification microstructures of the melt of 953 K without PEC treatment appear coarse dendritic structure; however, the microstructure of the melt of 903 K without PEC treatment shows rosette or equiaxed structure, the average size of the second dendrite arms spacing of which is 41. 5 μm and 49. 3 μm, respectively. After the PEC treatment, the solidification structure was refined apparently, the DAS reducing to 31. 7 μm and 45. 6 μm, respectively. Fig. 4 indicates the difference of cooling curve of the LTM with and without PEC treatment. There is an obvious undercooling(about 5 K, showing with arrow) in the cooling curve of the LTM with PEC treatment, and the solidification time is shorter than that of the untreated one.

3. 2 Microstructure and mechanical properties of A356 alloy treated by PEC+ MTT process

Fig. 5 shows the solidification microstructures of A356 alloy with or without PEC+ MTT process treatment. It can be seen that the microstructure shows coarse dendrite when the untreated melt solidified at 993 K(Fig. 5 (a)) . After the LTM is treated by PEC, the final solidification structure becomes fine, such as Figs. 5(b) and (c) . The average DAS measured is 34. 2, 21. 3 and 30. 3 μm, respectively. The mechanical properties tested are shown in the Table 3. There appears no large difference of the tensile strength(σ) between treated and untreated samples, however, the difference of the elongation ratio (δ) between them is much obvious, the δ of the treated samples is much higher than that of untreated ones. Meanwhile, the mechanical properties of treated samples with the LTM discharged at 953 K are higher than those of the samples with the LTM treated at 903 K.

Table 3 Mechanical properties of A356 alloy treated or untreated by PEC+ MTT process

Untreated(993 K)	Treated(993 K)	
	903 K LTM	953 K LTM
185/ 2. 8*	188. 5/ 4. 4	190. 7/ 5. 2

* —means tensile strength(MPa) / elongation ratio(%)

4 DISCUSSION

4. 1 Effect of pulse electric current on LTM

It is known that there exist some solid- like

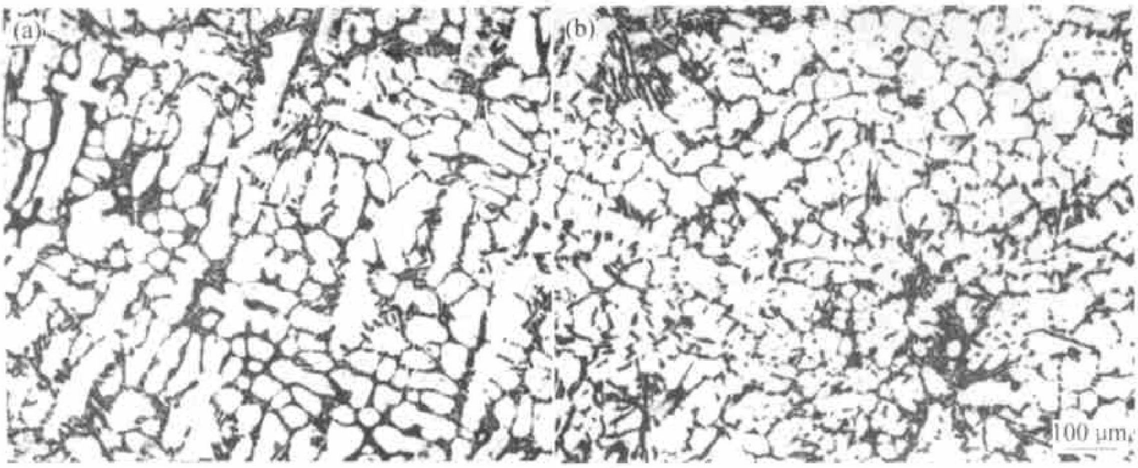

Fig. 2　Solidification structures of melt at 953 K

(a) —Without PEC treatment; (b) —With 1 kV charge voltage PEC 10 times treatment

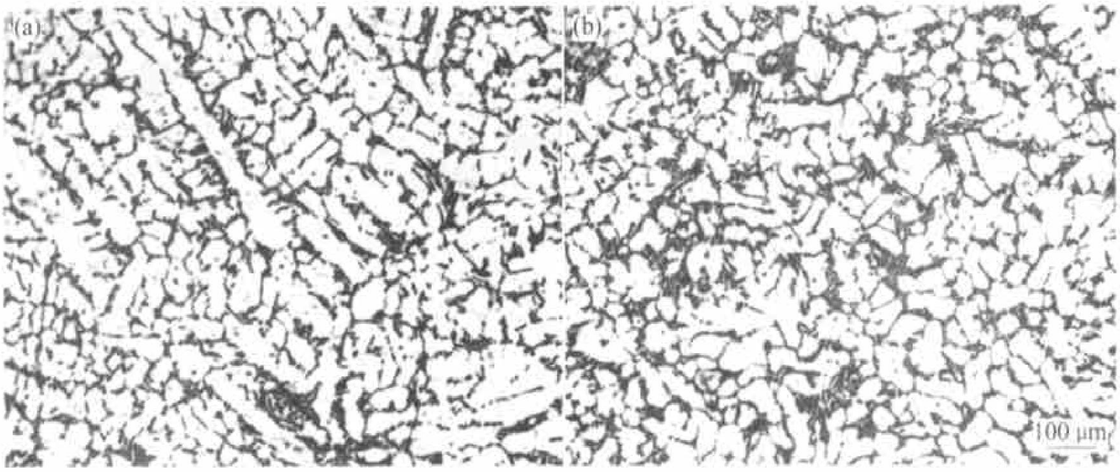

Fig. 3　Solidification structures of melt at 903 K

(a) —Without PEC treatment; (b) —With 1 kV charge voltage PEC 10 times treatment

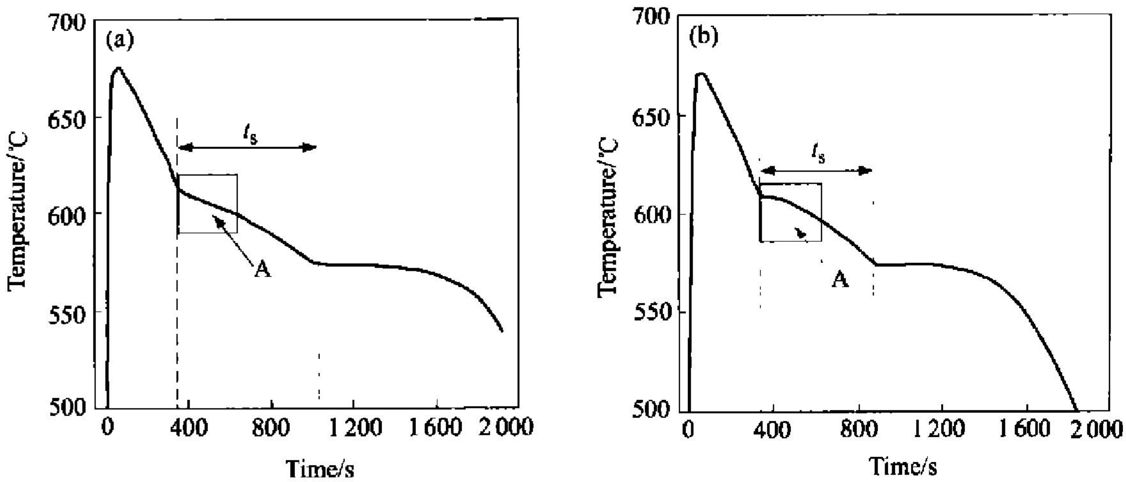

Fig. 4　Air cooling curve of 953 K melt with or without PEC treatment

(a) —Without treatment; (b) —With PEC treatment

structures in the low temperature melt, and the lower the melt temperature, the more the solid-like structures[11]. When the PEC is applied to the low temperature melt, the pinch force self-induced at the moment of discharge will act on the clusters inevitably, which can break up the clusters and decrease the size and increase the number of clusters in the melt. The maximum pinch force in unit area can be calculated[9] as about 4 kPa. As to the Joule-heat generated during the discharging of the PEC, according to the data measured in the experiments, the expected

Fig. 5 Solidification microstructures of A356 alloy with and without MTT+ PEC process treatment
(a) —Without treatment;
(b) —953 K LTM with MTT+ PEC treatment;
(c) —903 K LTM with MTT+ PEC treatment

temperature increase ΔT is calculated as follows:

$$\Delta T = \frac{R \cdot \sum_{i=1}^{5} I_i^2 t_i}{C_m m_{\mathrm{Al}}} \quad (1)$$

where R is the average resistance of the melt, I_i and t_i are the electric current and duration time of i half-wave (shown as Table 2), C_m is the specific heat, m_{Al} is the mass of the LTM.

The temperature increment calculated is about 5 K, so the effect of Joule-heat on the structure of the melt can be neglected. Because there are many clusters in the melt which can act as nuclei when the phase transformation begins at the liquidus. This effect can decrease the cooling rate, and promote the refinement of the solidification structure of the LTM, such as Fig. 2(b) and Fig. 3(b).

4.2 Effect of melt thermal treatment

The melt structure changes with the melt temperature. With the temperature rising, the close-pack clusters will melt and break down. Finally, the melt structure will be non-cluster and more homogeneous at higher temperatures.

When the HTM and LTM are mixed, it is assumed that there should be a sharp temperature gradient in the mixed melt, shown as Fig. 6. The temperature of the HTM is decreasing and the LTM is rising quickly. The non-cluster and homogeneous structure character of HTM will be remained to the pouring temperature for some time, and the close-pack clusters in the LTM will be remelted and the size of which will become smaller in a short time.

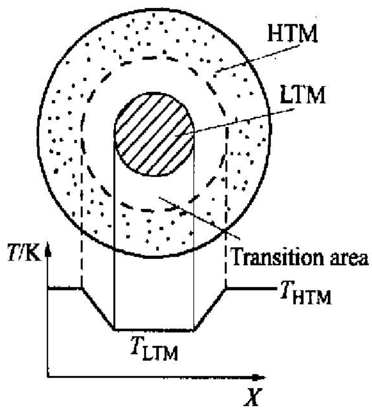

Fig. 6 Schematic of model of mixing melt

When the melt mixed with the PEC treated LTM and HTM is poured, the more, smaller solid-like structures in the melt can be used as nuclei to precipitate to be primary phases when the melt temperature is below the liquidus, and the final solidification structure is refined. And the mechanical properties will be improved. As to the great improvement of the elongation ratio of the sample treated with PEC+ MTT process, it is assumed that the MTT process is beneficial to suppressing the segregation of the compound phases[12, 13]. So the bad effect of the intercrystalline segregation on the tensile properties can be reduced.

5 CONCLUSIONS

1) The discharge of PEC in the low temperature melt can refine the solidification structure of A356 alloy obviously.

2) The pinch force is the main reason for the refinement of the low temperature melt of A356 alloy, and the effect of Joule heat can be neglected.

3) Using PEC+ MTT process, the mechanical properties, especially the elongation ratio of the samples are increased greatly.

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