[Article ID] 1003- 6326(2002)03- 0414- 05

Effect of high density pulse electric current on solidification structure of low temperature melt of A356 alloy ①

HE Shu-xian(何树先), WANG Jun(王 俊), SUN Bao-de(孙宝德), ZHOU Yao-he(周尧和)
(School of Materials Science and Engineering,
Shanghai Jiaotong University, Shanghai 200030, China)

[Abstract] The effect of high density pulse electric current (HDPEC) on the solidification structure of the low temperature melt(LTM) of commercial A356 alloy was investigated. In the experiments, the HDPEC was discharged in the LTM (953 K, 903 K and 873 K). By the control experiments, the results showed that the solidification structure of the LTM of A356 alloy is refined apparently when the HDPEC is discharged in low temperature melt. However, the holding time of melt treated has an adverse effect on the solidification structure. The longer the holding time of the melt treated with HDPEC, the coarser the microstructure. With the same discharge voltage, the lower the temperature of LTM, the more obscure the refinement of solidification structure. Finally, the mechanism of microstructure refining by HDPEC was analyzed.

[Key words] A356 alloy; low temperature melt; solidification structure; high density pulse electric current
[CLC number] TF 111.18; TF 114.12 **[Document code]** A

1 INTRODUCTION

The hypoeutectic A356 alloy is one of the most important industrial materials. More and more attention has been paid to improve its mechanical properties recently. Microstructure refining can effectively improve metal 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.

The study showed that the pulse electric current discharge during the solidification course is an effective method to refine the microstructure of Pb-Sn alloys apparently[1~5]. The pulse current can be applied to not only the onset of the solidification but also the later half of the solidification. But the result indicated that the microstructure refinement is indistinguishable when the pulse electric current is discharged in the later half of the solidification[3]. With the development of solidification technology and cluster theory, more and more researches have been focused on the effects of structure of liquid metal on the final solidification structure[6~9]. And it is believed that there exist many kinds of solid-like cluster-structures in the low temperature melt(LTM) whose temperature is a little higher than the liquidus. When the temperature of the LTM is below the liquidus, these solid-like clusters will precipitate as solid phases. The relationship between cluster-structures and solidification structure has attracted more and more interest of the material scientists. It is believed that the cluster-structure in the low temperature melt can be broken by some physical or chemical methods to affect the final solidification structure. Based on this idea, the present paper reported the influence of high density pulse electric current (HDPEC) discharged in the LTM on the solidification structure of hypoeutectic A356 alloy.

2 EXPERIMENTAL

The commercial A356 alloy was employed as the raw material and whose compositions was shown in Table 1.

Table 1 Compositions of commercial A356 alloy (%)

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

The JD-1 high density pulse electric current (HDPEC) generator with 1000 μF capacitance was used in our experiment, which can be charged up to 5 kV. The experimental setup is shown in Fig. 1. The discharging time was set as once 1.5 s. TDS-210 digital real-time oscilloscope was used for data storage of HDPEC discharge in the experiments.

The alloy was melted and refined with C2Cl6 in the graphite crucible at 1023 K. Then the melt was cooled with the furnace to the experimental temperature (953 K and 903 K) and held for 30 min. The tungsten electrodes were preheated to the melt

① **[Foundation item]** Project (G1999064900) supported by the National Key Fundamental Research and Development Program, and project supported by General Motors (China) Inc **[Received date]** 2001- 08- 20; **[Accepted date]** 2001- 10- 05

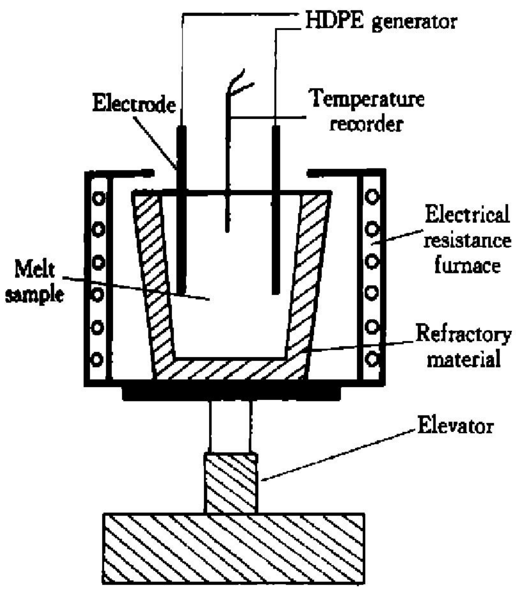

Fig. 1 Discharging setup of HDPEC for temperature melt treatment

temperature before immersion. In the experiment, the capacitance was charged up to 1 kV and discharged 10 times. A certain amount of melt treated at experimental temperature was taken out with a quartz tube (*d* 8 mm, not preheated) after holding for 0, 300 and 600 s respectively to produce the specimen. Then the solidification structure of the specimen was observed with the LECO-IA32 image analysis system. The control samples were prepared without the HDPEC treatment.

Fig. 2 shows the results of the discharging of HDPEC. The maximum voltage drop across the specimen with 1 kV charge voltage of the capacitor bank is about 450 V with oscillating frequency of about 6 kHz. And the discharging time is 440 ms. The resistance of the melt measured by ZY9858 microresistivity surveyor. Therefore, the maximum

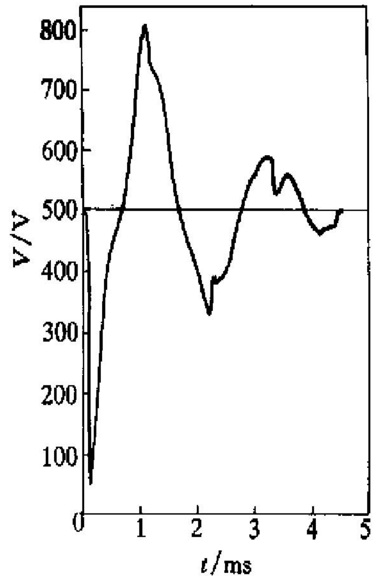

Fig. 2 Measured voltage drop across specimen during discharge for initial capacitor bank voltage of 1 kV

density of pulse electric current passing through the melt was about $2 \times 10^5 A/cm^2$.

3 RESULTS

Figs. 3~ 5 show the typical optical solidification structures of A356 alloy without or with HDPEC treatment at 953 K, 903 K and 873 K, respectively. The light phases in the figures correspond to the primary α(Al) phase and the dark regions are eutectic. From the figures, the solidification structures of the melt of 953 K and 903 K without HDPEC treatment appear coarse dendritic structure; however, the structure of the melt of 873 K without HDPEC treatment shows rosette or equiaxed structure whose average size of the second dendrite arms spacing is 46.5 μm, 41.5 μm and 49.3 μm, respectively. After the HDPEC treatment, the solidification structure was refined. The coarse

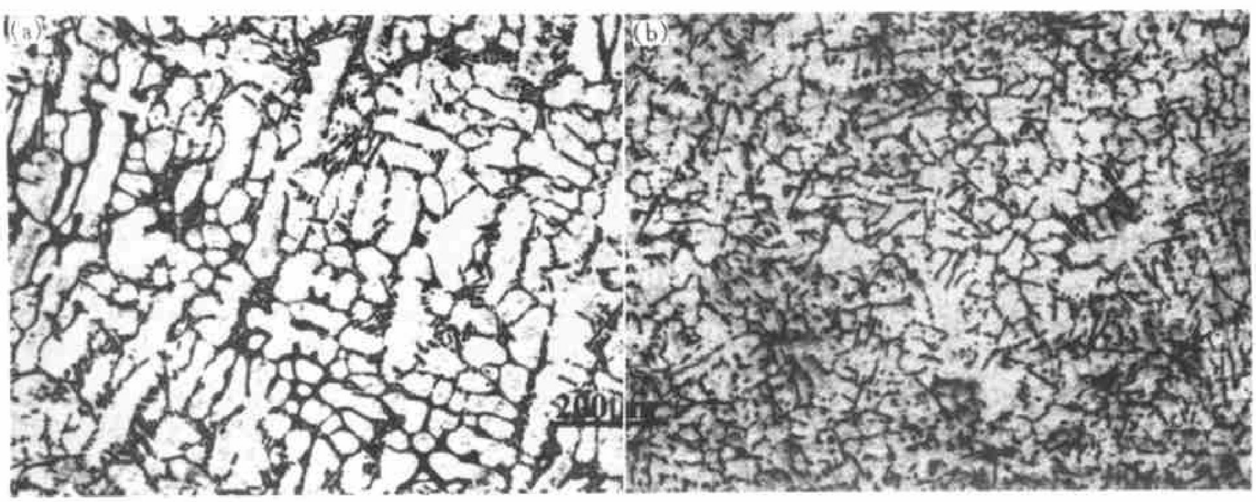

Fig. 3 Solidification microstructures of melt at 953 K
(a) —Without HDPEC treatment; (b) —With 1 kV charge voltage after HDPEC treated for 10 times

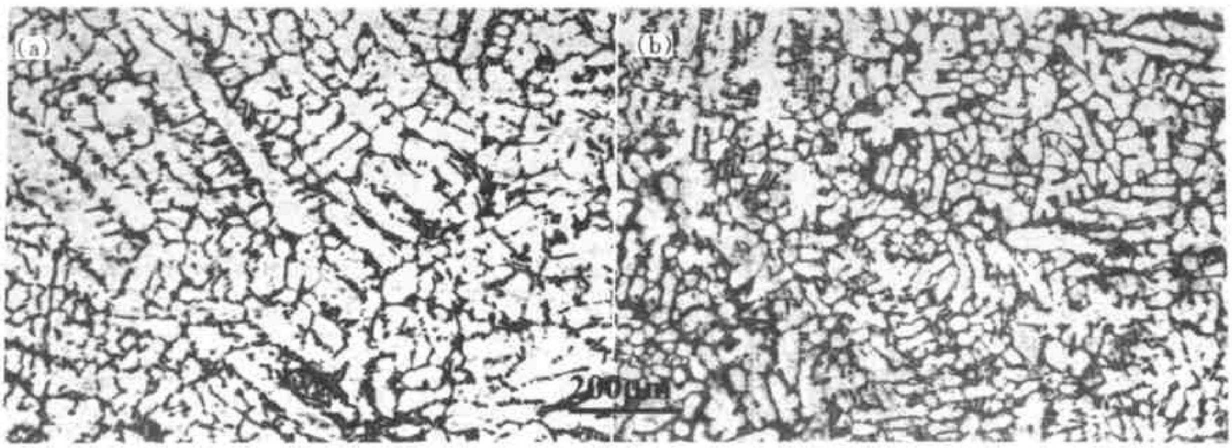

Fig. 4 Solidification microstructures of melt at 903 K
(a) —Without HDPEC treatment; (b) —With 1 kV charge voltage after HDPEC treated for 10 times

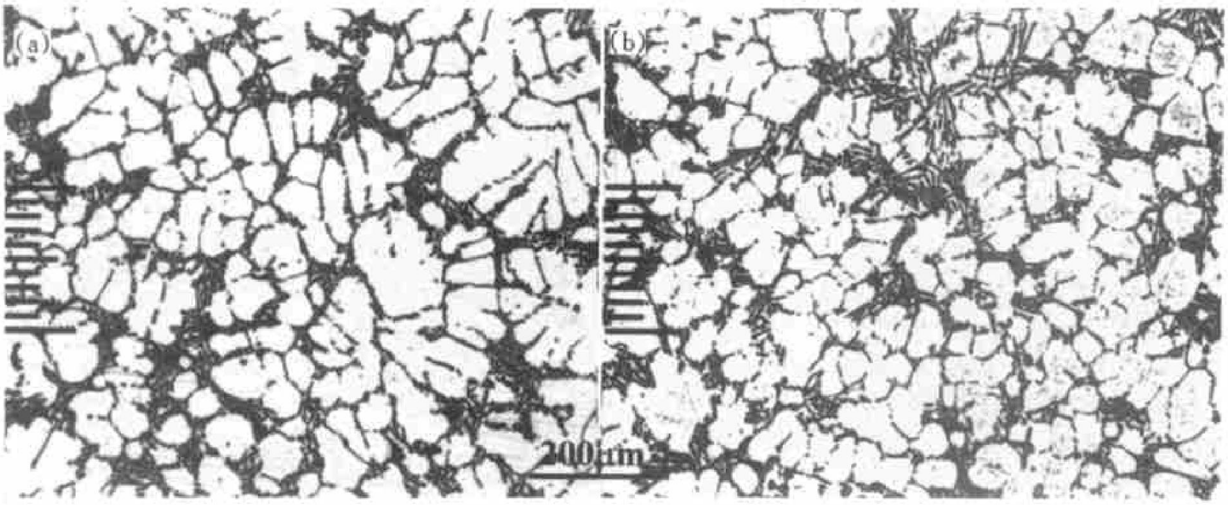

Fig. 5 Solidification microstructures of melt at 873 K
(a) —Without HDPEC treatment; (b) —With 1 kV charge voltage after HDPEC treated for 10 times

dendritic structure of the melt of 953 K disappears and the modified structure is a fine non-dendritic type structure and the average size of the grains is about 28.9 μm (Fig. 3(b)). However, although the solidification structure of the melt of 903 K and 873 K is also refined (with the DAS reducing to 31.7 μm and 45.6 μm, respectively), the character of dendritic or equiaxed structure is not changed (Fig. 4(b) and Fig. 5(b)). Because the cooling rate is so fast, the solidification structure can reflect the structure character of the melt.

Fig. 6 and Fig. 7 show the effect of holding time of the melt treated by HDPEC on the solidification structure. The figures illustrate that the holding time of the melt has an adverse effect on the refinement of the solidification structure. With increasing the holding time, the structure of the melt becomes coarse gradually. Fig. 7 also indicates that the rate of the structure coarsening of 953 K, 903 K and 873 K LTM is different, the rate of coarsening of 953 K LTM is the fastest, and that of 873 K LTM is the lowest. However, the morphology of the solidification structure of 953 K melt remains the non-dendritic structure after holding for 600 s (Fig. 6(a)). Therefore, it can be concluded from the figures that the effect of the holding time of the melt on the solidification structure is to coarsen the dendrites but not change the morphology of the solidification structure.

4 DISCUSSION

It is known that the melt structure changes with the melt temperature, and there are a lot of solid-like clusters in the low temperature melt[9]. With increasing the temperature, these clusters will melt and break down. So the melt structure will be non-cluster and evenly at higher temperature, as shown in Fig. 8.

When the HDPEC is applied in the low temperature melt, the pinch force at the moment of discharge will act on the clusters inevitably, which

Fig. 6 Solidification microstructures of melt treated for 10 min at different temperatures
(a) —953 K; (b) —903 K

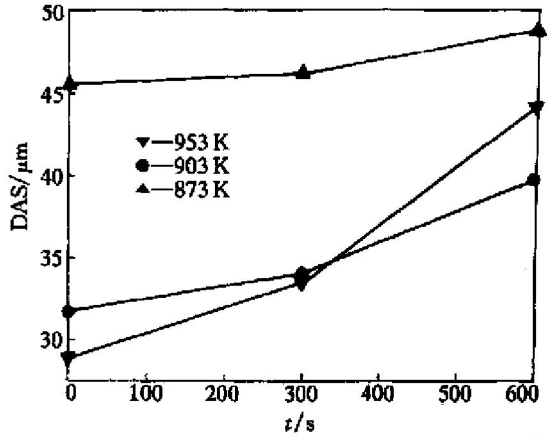

Fig. 7 Relationship between holding time of melt treatment and DAS

can break up the clusters and decrease the size and increase the number of clusters of the melt, the schematic is shown in Fig. 9. As to the Joule-heat generated during the discharging of the HDPEC, Ref. [10] showed that the expected temperature increases due to the Joule-heat is very small, so the effect of Joule-heat on the structure of the melt can be neglected. Therefore, the solidification structure will be refined because so many clusters in the melt can act as nuclei when the temperature of melt is cooled to the liquidus.

As it is known to us that there exist some solid-like structures in the low temperature melt, and the lower the melt temperature, the more these solid-like structures. These solid-like structures can precipitate to be primary phases when the melt temperature is down to the liquidus. The experimental results indicate that when the structure of the melt appears dendritic, the solidification structure is also dendritic; when the structure of the melt shows non-dendritic,

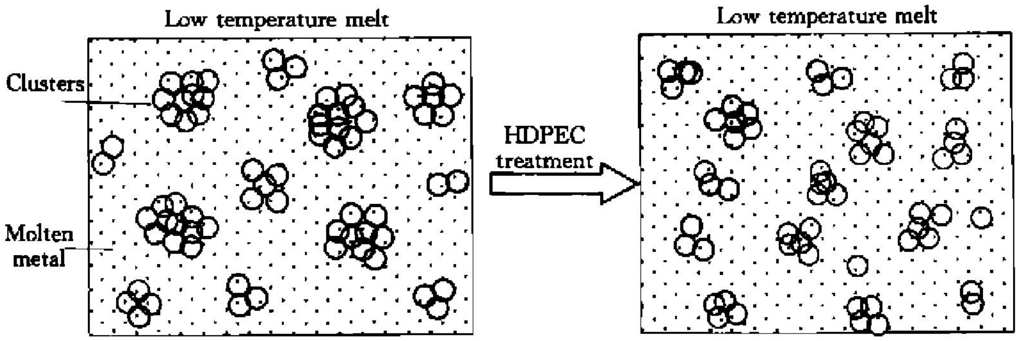

Fig. 8 Schematic of melt structure changing with temperature

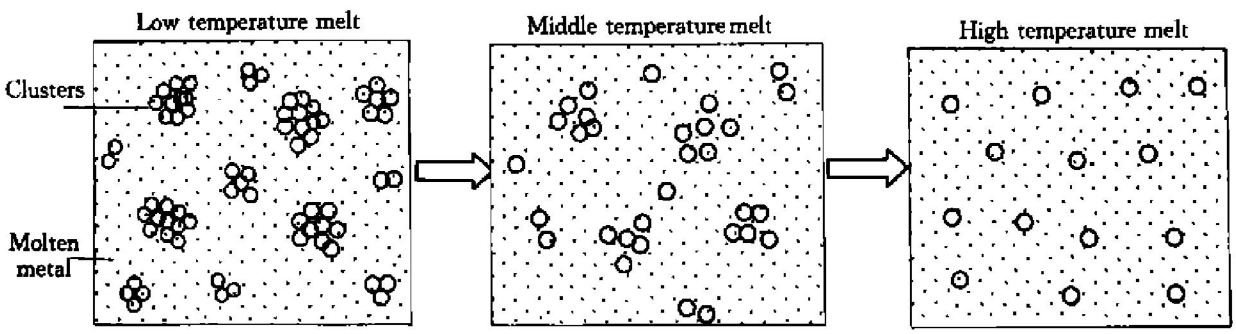

Fig. 9 Schematic of melt structure change of low temperature melt after HDPEC treatment

the final solidification structure also appears non-dendritic. This suggests that the structure of the melt will determine the morphology of the solidification structure of A356 alloy, and because the strength of clusters in the melt is much smaller than that of the primary solid phases during the solidification, the break of the clusters can be much easier than that of the solid phases. So we can predict that the effect of the melt on the solidification structure is more important than that of the solidifying course.

The results also illustrate that the structure of the low temperature melt will change with the holding time. Because of the motion and diffusion of the atoms in the melt, the broken solid-like structures will combine again. This combination results in the decreasing of the number of nuclei in the melt and the coarse solidification structure in the end. However, because of the rate of motion and diffusion in 953 K LTM is faster than that in 873 K LTM, so the coarsing rate of the structure of 953 K LTM will be faster than that of 853 K LTM. On the other hand, the effect of holding time of the melt on the solidification structure can further prove that the significance of the LTM on the final solidification structure, that is, the pre-crystallizing in the LTM plays a more important role on the final solidifying course.

5 CONCLUSIONS

1) The discharge of HDPEC in the low temperature melt can refine the solidification structure of A356 alloy obviously. In our experiments, the solidification structure of 953 K melt becomes non-dendritic structure completely. However, the structure of 903 K melt is just refined, without obvious change of the dendritic structure.

2) The holding time of the melt after HDPEC treatment has an adverse effect on the solidification structure. The longer the holding time of the melt, the coarser the final solidification structure.

3) The effect of the pre-crystallizing in the LTM on the solidification structure is more important than that of the solidifying course.

ACKNOWLEDGEMENT

The authors wish to thank Focus-group Principal Investigator Dr. Herbert W. Doty, and Dr. Bob Powell.

[REFERENCES]

[1] Misra A K. Misra technique applied to solidification of cast iron [J]. Metall Trans, 1985, 16A: 1354.

[2] Ahmed S, McKannan E C. Control of γ′ morphology in nickel base superalloys through alloy design and densification processing under electric field [J]. Material Science and Technology, 1994, 10: 941.

[3] Nakada M, Shiohara Y, Flemings M C. Modification of solidification struture by pulse electric discharging [J]. ISIJ International, 1990, 30(1): 27.

[4] LI Jian-ming, LI Sheng-li, LI Jin, et al. Modification of solidification structure by pulse electric discharging [J]. Scripta Metallurgica et Materiallia, 1994, 31 (12): 1691.

[5] Barnak J, Sprecher A F S, Conrad H. Colony(grain) size reduction in eutectic Pb-Sn casting by electropulsing [J]. Scripta Metall Mater, 1995, 32(6): 879.

[6] ZHANG Lin, BIAN Xiu-fang, MA Jia-ji. Microstructural transformation of Al-Si alloy in the liquid state [J]. Foundry, (in Chinese), 1995, 10: 7.

[7] LI Pei-jie, GUI Man-chang, JA Jun. Study on the electrical resistivity and the structure of Al-Si alloy melt [J]. Foundry, (in Chinese), 1995, 9: 15.

[8] WANG Wei-min, BIAN Xiu-fang, QIN Jing-yu, et al. Structural transformation and its reversibility in liquid Al-13%Si alloy at high temperatures [J]. Trans Nonferrous Met Soc China, 1998, 8(2): 230.

[9] Moon F C. Magneto-solid Mechanics [M]. New York: A Wiley-Interscience Publication, 1984.

[10] Nakada M. Thesis for Master of Science [M]. Massachusetts Inst Tech, 1985.

(Edited by HUANG Jin-song)