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Effect of low temperature melt on solidification structure of A356 alloy with melt thermal treatment 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 and Engineering, Shanghai Jiaotong University,
Shanghai 200030, P. R. China)

[Abstract] The influence of the low temperature melt (LTM) structure on solidification structure of the sample with melt thermal treatment (MTT) process was studied. And the mechanism of the MTT process was analyzed with cluster theory. It is shown that the final solidification structure is dependent mainly on the structure of LTM. Dendrites will appear in the solidification structure if the structure of LTM is dendritic before MTT. Otherwise, non-dendritic grains will appear in the solidification structure. And the lower the temperature of LTM, the more remarkable the effect of the LTM structure is.

[Key words] aluminum alloy melt; solidification structure; MTT; cluster
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1 INTRODUCTION

With the development of the solidification technology and clusters, the effect of the structure of the liquid metal on the final solidification structure is paid more attention[1~6]. The melt temperature treatment (MTT) is such a process that can improve the solidification structure by changing the melt structure.

The thought of refining solidification structure with MTT was put forward by former USSR scientists in 1960s. In the late 1980s, Ohmi[7~9] studied slurry-melt mixing process (SMM), in which a hypereutectic Al-Si alloy melt (second-alloy melt) was mixed by agitation with a semi-solid hypoeutectic Al-Si alloy slurry (first-alloy slurry) under a furnace-cooling atmosphere. As the two kinds of alloys were brought into contact, the second-alloy melt was rapidly quenched to precipitate numerous fine primary silicon crystals, while the equiaxed alpha solid solution in the first-alloy slurry was remelted by absorbing the latent heat of fusion. The results showed that the primary Si grains were refined distinctly. JIAN[10] also found the Al-18Si and Al-4.5Cu alloy were refined obviously by MTT as well as the mechanical properties of the castings were improved.

In this paper, the effect of low temperature melt structure on the solidification structure of MTT-treated A356 alloy is investigated systematically.

2 EXPERIMENTAL

The hypoeutectic A356 alloy was employed in the experiments. The composition was analyzed, as listed in Table 1.

Table 1 Composition of experimental material (mass fraction, %)

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

The electrical resistance furnace (SG2-7.5-1.3) was used for preparing the low temperature melt and the silicon-molybdenum bar furnace (SSG2-12-16) for high temperature melt (HTM).

In order to study the influence of the structure of LTM on the solidification structure with MTT, the experiments were carried out as follows.

1) Determining the quenching solidification structure of the stirred and non-stirred melt. Firstly, samples were melted at 600 ℃ and 640 ℃ in graphite crucibles respectively. Then the melt was quenched into water after mechanical stirring or not.

2) Comparing the solidification structure of the samples treated with different temperature LTMs and the same temperature HTM (950 ℃). The temperature of the mixed melt was fixed at 720 ℃ by adjusting the mass fraction of the LTM and HTM. The mixed melt was poured into a permanent mold preheated to 220 ℃. Then samples were cut, polished and etched with 0.5%HF aqueous solution. The microstructures were observed and analyzed with LECO-IA32 image analysis system.

3 RESULTS AND DISCUSSION

3.1 Structure of LTM

Fig. 1 and Fig. 2 show the quenching solidification structures of LTM at 640 ℃ and 600 ℃ respectively, in which the white phase is primary α(Al)

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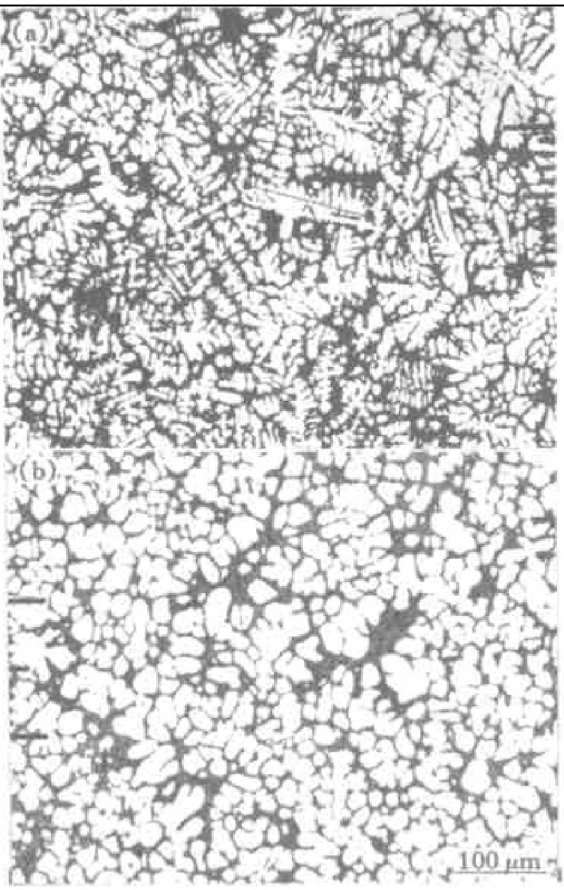

Fig. 1 Quenched solidification structure of LTM (640 ℃)
(a) —Without stirring; (b) —With stirring

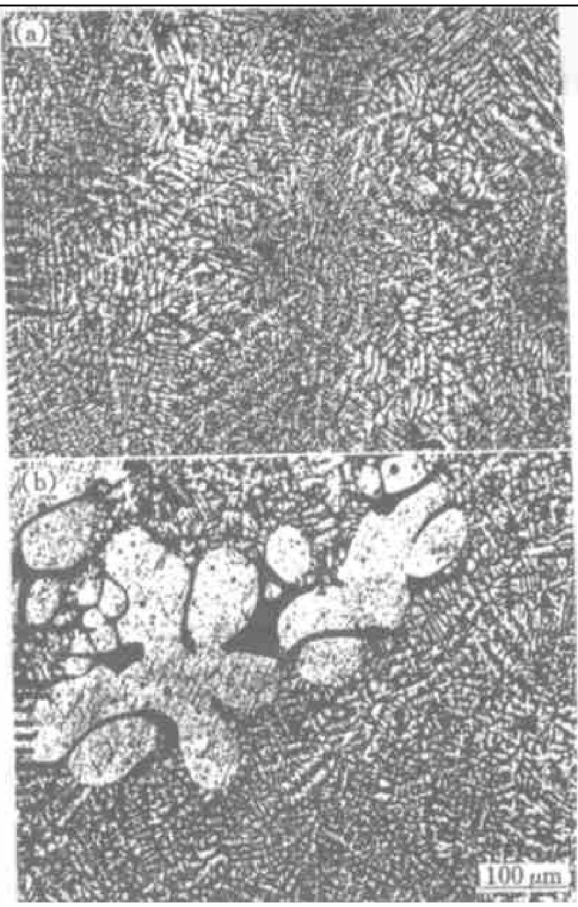

Fig. 2 Quenched solidification structure of LTM (600 ℃)
(a) —Without stirring; (b) —With stirring

solid solute and the gray phase has eutectic structure. In Fig. 1(a), it is clearly shown that the primary α phase is dendritic. After the melt is stirred, equiaxial dendrite and rosette appears in the α phase, as shown in Fig. 1(b). Fig. 2 shows that there exist some solid phases which are not melted. And when the fraction of the solid phase not melted is about 33% calculated according to the Scheil equation, dendritic and coarse equiaxial dendrites appears in the α phase without or with stirring (as shown in Fig. 2(a) and (b)).

The cooling rate of the sample is so fast that the quenching structure can reflect the structure characteristics of the LTM. The lots of dendritic solid phases or like solid phases of the LTM without stirring come from the raw material for the heredity[11]. These solid phase will evolve into clusters when the temperature of the melt is higher than that of liquidus. The size of the clusters is smaller than that of solid phase, but is much larger than nuclei. When the LTM is stirred, the dendritic arms are sheared and broken off, which will promote the remelting of the dendrites. The tiny broken dendrites in the melt will collide, scrape and scour. This will make the temperature distribute within the clusters or solid phases uniformly in any direction. And the effect of undercooling resulted from composition gradient will disappear. This will promote the growing of the dendrite in all directions, which results in regularizing and spheroidizing of the grains.

3.2 Structure of mixed melt

Fig. 3 shows the solidification structures of A356 alloy treated with 950 ℃ HTM and unstirred LTM, in which the white phase is primary α phase and the gray phase has eutectic structure. The average size of the primary dendrites measured is listed in the Table 2. It can be seen that there are many large dendrites in this kind of solidification structure. When the temperature of the LTM is 600 ℃, in the primary dendrite, typical tree-like dendrite appears and the size of it is the largest, as shown in Fig. 3(a). When the temperature is 680 ℃, there exist some dendrites and near-rosette like dendrites in the solidification structure, and the sizes of these dendrites are smaller. (as shown in Fig. 3(c)).

The phenomena is resulted from the amount of clusters in the melt varying with the temperature. The clusters unite with each other by chemical bound at the lower temperature and exhibit short-range order. The quantity of the clusters increase with decreasing the melt temperature. The clusters will change into solid phase gradually when the temperature of the melt falls below the liquidus. The existing of the clusters or solid phases results in the high vis-

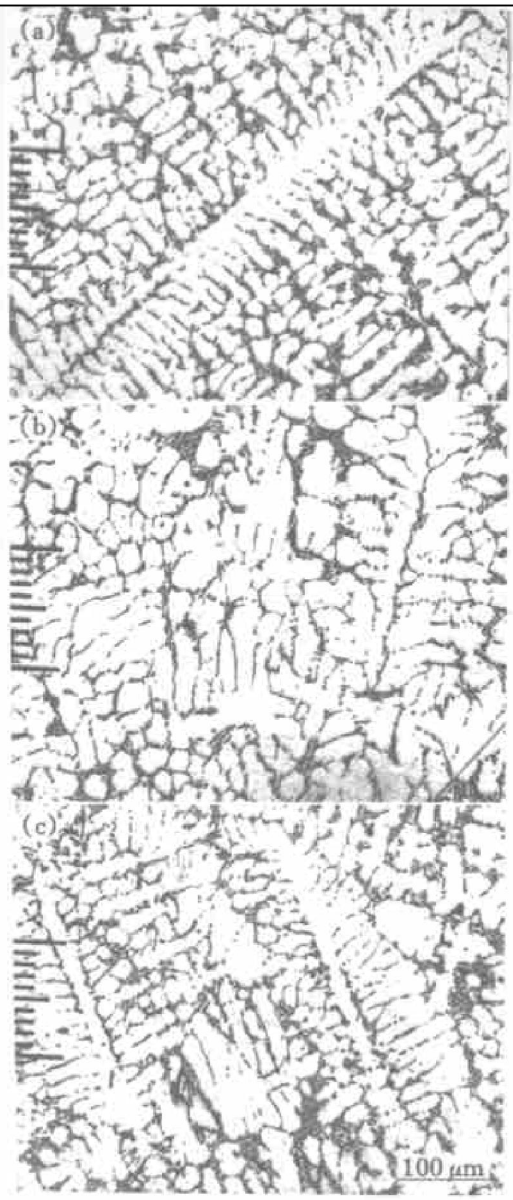

Fig. 3 Solidification structure of A356 alloy treated with 950 ℃ HTM and different temperature LTMs (LTM is not stirred)
(a) —600 ℃; (b) —640 ℃; (c) —680 ℃

Table 2 Size of primary dendrites of A356 alloy with different LTMs

Temperature of LTM / ℃	State of LTM	Primary dentrite space / μm
600	Without stirring	547
	With stirring	210
640	Without stirring	480
	With stirring	354
680	Without stirring	471
	With stirring	459

Temperature of HTM is 950 ℃

cosity of the LTM[12]. When the HTM is poured into the LTM, the clusters or solid phase will be melted to small size because of the effect of impact and heat from HTM. So more and smaller clusters will form in the mixed melt. However, the destructive function of HTM will be weakened with decreasing the LTM temperature because there are too many large solid phase or clusters involved in the mixed melt when the temperature of LTM is below the melting point. Thus, these larger solid phases or clusters will grow preferentially, and are prone to developing into larger tree-like dendrites.

Fig. 4 shows the solidification structure of A356 alloy treated with stirred LTM and 950 ℃ HTM. Compared with Fig. 3, the solidification structure in the Fig. 4 is quite different. In the structure in Fig. 4(a), rosette dendrite plus eutectic structure appear, but the space of second dendrite arms is coarse. The structure of Fig. 4(b) is composed of some smaller tree-like and rosette grains, and the space of second dendrite arms is a bit smaller than that of Fig. 4(a). When the LTM temperature is 600 ℃, there are more primary dendrites of which the size is larger than that of Fig. 4(b). But the primary dendrite sizes and the space of second dendrite arms are much smaller than those of Fig. 3.

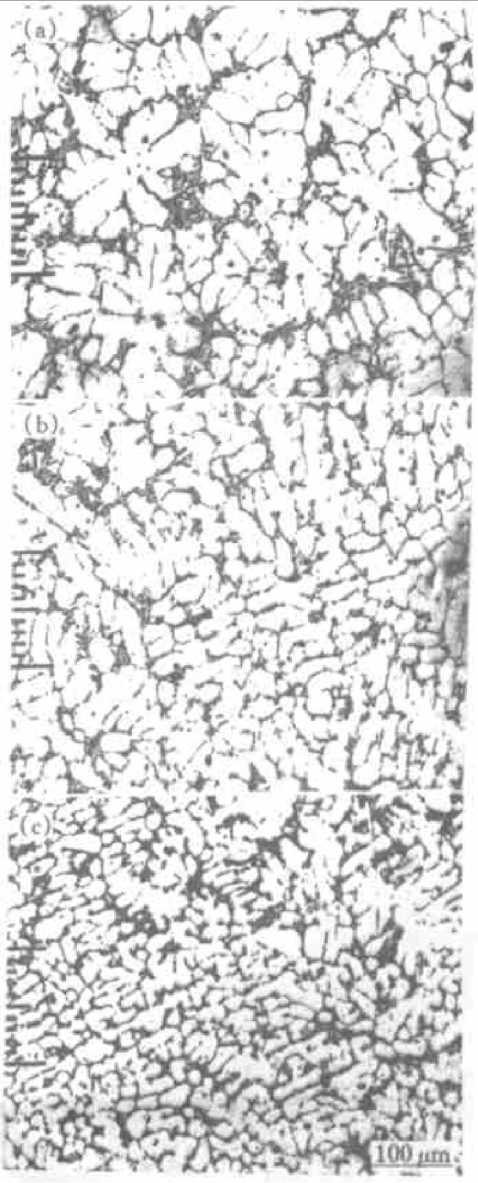

Fig. 4 Solidification structure of A356 alloy with MTT (LTM is stirred at different temperatures)
(a) —600 ℃; (b) —640 ℃; (c) —680 ℃

This is resulted from the structure of the LTM changing before the melt mixing. As shown in Fig. 1(b), the primary phase in the melt with stirring is round rosette instead of the larger tree-like dendrite. With the effect of the heat and the impact of the HTM, these equiaxed grains will be melted and destructed, they will become smaller and distribute more uniformly. In the following solidification procedure, these tiny and regular solid phases will grow in all directions without prior growing direction. This will promote the uniform distribution of the component in the melt. And the uniform distribution of the component will also be beneficial to the homogeneous growth of the eutectic. So finally, eutectic dendrites appears in the solidification structure. With increasing LTM temperature, the quantity of clusters in the melt will decrease and the size of them will become smaller. This kind of melt structure can hardly be affected by the stirring. Therefore, those fewer and smaller clusters in the LTM will melt and disappear completely while HTM is added. And the primary dendrites become coarse tree-like dendrites (Fig. 4(c)) due to the lack of the nuclei needed in the following solidification.

Undercooling of the melt is considered to be the reason of changing of the dendrite arm space (DAS). The LTM in semisolid state contains many unmelted solid phases, of which the size is smaller in macro-scale, but is larger in micro-scale. These solid phases will not melt completely at once as LTM and HTM are mixed. Thus the temperature of these unmelted solid phases is also much low. In the following solidification, these solid phases will become the nuclei with undercooling. It is assumed there should be a sharp temperature gradient around these undercooling nuclei, as shown in Fig. 5. It is obvious that these undercooling solid phases will grow firstly. The fast growing rate of second dendrite is owing to the large undercooling between the LTM and HTM. The stirring of LTM make the composition and the undercooling solid phases distribute more uniformly with better flow ability. Combined with the stirring effect of HTM, these distributions become more homogeneous. Therefore, the axial growth of second dendrite will be restrained, but the radial growth is free. In the final solidification structure, not only the equiaxed grains but also the coarse of the DAS will appear. However, the case is different when the temperature of the LTM is above the liquidus. The LTM will contain the like solid clusters with more tiny size other than the unmelted solid phases. The bonding force of these clusters is much lower than that of the solid phases. By the effect of heating and stirring while HTM being added, these larger clusters can be easily broken into smaller ones which disperse in the melt uniformly acting as the nuclei. Because the temperature of the clusters is higher than that of the solid phases, the growing rate of these cluster nuclei will be slower than that of solid phase ones. And the second dendrite will also grow slowly. So Finally, the DAS becomes smaller.

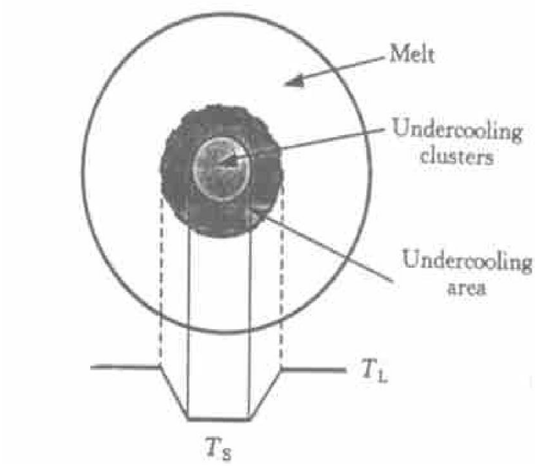

Fig. 5 Schematic diagram of temperature fluctuation of mixing melt structure

3.3 Mechanism of MTT process

From above experiments and analysis, it is considered that the structure of the LTM plays a very important effect on the solidification structure of the samples treated with MTT process. In order to illustrate the mechanism of the effect of the LTM, the schedule model is shown in Fig. 6 and Fig. 7. If the primary phase of the LTM is tree-like dendrite, the dendrite size will become smaller owing to the effect of the heat and impact of HTM, but the morphology

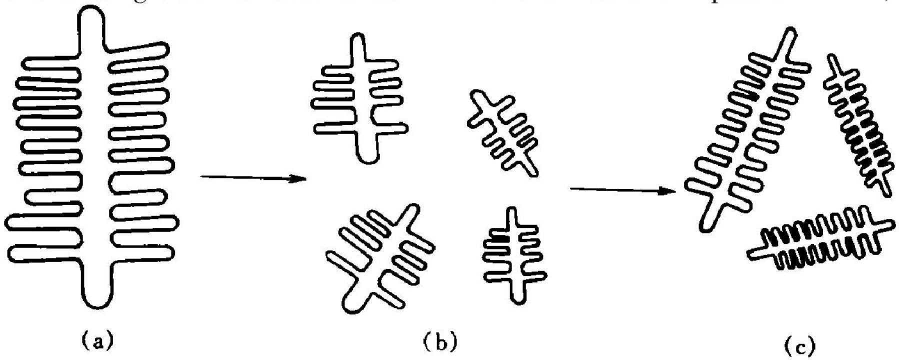

Fig. 6 Schematic of solidification structure treated with MTT without stirring LTM
(a) —Structure of LTM; (b) —Structure of mixing melt; (c) —Structure of solidification

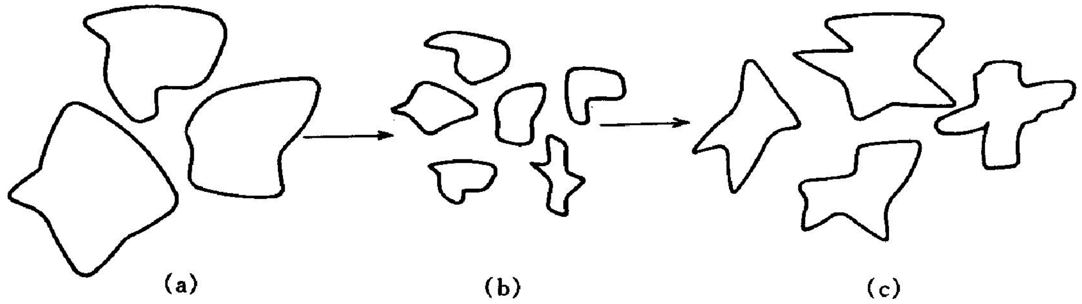

Fig. 7 Schematic of solidification structure treated with MTT with stirring LTM
(a) —Structure of LTM; (b) —Structure of mixing melt; (c) —Structure of solidification

of the primary phase does not change. So tree-like dendrite will appear in the final solidification structure, but the grain size of it will decrease obviously. Otherwise, if the primary phase in the LTM is non-dendrite, the non-dendrite grain will also become smaller as well as the grain number increasing because of the effect of the heat and impact of HTM. And then, the solidification structure will be non-dendrite with small size. The main influence of the HTM is to supply instant thermal energy to LTM for nuclei multiplication.

4 CONCLUSIONS

1) Coarse tree-like dendrite will appear in the primary phase of the LTM without stirring, and the solidification structure also presents tree-like dendrite when the LTM and the HTM are mixed. The size of the primary phase increases with decreasing LTM temperature.

2) Round, rosette-like equiaxial dendrite will appear in the primary phase of the LTM with stirring, and non-dendritic will also appear in the solidification structure when the LTM and HTM are mixed. And the lower the temperature of the LTM, the more obvious the effect of the LTM on the solidification structure is.

3) The evolution of the solidification structure is different if the different temperature LTMs is mixed with HTM. The solidifying procedure will start from the undercooling solid phases when the LTM temperature is lower than the liquidus of the alloy. And this procedure will start from the undercooling clusters when it is higher than that temperature.

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