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Porosity of aluminum alloy in lost foam casting process ①

WU Guo-hua(吴国华)[1], LUO Ji-rong(罗吉荣)[1], XIE Min(谢 敏)[2]
(1. Foundry Research Institute, Huazhong University of Science and Technology, Wuhan 430074, P.R.China;
2. Department of Foreign Languages, Hefei University of Technology, Hefei 230069, P.R.China)

[Abstract] The effects of modification, grain refinement, polystyrene pattern, pouring temperature and reduced pressure degree on aluminum alloy porosity in lost foam casting (LFC) process were studied. The results show that the solidification rate of LFC process is slower than that of resin sand process or clay sand process. The effect of modification and grain refinement on the aluminum alloy casting density in LFC is greater than that on resin sand process. Through α-Al phase refinement process with 0.2 %Ti for aluminum melt, the subversive effect of Sr modification in LFC process is decreased greatly, and the aluminum casting density in LFC process is nearly equal to that in resin sand process. To decrease the porosity of aluminum castings in LFC process, lower density of polystyrene pattern, higher pouring temperature (760 ~ 780 ℃) and lower reduced pressure degree (≤20 kPa) should be applied.

[Key words] aluminum alloy; lost foam casting process; porosity; modification
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1 INTRODUCTION

The lost foam casting (LFC) process is called as the 21st century technology. Its forming is different from that of the conventional empty-cavity casting method[1,2]. For aluminum alloy in LFC process, pouring temperature of aluminum melt is much higher than that of the empty-cavity casting process in order to remove the products of polystyrene pattern thermal degradation from the mold cavity and to ensure high mold filling ability[3,4]. High pouring temperature in combination with other characteristics of LFC process result in serious pinhole phenomenon and worse tightness in the castings. It is urgent to decrease the amount of pinholes and improve the tightness of LFC castings.

At present, systematic investigation of pinhole formation for Al alloy castings in dry sand LFC is lack. In this article, the effects of modification of aluminum alloy melt, polystyrene pattern and reduced pressure degree at higher pouring temperature (760 ~ 780 ℃) on the casting pinhole were investigated to improve the quality of aluminum castings. The characteristics of pinhole formation of aluminum alloy in LFC process were discussed in detail.

2 EXPERIMENTAL

The experimental material was aluminum-silicon alloy containing 9.5 %Si, 0.45 %Fe, 0.22 %Mg, and 0.5 %Mn (mass fraction). The modifiers were Al-10 %Sr and Al-5Ti-1B master alloys. In each experiment, the aluminum melt was degassed with argon prior to pouring.

The polystyrene strip patterns (210 mm × 45 mm × 20 mm) and gating systems for experiments were cut from a polystyrene sheet with a density of 20 kg/m^3 using a hot wire cutter, and assembled with commercial hot melt glue. The coating was applied by dipping the pattern into a self-developed refractory slurry adjusted to a density of 1.35×10^3 kg/m^3. The thickness of coating was 0.2 ~ 0.3 mm. The patterns were then dried in a temperature-controlled drying oven at 55 ~ 60 ℃ for 24 h. The dried pattern clusters were placed horizontally in a 40 cm × 40 cm × 50 cm steel flash and compacted with an unbinded, three-screen AFS 55 silica sand , using 3-dimensional vibrating table. Then aluminum melt was poured into the casting mould. The pouring temperature was 780 ℃. The NiCr-NiSi thermocouples were located at the sample center to monitor and record the cooling rate of the metal by a data collecting system.

To investigate the effect of polystyrene pattern on the aluminum casting density, some iron wire frames with the size of 210 mm × 45 mm × 20 mm were made by fine wire netting. Some iron wire frames were filled with polystyrene pattern and the others were unfilled. The wire netting was coated by the self-developed LFC coating. The thickness of coating layer is about 1 mm. After dried, they were placed into sand box for molding. Then the liquid aluminum was poured into the box under the same casting conditions. Density measurement and microscopic analysis were conducted to analyze the extent

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of porosity in the castings.

3 RESULTS AND DISCUSSION

3.1 Solidification characteristic of aluminum castings in LFC

The cooling curves of samples in LFC, resin sand and clay sand processes are shown in Fig.1. The formation of pinhole partially depends on the casting cooling rate[5,6]. The slower the solidification rate of the casting, the wider the solidification zone. Thus the microshrinkage pore between dendrites is favorable for the precipitation of gas in liquid metal. When the solidification rate increases, the volume fraction and size of pore decrease. Because of the smaller coefficient of heat accumulation of sand in LFC process, the solidification rate of LFC process is slower than that of resin sand and clay sand processes, and the castings tend to solidify in a mushy state. Hence, porosity is more prone to form in castings.

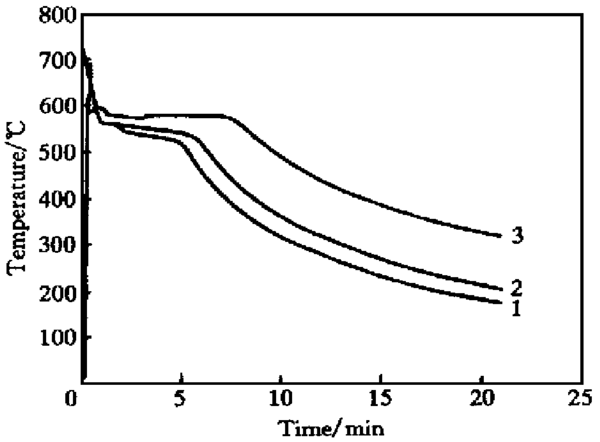

Fig.1 Cooling curves of castings
1 —Clay sand process; 2 —Resin sand process; 3 —LFC process

3.2 Modification of aluminum melt

Al-9.5%Si hypoeutectic casting alloy tends to form the coarse acicular eutectic silicon phase, which leads to feeding difficulties in the interdendritic region and increases quantity of porosity[7], especially for LFC process because of higher pouring temperature and slower solidfication rate. Through Sr modification, the silicon phase can be fined. For empty-cavity casting process, Sr modification is conducted below 750 ℃. For LFC process, Sr modification is conducted at 780 ℃.

The effects of Sr modification on the aluminum casting densities in both LFC and resin sand processes are shown in Fig.2. It can be seen that the castings densities decrease with increasing of Sr content in the both processes and the density of casting in LFC is lower than that in resin sand process, which is due to higher content of pores in LFC process. It also can be seen from Fig.2 that the effect of Sr modification

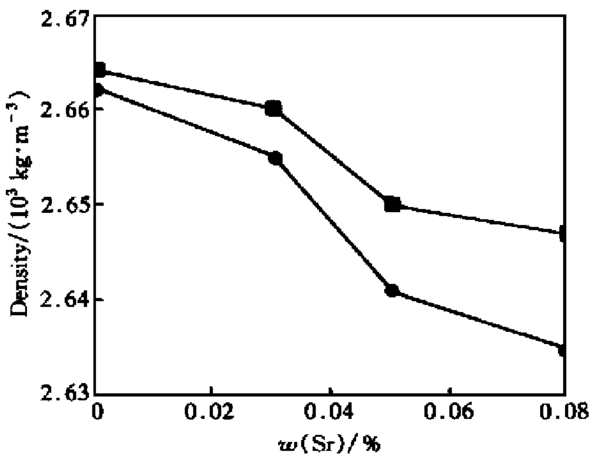

Fig.2 Effect of Sr-modification on aluminum casting density
● —LFC process; ■ —Resin sand process

in LFC process is more serious than that in resin sand process. Compared with that of unmodified alloy, the densities of 0.03%Sr and 0.05%Sr modified Al-castings are reduced by 0.263% and 0.789% in LFC and only by 0.150% and 0.525% in resin sand mold, respectively. This may be due to lower surface tension of Sr modified Al melt, which are prone to the formation of pinhole in castings[8]. The precipitated gas under slow solidification rate could diffuse over long distance and into the pores. Furthermore, the polystyrene thermal degradation products entrapped in the melt would enhance the formation of pinhole.

For Al casting in LFC process, Al-Ti-B alloy is added as a modifier to increase the density by α-Al phase grain refinement. The changes of aluminum casting densities with Ti content in Al-5Ti-1B master alloy treated Al-casting are shown in Fig.3. It can be seen that the density of 0.2%Ti treated Al-casting is increased by 0.15% in LFC and only by 0.075% in resin mold in comparison with that of untreated cast-

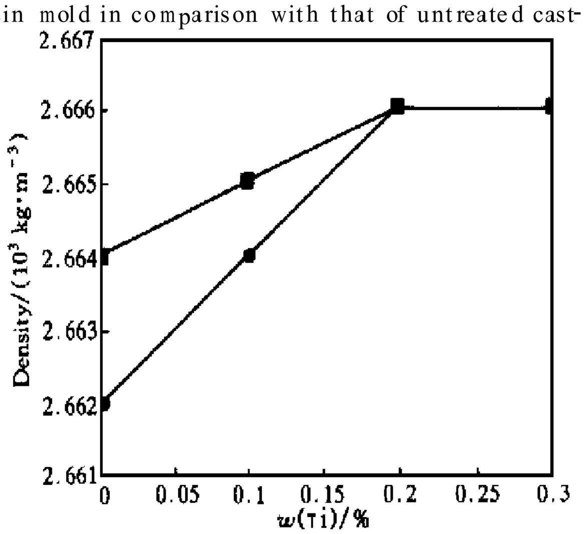

Fig.3 Effects of Ti-modification on aluminum casting densities
● —LFC process; ■ —Resin sand process

ings. Namely, the effect of α-Al phase grain refinement is relatively higher in LFC than that in resin sand mold and the densities of 0.2 % Ti treated Al-casting are nearly equal in both LFC and resin sand mold. This is because the active nuclei provided by Al-Ti-B master alloys promote preferential heterogeneous nucleation at low undercooling which results in refinement of α-Al grain. This promotes feeding and results in a less porosity. In addition, grain refinement hinders nucleation of the gas bubble[9,10]. The subversive effect of slower solidification rate on the pinhole in LFC is decreased greatly by addition of Al-5Ti-1B modifier.

The microstructures of 0.2 %Ti treated and untreated aluminum casting in LFC are shown in Fig.4, in which 0.03 %Sr is used as modifier. It can be seen that better modification effect can be attained with 0.03 %Sr. And α-Al phase can be well refined with 0.2 % Ti. The castings densities treated by 0.2 % Ti and 0.0 % ~ 0.8 %Sr modifiers in two kinds of processes are shown in Fig.5. The densities of aluminum castings treated by the combination of 0.2 % Ti and 0.03 % Sr in LFC and in resin sand processes are nearly equal. It is concluded that, for aluminum LFC process, the casting pinholes can be decreased effectively by addition of Al-5Ti-1B modifier even at higher pouring temperature and slower solidification rate.

3.3 Polystyrene pattern

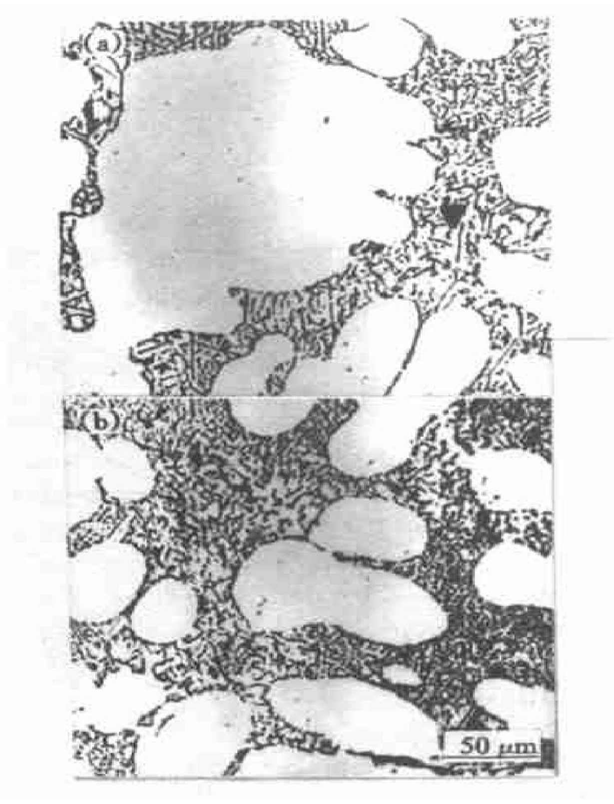

Fig.4 Structures of LFC aluminum castings (0.03 %Sr)
(a) —0 %Ti; (b) —0.2 %Ti

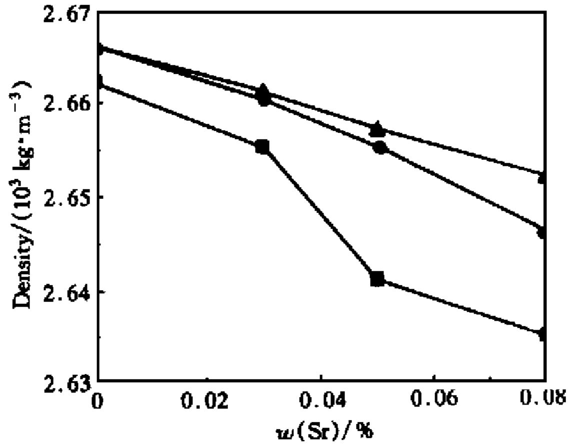

Fig.5 Effects of Sr and Ti modification on aluminum casting densities
● —LFC process (0.2 %Ti); ■ —LFC process (0 %Ti);
▲ —Resin sand process (0.2 %Ti)

The effects of polostyrene patterns on casting densities are shown in Fig.6. It is obvious that existence of polystyrene increases the casting porosity. And the higher the polystyrene pattern density, the more serious the casting pinhole exhibits. Hence, the lower density polystyrene pattern should be applied preferentially to decrease the pinholes of aluminum castings in LFC.

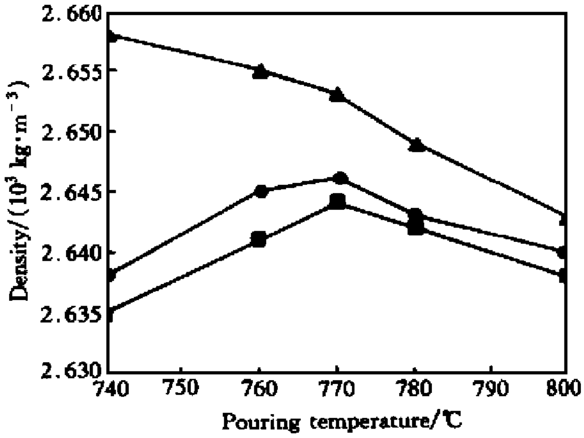

Fig.6 Effect of polystyrene pattern on aluminum casting densities
● —Polystyrene pattern (20 kg/m³);
■ —Polystyrene pattern (28 kg/m³);
▲ —No polystyrene pattern

It also can be seen from Fig.6 that in order to decrease the porosity of casting, higher pouring temperature in LFC process should be used in comparison with the conventional empty casting. The pinhole photographs are shown in Fig.7 and Fig.8. In LFC process, the majority thermal degradation products of the polystyrene pattern are in liquid state[11]. The transporting process of the liquid polystyrene into and through the coating can be divided into the wetting and wicking stages. High pouring temperatures enhance the wetting and wicking of the coating[12,13].

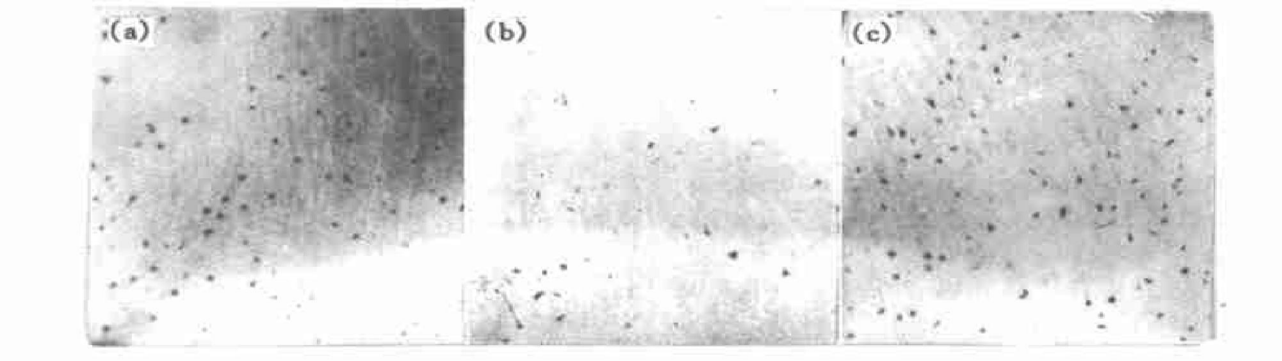

Fig.7 Effect of pouring temperature on aluminum casting porosity in LFC
(a) —740 ℃; (b) —770 ℃; (c) —800 ℃

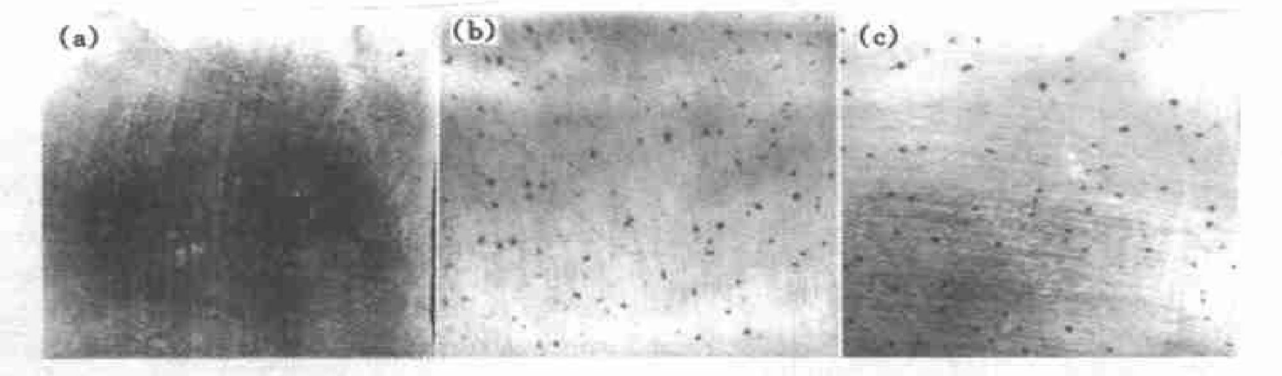

Fig.8 Effect of pouring temperature on aluminum casting porosity in resin sand process
(a) —740 ℃; (b) —770 ℃; (c) —800 ℃

High pouring temperatures also encourage higher percentage of gaseous foam decomposition products, so less liquid polymer is available to be trapped. If the pouring temperature is low, it is detrimental to transporting of liquid polystyrene into and through coating wafer. Before the end of solidification, there would be some liquid polystyrene entrapped at the metal front. During the mold filling process, the liquid polystyrene cannot reach the interface between the coating and the molten metal. This entrapped liquid polystyrene eventually decomposes and forms pores. But the extremely high pouring temperature increases gas content in melts and casting porosity. Here, relative higher pouring temperature (760 ~ 780 ℃) is beneficial to removal of polystyrene decomposition products and prevent from entering in the casting.

3.4 Reduced pressure degree

The mold filling ability of aluminum melt can be improved greatly by applying reduced pressure[14,15]. The effects of reduced pressure degree on aluminum casting densities are shown in Fig.9. There is a peak value in Fig.9. On the one hand, lower reduced pressure is helpful for polystyrene thermal degradation products to be removed through coating, turbulence can not be formed easily in the aluminum melt during mold filling and the polystyrene decomposition products can not be trapped in the melt. Therefore, lower reduced pressure degree is helpful to decrease the casting pinhole and increase its density. On the other

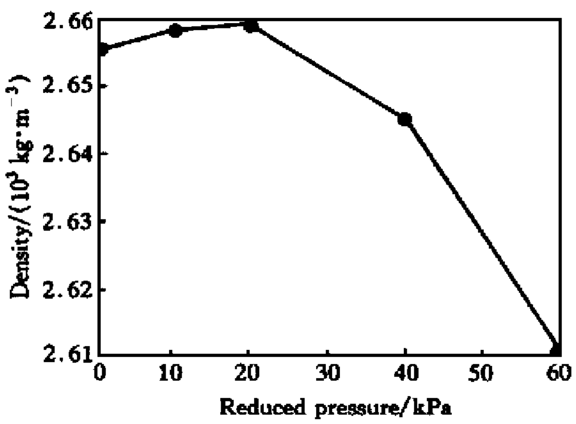

Fig.9 Effect of reduced pressure on aluminum casting densities (0.03 %Sr)

hand, when higher reduced pressure is applied, the polystyrene decomposition product can be easily entrapped in aluminum melt by the melt turbulence produced during mold filling and enhance the casting porosity and decrease its density. Thus, the suitable reduced pressure is less than 20 kPa.

4 CONCLUSIONS

1) The solidification rate in LFC process is slower than that in both resin sand and clay sand processes. Hence, the castings are more prone to form pinholes.

2) The casting densities decrease with addition

of Sr in both LFC and resin sand processes. And the subversive effect of Sr modification on aluminum casting density in LFC process is more serious than that in resin sand process. The unique grain refinement with an Al-Ti-B master alloy for LFC aluminum melt weakens the subversive effect of lower solidification rate on the casting pinhole greatly. The densities of casting refined by 0.2% Ti in LFC and resin sand processes are equal.

3) Polystyrene enhances the casting porosity and decreases its density. To decrease the porosity of LFC castings, the lower density polystyrene pattern and suitably higher pouring temperature (760 ~ 780 ℃) should be applied.

4) Lower reduced pressure (< 20 kPa) during mold filling is helpful to decrease the porosity of the casting.

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