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A Comparison Study between Suspension Casting Process and Low Superheat Casting Process

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Abstract: Taking GCr15 bearing steel as experiment material, the effects of suspension casting process and low superheat casting process on the solidification of ingot were studied comparatively. The results show that both suspension casting process and low superheat casting process can improve the central segregation and crystal structure of ingot. As the acting mechanism is different between the two kinds of processes, it is found that suspension casting process is more effective than low superheat casting process in improving the quality of ingot.

Key words: suspension casting process; low superheat casting process; solidification

Low superheat casting process is an ordinary means to improve the quality of cast ingot, especially in continuous casting billet, but the application is sometimes restricted by some problems such as short running and even freezing in ladle *etc.*. Suspension casting process can also decrease the superheat of molten steel by adding some small solid metal particles into liquid metal during pouring [1], and can overcome the shortcomings of low superheat casting process. Taking GCr15 bearing steel as experiment material whose chemical composition (mass fraction in %) is: C, 0.95 ~ 1.05; Si, 0.15 ~ 0.35; Mn, 0.20 ~ 0.40; Cr, 1.30 ~ 1.65; Ni, ≤0.30; Cu, ≤0.25; Ni+Cu, ≤0.50; S, ≤0.020; P, ≤0.027. The effects of suspension casting process and low superheat casting process on the solidification of ingot were studied comparatively in this paper.

1 Experiment Methods

GCr15 bearing steel was taken as experiment material and remelted in a medium-frequency induction furnace. A metal mold with the inner and outer size of ϕ70 mm × 400 mm and ϕ160 mm × 400 mm respectively was employed to cast and closed with a cope (suspension pouring system) and a drag made of water-glass sand (as shown in **figure 1**). The solid particles with the composition of medium carbon alloy and the size of ϕ0.5 mm × 0.5 mm were added into the cavity of the mold during pouring. Three pieces of thermal-couples were inserted into the cavity to measure the temperature of the fringe, half distance from edge to center, and the center of ingot continuously during cooling. The cooling curves and temperature profiles were made according to the measurement results of thermal couples. In order to study the different effects produced by the two processes, two types of pouring condition were designed: (1) pouring at 1510 ℃ and adding no solid particles; (2) pouring at 1550 ℃ and adding 2% solid particles.

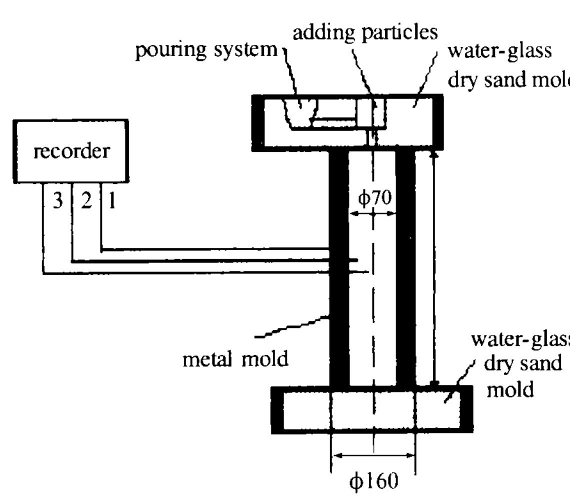


Figure 1 Scheme of mold closed

2 Results and Discussion

2.1 Effects of different casting processes on solidification rate

Solidification rate is an important parameter during solidification process that affects the size and morphology of crystal and the segregation of elements directly. The solidification rate is:

$$R = V / G \tag{1}$$

where V is the cooling rate, ℃ / s; R the solidification rate, m/s; and G the temperature gradient, ℃/m.

Figure 2 shows that although the cooling rate of suspension casting process is slower than that of low superheat casting process, the temperature gradient of ingot is much plain, especially in the central region of ingot. From equation (1), the solidification rate of suspension casting process is higher than that of low superheat casting process. The experiment results indicate that suspension casting process raises the solidification rate of ingot especially in the central region, while low superheat process increases the cooling rate, especially in the marginal region.

2.2 Mechanisms for fining the structure of crystal

The reason of fining the structure for low superheat casting process is that low superheat casting not only raises the cooling rate of ingot during solidification, but also enhances undercooling. The undercooling(ΔT, ℃) measured in the central region of ingot is: suspension casting, ΔT= 5 ℃; low superheat casting, ΔT= 25 ℃.

When metal solidifies at the temperature lower than liquidus, the solidification driving force is [2]:

$$\Delta G_{\mathrm{m}} = \frac{\Delta H_{\mathrm{m}} \Delta T}{T_{\mathrm{m}}} \tag{2}$$

where ΔG is the solidification driving force, ΔH_{m} the latent heat of crystallization, ΔT the undercooling, and T_{m} the liquidus.

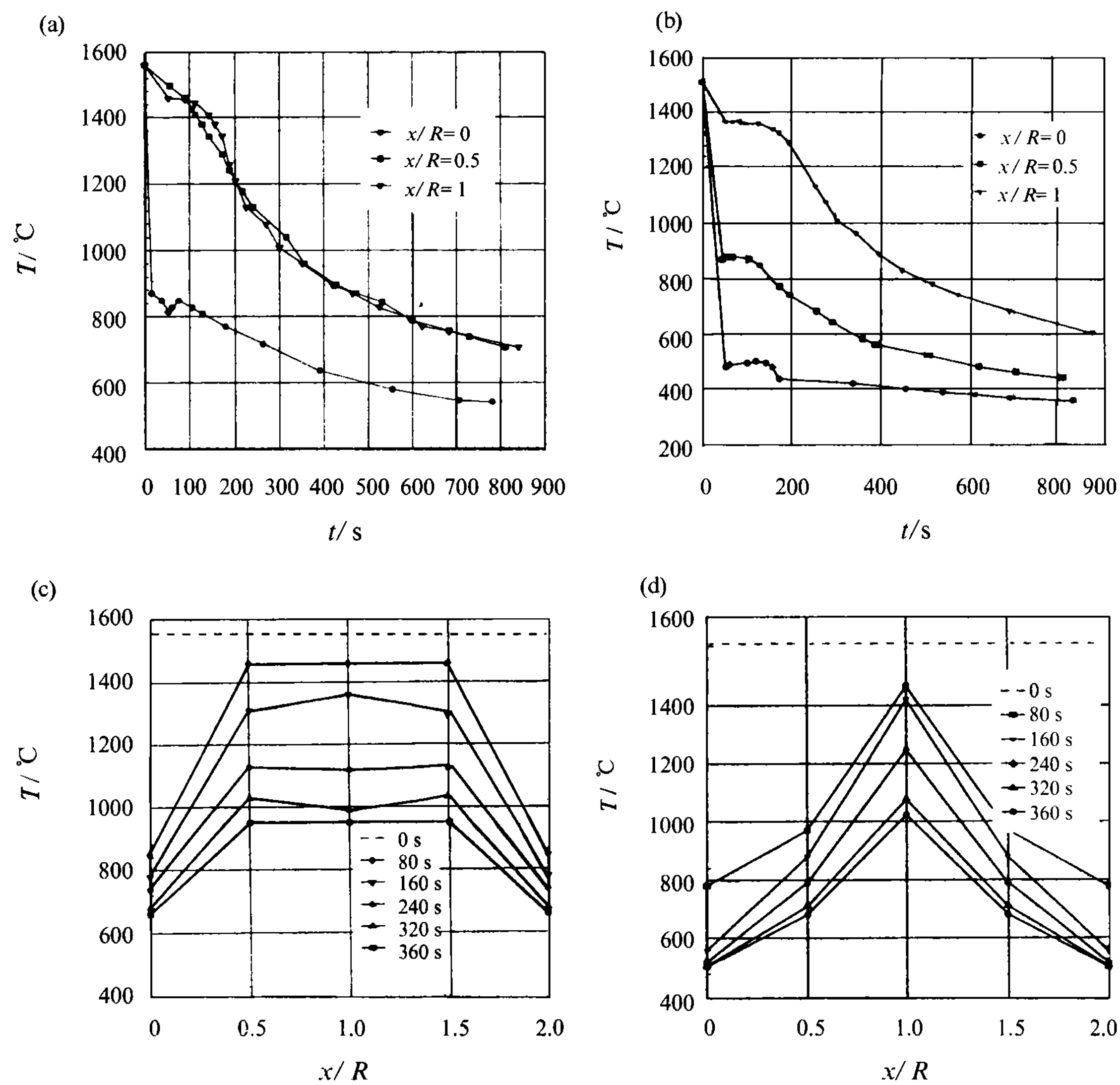


Figure 2 Cooling curves and temperature profiles drawn from the measure results of thermal couples
***x*—the distance to the boundary of ingot; *R*—radius of ingot**
(a) cooling curves in suspension casting process; (b) cooling curves in low superheat casting process; (c) temperature profiles in suspension casting process; (d) temperature profiles in low superheat casting process.

Equation (2) shows that solidification driving force increases with the increasing of undercooling. If solidification driving force increases, the nucleation frequency will rise and the cast structure will be fined. The results are shown in **figure 3**. On the other hand,

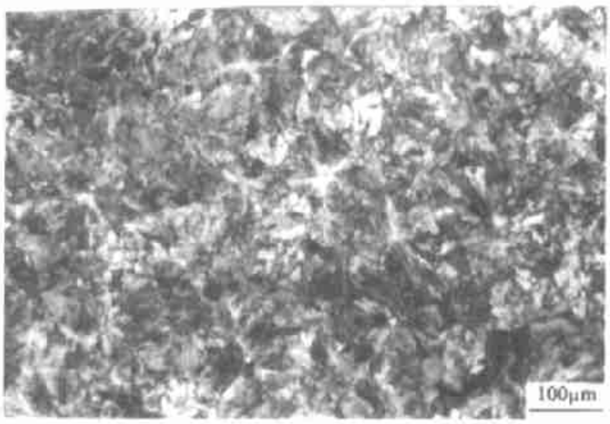


Figure 3 Strusture of ingot in suspension casting process

the nucleation conditions depend on if the follow equation is satisfied:

$$\Delta T \geq \Delta T^* \quad (3)$$

where ΔT is the real undercooling in molten steel, and ΔT^* the critical undercooling in molten steel.

Although suspension casting process produces lower undercooling (ΔT) than low superheat cast process, the critical undercooling (ΔT^*) is decreased greatly due to a large amount of unmelted particles in molten steel which act as exotic nucleus. As a result, the crystal-size of ingot in suspension casting process is smaller than that in low superheat casting process (as shown in **figure 4**).

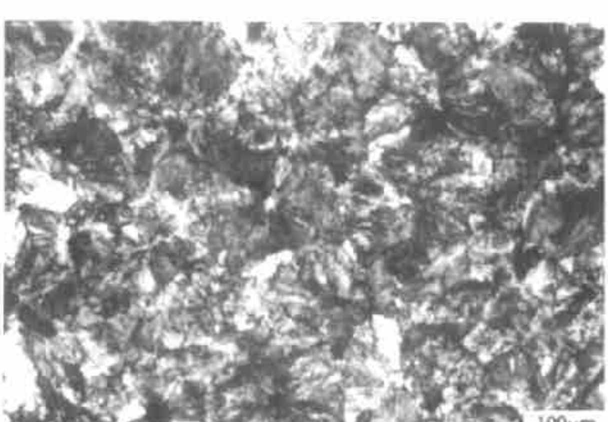


Figure 4 Structure of ingot in low superheat casting process

2.3 Results of macrosegregation of C, S, P

The central segregation of carbon element is serious in high carbon steel such as GCr15 bearing steel. Supposing that there is no diffusion in solid phase and there is convection in liquid, the segregation of elements in interdendrite is given as follows:

$$\overline{C_s} = k_0 C_0 \frac{q}{k_0 - 1 + q} \quad (4)$$

$$q = (1 - \beta)(1 - v / R) \quad (5)$$

where $\overline{C_0}$ is the original concentration in liquid, $\overline{C_s}$ the solute mean concentration in local area, k_0 the equilibrium partition coefficient, β the alloy solidification shrinkage, v the flow velocity of liquid, and R the sodification rate.

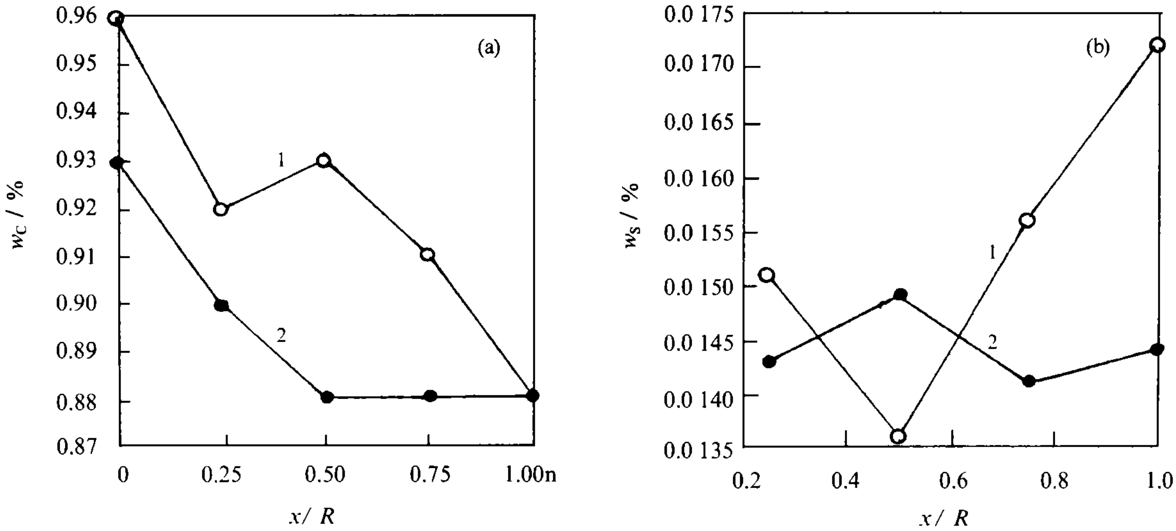
We can see from the above equations that q is a key factor which affects the macrosegregation. As f_s<1, to the alloys k_0< 1, solute segregation will become serious with the increasing of flow velocity and the decreasing of solidification rate. Because suspension casting process raises the solidification rate in the central region of ingot, the elements distribution is much even in that region. Low superheat casting process can improve the macrosegregation due to low flow velocity in molten steel because of its low pouring temperature that decreases the viscosity of molten steel. On the other hand, the small crystal sizes can also improve the segregation of elements. The carbon distribution in **figure 5**(a) is got from chemical analysis. We can see that carbon distribution is much even in suspension casting process than that in low superheat process. Figure 5(b) and (c) shows that suspension casting process can improve S, P distributions more effectively than low superheat process.

3 Conclusions

(1) Both suspension casting process and low superheat casting process can improve the structure and macrosegregation of ingot.

(2) The mechanism of improving the structure and segregation of ingot is different between these two kinds of processes. Suspension casting process enhances the quality by increasing the solidification rate, improving the temperature profile and adding exotic nucleus, while low superheat casting process by raising the cooling rate and undercooling.

(3) Because suspension casting process can overcome the shortcomings of low superheat casting process such as short running and even freezing in ladle and the effects of improving the central segregation and fining structure is better than that of low superheat casting process, suspension casting process has a bright future in controlling the solidification process and improving the quality of ingot or billet.



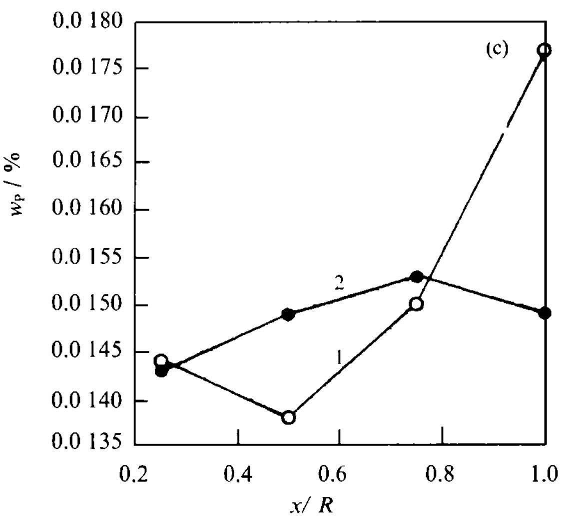


Figure 5 Elements distribution (w_i, i= C, S, P, mass fraction) in two different casting process

1—low superheat casting process
2—suspension casting process
x—the distance to the boundary of ingot
R—radius of ingot

(a) C; (b) S; (c) P.

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