

# Effects of the Critical Solidification Rate on the Cooling Process of the Fused Zirconia-Corundum-Silica Material

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**Abstract**—In order to optimize the process of the fused zirconia-corundum-silica (AZS) material, by the Any-casting software, the cooling process of AZS was simulated to explore effects of the critical solidification rate of cast on solidification sequence, coagulation time, probability of shrinkage cavity and cooling rate. The result showed: When the critical solidification rate was less than 40%, the system got a bottom-up solidification sequence to guarantee the good riser feeding effect. With the increase of the critical solidification rate, the coagulation time decreased to improve the production yield and lower the cost of fused AZS material. The difference of coagulation time that obtained by the coagulation time at the bottom center of riser subtracting that at the center of cast got the maximum value when the critical solidification rate was 20%-30%, which ensured the good feeding effect of riser. When the critical solidification rate was 20%-70%, the microscopic shrinkage cavity appeared neither at the center of riser nor at the center of cast. Considering cooling rate at the bottom center of riser, the critical solidification rate preferred less than 30% to reduce the shrinkage defects. The optimized critical solidification rate should be 20%- 30%.

**Keywords**-fused AZS material; coagulation time; solidification sequence; defects probability; critical solidification rate

## I. INTRODUCTION

The fused zirconia-corundum-silica material (AZS) was a kind of refractory material made from corundum, zircon, zirconia and other small amounts of raw materials such as soda, that were mixed in mixer, melted in electric furnace, cooled in the model, and machined to be a suitable formation. It was mainly used as glass kiln lining because of its good characteristics of high temperature corrosion [1-4]. However, its production yield was low. The cost was high. It was easy to produce defects. The Numerical Simulation of

Solidification Process could help to improve the produce [5-10]. According to Any-cast simulation software, effects of the critical solidification rate on the coagulation time and defects probability could be analyzed to determine the best simulation condition, which would be helpful to optimize the production process and improve the properties of the material.

## II. SIMULATION CONDITION

### A. Basic Condition

The simulation parameters set in Any-casting software were shown in Table 1.

TABLE I. RELATED MATERIAL PARAMETERS

| Properties   | AZS cast     | Sand mould  |
|--|--------------|-------------|
| Density<br>( $\text{kg}\cdot\text{m}^{-3}$ )                               | 3000         | 1520-1482*  |
| Specific heat<br>( $\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$ )       | 3            | 676-1260*   |
| Thermal conductivity<br>( $\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ ) | 5.978-8.391* | 0.737-1.05* |
| Liquidus temperature<br>( $^{\circ}\text{C}$ )                             | 1790         | 1720        |
| Solidus temperature<br>( $^{\circ}\text{C}$ )                              | 1420         | 1500        |
| Dynamic viscosit<br>( $\text{kg}\cdot\text{m}^{-1}\cdot\text{s}^{-1}$ )    | 200          | -           |
| Surface tension<br>( $\text{N/m}$ )  | 0.2          | -           |
| Latent heat<br>( $\text{J}\cdot\text{kg}^{-1}$ )                           | 3476         | -           |
| Note: * The parameters varied the temperature                              |              |             |

In Any-cast simulation software, the AZS material was set as the cast system, and silica sand material was set as mould. The main parameters of these two kinds of material were shown in Table I. During the simulation process, set the system initial temperature 25 °C, mould thickness 50 mm. The casting system was evenly divided into 500000 grids. The cast temperature of AZS melt was 1900 °C. The filling melt radius was 70 mm, and the filling time was 10 s. It was assumed that the slurry temperature and composition were uniform.

In this simulation, the cast size was 600 mm × 400 mm × 300 mm (length × width × height), volume  $7.2 \times 10^7 \text{ mm}^3$ . The riser located at surface center of 600 mm × 400 mm. The riser size was: the bottom surface 150 mm × 150 mm, the top surface 450 mm × 450 mm and height 250 mm.

### B. Variable Settings

In the Simulation, the critical solidification rate was set as a variable parameter (shown in Table II).

TABLE II. CRITICAL SOLIDIFICATION RATE USED IN SIMULATION

| Simulation number | Critical solidification rate |
|-------------------|------------------------------|
| 1                 | 10%                          |
| 2                 | 20%                          |
| 3                 | 30%                          |
| 4                 | 40%                          |
| 5                 | 50%                          |
| 6                 | 60%                          |
| 7                 | 70%                          |
| 8                 | 80%                          |
| 9                 | 90%                          |

## III. SIMULATION RESULTS AND ANALYSIS

### A. Solidification Sequence

According to the solidification sequence distribution on the central cross section of the cast system, different critical solidification rate resulted into different solidification sequence (Fig. 1).

When the critical solidification rate was less than 40%, the system had a bottom-up solidification sequence. Riser coagulated after the cast to provide a full feeding function. In this case, there were much melt in the riser filling into the cast to help the riser to improve the feeding effect. So the center of cast was not easy to produce shrinkage cavity defects.

When the critical solidification rate was greater than 40%, the bottom center of riser would solidify before the center of cast. The riser could not play a well role of feeding. The center of cast could not produce a compact structure. There would be shrinkage cavity at the center of cast. Moreover, the bigger the critical solidification rate was, the greater the shrinkage probability at center of cast would be.

Therefore, the critical solidification rate should be less than 40% to guarantee the good riser feeding effect.

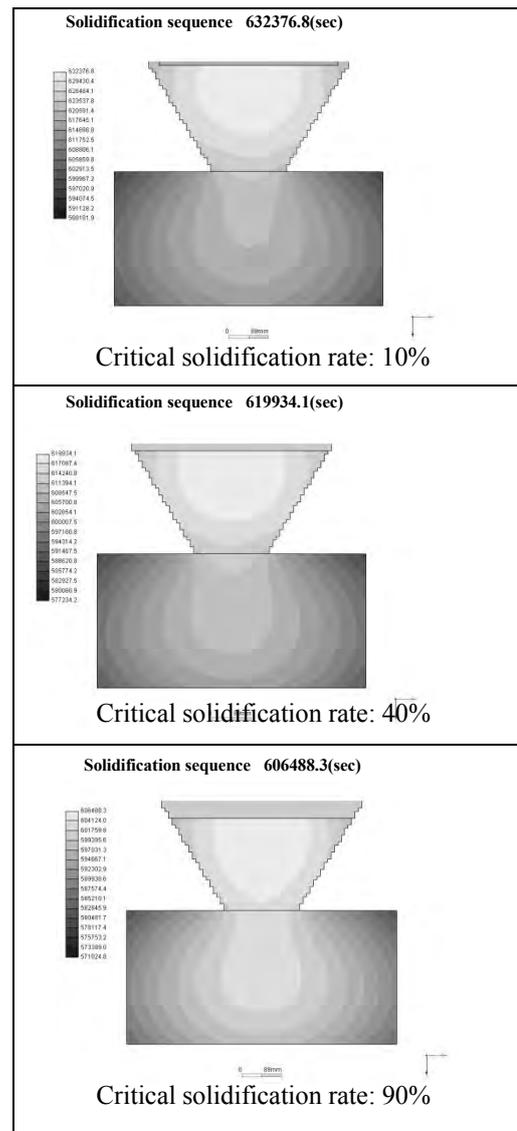


Figure .1 Effects of the critical solidification rate on solidification sequence

### B. Coagulation Time

As shown in Fig .2, with the increase of the critical solidification rate, the coagulation time both at the bottom center of riser and the center of cast decreased.

When the critical solidification rate was less than 30%, the coagulation time both at the bottom center of riser and the center of cast decreased slowly. When the critical solidification rate was 30%-50%, the coagulation time both at the bottom center of riser and the center of cast fast decreased. If the critical solidification rate was more than 50%, these two coagulation times slowly decreased again.

If the coagulation time was short, the production yield was high; the cost of production was low. So the preferable coagulation time should not be long.

The difference of coagulation time obtained by the coagulation time at the bottom center of riser subtracting the coagulation time at the center of cast was shown in

Fig .3. It got the maximum value when the critical solidification rate was 20%-30%. The bigger the difference of coagulation time was, the earlier the solidification at the bottom center of riser was.

So the critical solidification rate should be 20%-30% to guarantee the short coagulation time, the big difference coagulation time and the good feeding effect of riser.

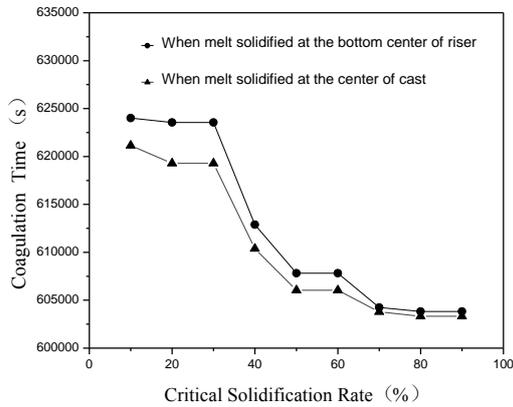


Figure .2 Effects of critical solidification rate on coagulation time

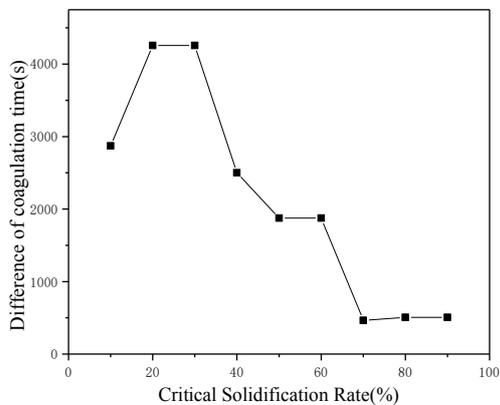


Figure .3 Effects of critical solidification rate on the difference of coagulation time

### C. Probability of Shrinkage Cavity

According to the probability distribution of the residual melt module, it could be predicted that the microscopic shrinkage cavity would emerge in the area of shallow color. The size of this area predicted the scope of the shrinkage cavity.

As shown in Fig .4, the size of microscopic shrinkage cavity decreased with the increasing critical solidification rate. When the critical solidification rate was 10%, there would be the thin circular microscopic shrinkage cavity appeared at the center of cast. When the critical solidification rate was 20%-70%, the microscopic shrinkage cavity appeared neither at the center of riser nor at the center of cast. When the critical solidification rate was more than 80%, the microscopic shrinkage cavity appeared at the center of cast. So the optimized critical solidification rate should be 20%-70% to ensure the minimum probability and the smallest area of the shrinkage cavity.

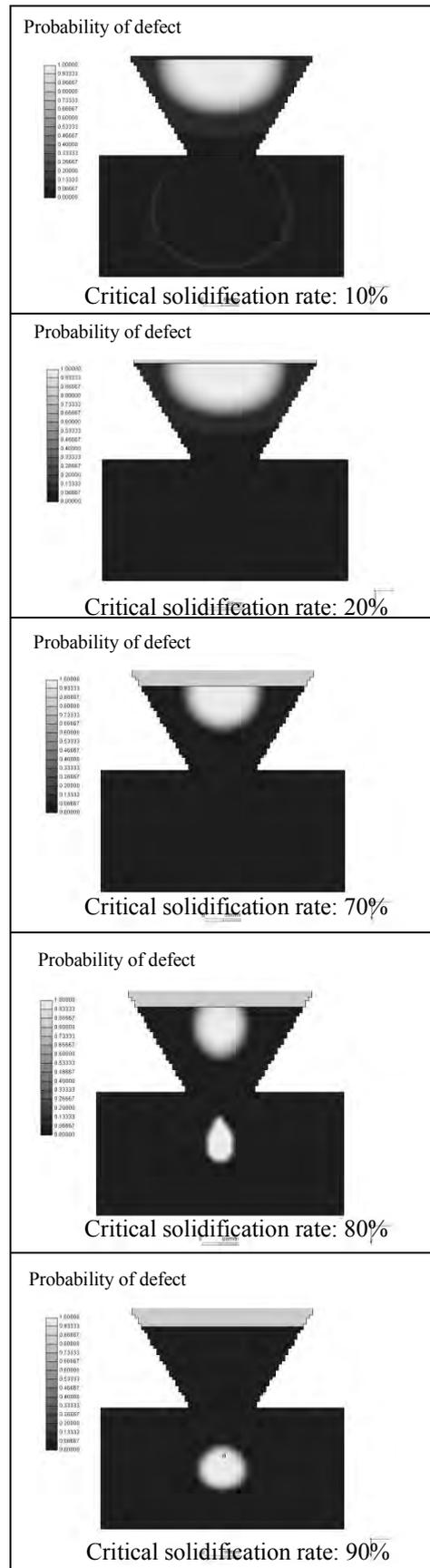


Figure .4 Effects of the critical solidification rate on probability distribution of the residual melt module

#### D. Cooling rate

As shown in Fig .5, with the increase of the critical solidification rate, the cooling rate at the bottom center of cast increased.

When the critical solidification rate was from 10% to 30%, the cooling rate slowly increased. So the cooling rate at the bottom center of riser was small, the shrinkage defects were not easy to produce.

When the critical solidification rate was 30%-50%, the cooling rate fast increased to enlarge the defect probability at the bottom center of riser.

When the critical solidification rate was more than 50%, the cooling rate slowly increased again. So the cooling rate at the bottom center of riser was large, the shrinkage defects were easy to produce.

So, considering the cooling rate to be small to reduce the shrinkage defects, the cooling rate should choose no more than 30% in this simulation.

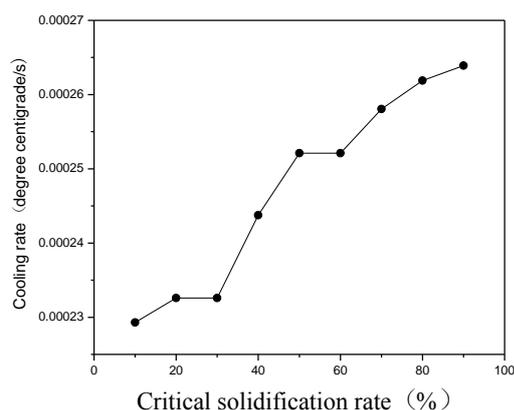


Figure .5 Effect of critical solidification rate on the cooling rate

#### IV. CONCLUSION

- 1) When the critical solidification rate was less than 40%, the cooling system got a bottom-up solidification sequence to guarantee the good riser feeding effect. When the critical solidification rate was greater than 40%, the bottom center of riser would solidify before the center of cast.
- 2) With the increase of the critical solidification rate, the coagulation time both at the bottom center of riser and the center of cast decreased to improve the production yield and lower the cost of fused AZS material.
- 3) The difference of coagulation time that obtained by the coagulation time at the bottom center of riser

subtracting the coagulation time at the center of cast got the maximum value when the critical solidification rate was 20%-30%, which ensured the good feeding effect of riser.

- 4) When the critical solidification rate was 20%-70%, the microscopic shrinkage cavity appeared neither at the center of riser nor at the center of cast.
- 5) Considering the cooling rate at the bottom center of riser, the critical solidification rate preferred less than 30% to reduce the shrinkage defects at the bottom center of riser.
- 6) The optimized critical solidification rate should be 20% to 30%.

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