Effects of the Mould Specific Heat on the Cooling Process of the Fused Zirconia-Alumina-Silica Material

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Abstract-In order to optimize the production process of the fused zirconia-alumina-silica material(AZS), the simulation was conducted by using the Anycasting software to study effects of the mould specific heat of SiO2 material on the system solidification time, solidification fraction, temperature gradient and solidification sequence. The results showed that: when the specific heat was more than 676 J•kg-1•k-1, the decrease of solidification time tended to be slow. When the melt at the bottom center of riser cooled down to the solidus temperature, the system solidification fraction reached 96% when the mold specific heat was less than 1352 J•kg-1•k-1. The temperature gradient increased along with the augment of SiO2 sand mold specific heat. Considering the temperature gradient at the bottom center of riser, the specific heat should be 13.52 J•kg-1•k-1-1352 J•kg-1•k-1. The riser feeding effect was the best when the specific heat was 1352 J•kg-1•k-1. The optimized mold specific heat was 1352J•kg-1•k-1.

Keywords-AZS material；Specific heat；Solidification time；Solidification fraction；Solidification sequence

I. INTRODUCTION

The fused zirconia-alumina-silica material (AZS) is a kind of essential refractory used in glass furnace. Its quality plays an important role in improving the quality of glass and prolonging the lifetime of glass furnace. At present its cost is high, and the production is easy to produce defect such as shrinkage porosity. In order to ensure the quality of the zirconium corundum products, reduce its cost and improve the lifetime of glass furnace, the most economical method is the computer simulation to optimize the production process, such as choosing the optimized casting system parameters to improve the yield of the product. In this paper, we study the effect of the specific heat of SiO_2 sand mold on the casting system parameters, such as solidification time, solidification fraction, temperature gradient, solidification sequence of the system, which obtained at the bottom center of riser at the solidus temperature. This can figure out the influence of specific heat of mould material on solidification process. It can also help us to select the optimized mould material.

II. BASIC SIMULATION CONDITION

A. Simulation System

In the simulation, AZS material was set as the casting system. SiO_2 material was set as the mold material. Major parameters of these two kinds of materials were listed in Table 1.

TABLE I. RELATED PARAMETERS OF AZS AND SiO₂ MATERIALS

Items	AZS	SiO₂
Volume density (kg m⁻³)	3701	1520
Thermal conductivity(W m⁻¹ k⁻¹)	8.391	0.733
Liquidus temperature(℃)	1790	1720
Solidus temperature(℃)	1420	1500
Latent heat(k J⁻¹ kg⁻¹)	3625.3	-

During the simulation, the initial temperature of the casting system was 25℃. The casting system was uniformly divided into 500000 mesh. The pouring gate radius was 70mm and the filling time was 60s. The size of the casting system was listed in Table 2. The riser located at the surface center of 600 mm×400 mm of the cast.

416

TABLE II. SIZE OF THE CASTING SYSTEM

Items		Data
Riser size （mm）	Upper surface	φ400
	Bottom surface	φ240
	Height	300
Riser volume	（mm³）	7.84×106
AZS cast （mm）	Length	600
	Width	400
	Height	300
Cast volume	（mm³）	7.2×107
Mold thickness （mm）		50

B. *Variable*

TABLE III. MATERIAL SPECIFIC HEAT AT ROOM TEMPERATURE USED IN SIMULATION

Simulation number	Specific heat (J·kg^{-1}k $^{-1}$)
1	13.52
2	67.6
3	135.2
4	338
5	676
6	1352
7	3380
8	6760
9	33800

In different simulation, different specific heat of SiO_2 sand mold was used to analyze the solidification time, solidification fraction, temperature gradient and other parameters of the casting system. As the material specific heat varied with the temperature, here used the variable specific heat in the simulation process. The typical value of material specific heat at room temperature were listed in Table 3.

III. RESULTS AND ANALYSIS

A. *Solidification Time*

As seen from Fig .1, the solidification time at the bottom center of riser changed with the specify heat of SiO_2 sand mold. When the specify heat was between 13.52 J·kg^{-1}k $^{-1}$ and 676 J·kg^{-1}k $^{-1}$, the solidification time rapidly decreased with the increasing of the specific heat.

When the specific heat was more than 676 J·kg^{-1}k $^{-1}$, the change of solidification time tended to be slow.

The shorter the solidification time was, the higher the production yield was. This could also reduce the production cost at a certain degree. So considering the solidification time of the cooling system, the specific heat of SiO_2 sand mold should be more than 676 J·kg^{-1}·k^{-1}.
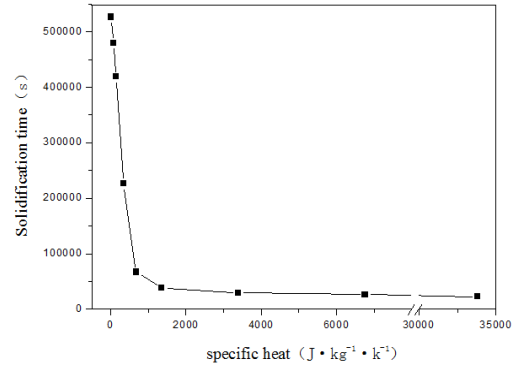

Figure 1. Effects of the mold specific heat on the solidification time of the cooling system

B. *Solidification Fraction*

If the melt at the bottom center of riser cooled down to the solidus temperature, the solidification fraction of the cooling system varied with the increase of SiO_2 sand mold specific heat (shown in Fig .2).
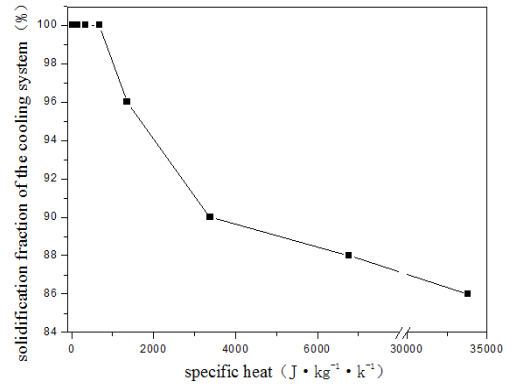

Figure 2. Effects of the mould specific heat on solidification fraction of the cooling system

When the mold specific heat was less than 676 J·kg^{-1}k $^{-1}$, the system solidification fraction reached 100%. This showed that the riser solidified after the cast and the riser played an perfect role of feeding. When the mold specific heat increased from 676 J·kg^{-1}k $^{-1}$ to 1352 J·kg^{-1}k $^{-1}$, the solidification fraction of the cooling system decreased to 96%, for 4% only. When the specific heat was more than 1352 J·kg^{-1}k $^{-1}$, the solidification fraction reduced below 90%.

With the growth of the solidification fraction, the casting solidification region increased. When the melt at bottom center of riser got to the solidus temperature, the greater the solidification fraction of the cooling system was, the better the riser feeding effect was. When the solidification fraction reduced below 90%, the cast was easy to produce shrinkage defect. Therefore, considering

the solidification fraction, the mould specific heat valued preferably between 13.52 J·kg⁻¹k⁻¹ -1352 J·kg⁻¹k⁻¹.

C. Temperature Gradient

As shown in Fig. 3, the temperature gradient at the bottom center of riser increased along with the augment of the specific heat of SiO₂ sand mold. If the specific heat was less than 338 J·kg⁻¹k⁻¹, the temperature gradient changed slightly. If the specific heat was in 338 J·kg⁻¹k⁻¹-3380 J·kg⁻¹k⁻¹, the temperature gradient increased fast with the augment of specific. When the specific heat was more than 3380 J·kg⁻¹k⁻¹, the temperature gradient increased slowly.

The temperature gradient was one of the important parameters affecting the performance of the cast body. It showed the maximum temperature change of the casting system in a certain direction. When the temperature gradient was large than this maximum value, the melt cooled too rapidly to produce compact structure. The cast might even produce shrinkage crack caused by the overlarge temperature gradient.

So when the specific heat was in 13.52 J·kg⁻¹k⁻¹-1352 J·kg⁻¹k⁻¹, the temperature gradient could be used as an effective data.
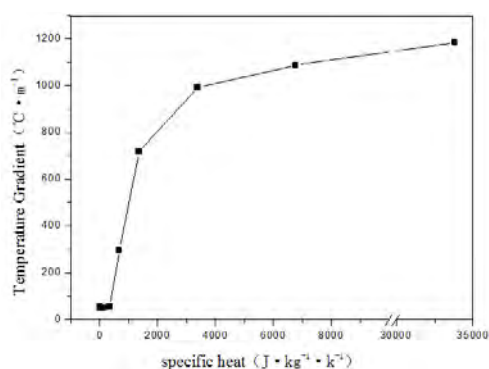

Figure 3.Effects of the mold specific heat on temperature gradient

D. Solidification Sequence

As shown in Fig .4, the solidification sequence of the casting system was bottom-up when the specific heat of SiO₂ sand mold was less than 33800 J·kg⁻¹k⁻¹. But the feeding effect of riser had slightly different.

Also seen from Fig .4, if the sand mold specific heat was less than 1352 J·kg⁻¹k⁻¹, the smaller the specific heat was, the larger area of the solidification sequence around the bottom center of riser. This would caused the unsatisfied feeding effect of the cast.

135.2 J·kg⁻¹k⁻¹
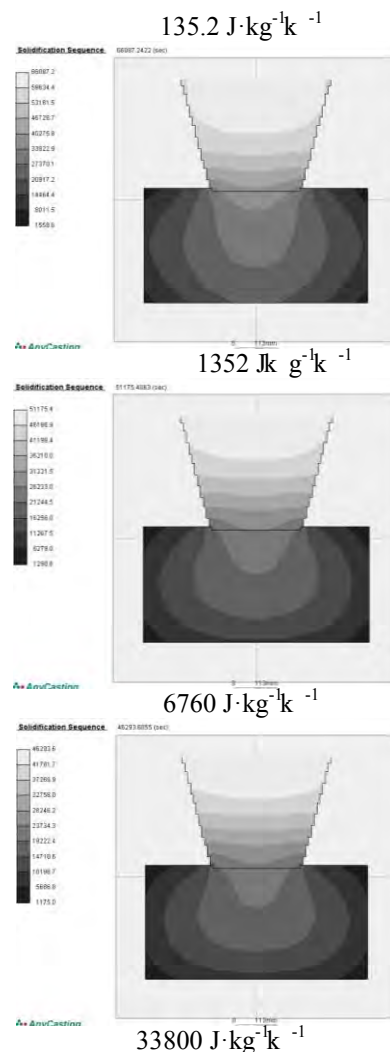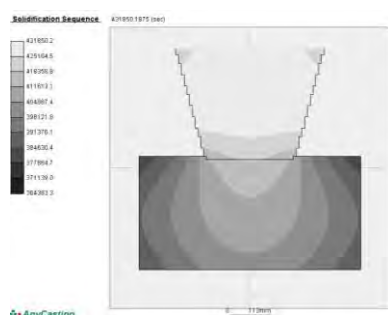
1352 Jk g⁻¹k⁻¹

6760 J·kg⁻¹k⁻¹

33800 J·kg⁻¹k⁻¹

Figure 4.   Effects of the mould specific heat on solidification sequence of the casting system

When the specific heat of SiO₂ sand mold was more than 1352 J·kg⁻¹k⁻¹, the bottom center of riser solidified early, and the solidification sequence was in advance slightly. The riser began to solidify before the cast solidified completely. The riser could not feed the cast as possible as it could. The cast would produce the shrinkage cavity at the bottom center of riser. Therefore, the best values of the sand mold specific heat was 1352 J·kg⁻¹k⁻¹.

IV.   CONCLUSIONS

(1) The solidification time at the bottom center of riser decreased with the increase of the sand mold specific heat. When specific heat was less than 676 J·kg⁻¹k⁻¹, the solidification   time decreased rapidly. When the specific heat   was   more   than   676   J·kg⁻¹k⁻¹, the decrease of solidification time tended to be slow. Considering   the solidification time of the   cooling system, the specific heat of SiO₂ sand mold should be more than 676 J·kg⁻¹k⁻¹.

(2) When the melt at the bottom center of riser cooled down   to   the   solidus   temperature,   the   system solidification fraction reached 96% when the mold

specific heat was less than 1352 $J \cdot kg^{-1}k^{-1}$. This would be helpful for producing the compact structure of the cast.

(3) The temperature gradient increased along with the augment of SiO_2 sand mold specific heat. Considering the temperature gradient at the bottom center of riser, the specific heat should be 13.52 $J \cdot kg^{-1}k^{-1}$-1352 $J \cdot kg^{-1}k^{-1}$.

(4) The solidification sequence of the casting system was bottom-up when the sand mold specific heat was less than 33800 $J kg^{-1} k^{-1}$. The riser feeding effect was the best when the specific heat was 1352 $J kg^{-1} k^{-1}$.

(5) The optimized mold specific heat was 1352 $J \cdot kg^{-1}k^{-1}$.

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