# Effects of Latent Heat on Cooling Process of the Fused AZS Material

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**Abstract—In order to optimize the production process of the fused Zirconia-Alumina-Silica (AZS) material, the cooling process of fused AZS material was analyzed and the influences of latent heat on solidification sequence, solidification time, temperature gradient and residual melt modulus of cast system were discussed by using AnyCasting software. The results showed that: When latent heat is less than 20000 J/kg, the casting system solidifies perfectly from bottom to top. With the increase of latent heat, the shrinkage defects will be more likely to appear at the center of cast. The maximum temperature gradient and the residual melt modulus of the casting system decreases with the increase of the latent heat, while the solidification time of casting system is prolonged when the latent heat increases. The preferable latent heat of AZS material is 20000 J/kg to optimize the casting system and the production process to improve the cast density and control the defects.**

***Keywords-fused AZS material; latent heat; solidification sequence; solidification time; residual melt modulus***

## I. INTRODUCTION

The fused zirconia-alumina-silica (AZS) material is a kind of high-grade refractory indispensable in glass furnace, but the production cost is still high currently. In order to improve the yield, reduce the costs and improve the properties it is necessary to optimize production processes or casting system by the finite element simulation method. In this paper, effects of latent heat on solidification sequence, solidification time, temperature gradient and residual melt modulus were studied in simulation to help us to optimize the casting system and the production process to improve the cast density and control the defects.

## II. BASIC SIMULATION CONDITIONS

The casting system of AZS material with Silica sand mold was simulated. The main parameters of these two kinds of materials were shown in Table 1.

TABLE1. RELATED PARAMETERS

| Items | AZS | $SiO_2$ |
|---|---|---|
| Volume Density($kg \cdot m^{-3}$) | 3701 | Variable |
| Thermal Conductivity($W \cdot m^{-1} \cdot k^{-1}$) | Variable | Variable |
| Specific Heat($J \cdot kg^{-1} \cdot k^{-1}$) | Variable | Variable |
| Liquidus Temperature(℃) | 1790 | 1720 |
| Solidus Temperature(℃) | 1420 | 1500 |

In the simulation by Any-casting software, set the initial temperature 25℃, the feed temperature 1900℃, pouring gate radius 70 mm, and the filling time 10s. The cast system was evenly divided into grids of 500,000. It was assumed that the melt temperature and composition of the fused AZS material was uniform. The sizes of casting system were shown in Table 2. The riser located at the center of cast surface 600 mm×400 mm. In order to obtain the necessary data, sensors were set at the bottom center of riser and at the center of cast.

TABLE2. SIZES OF THE CASTING SYSTEM

| Items | | Date |
|---|---|---|
| Riser | The lower | 450mm×450mm |
| | The upper | 150mm×150mm |
| | Height | 50mm |
| | Volume | $2.44\times10^7mm^3$ |
| Brick | Size | 600mm×400mm×300m |
| | Volume | $7.2\times10^7mm^3$ |
| Mold Thickness | | 50mm |

TABLE3. SETTINGS OF LATENT HEAT

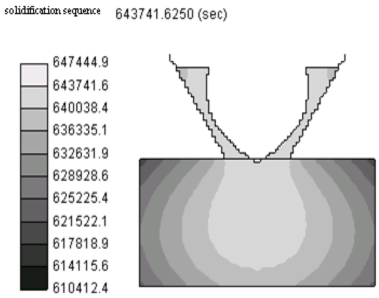
| No. | Latent Heat (J/kg) | No. | Latent Heat (J/kg) | No. | Latent Heat (J/kg) |
|---|---|---|---|---|---|
| 1 | 1500 | 6 | 6000 | 11 | 20000 |
| 2 | 2000 | 7 | 8000 | 12 | 23000 |
| 3 | 2500 | 8 | 10000 | 13 | 26000 |
| 4 | 3476 | 9 | 14000 | 14 | 32125 |
| 5 | 5000 | 10 | 17000 | 15 | 34760 |

As shown in Table 3, different values of the latent heat of AZS material were used in different simulations to study the influence of the AZS material parameters on solidification parameters of cast system, such as solidification sequence, solidification time, temperature gradient and residual melt modulus.

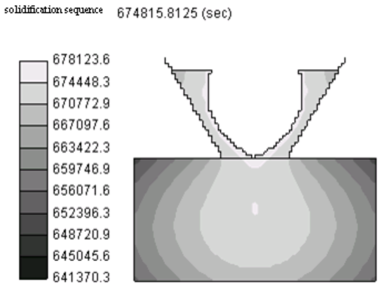
## III. RESULTS AND DISCUSSES

### *A. Solidification Sequence*

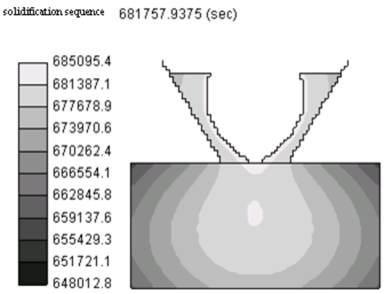
Seen from Fig .1, when the melt at the bottom center of riser solidified, the solidification time of the casting system increased from 643741 sec to 682129 sec with the increase of the latent heat. When latent heat is less than 20000 J/kg, the casting system solidifies perfectly from bottom to top. There is no shrinkage cavity at the center of cast. When latent heat is 32125 J/kg, the casting system solidifies roughly bottom-up. But there is a small shrinkage cavity at the center of cast. When the latent heat increases to 34760 J/kg, the solidification sequence is similar to that of 32125 J/kg. But the shrinkage cavity at the center of cast is bigger than that of 32125 J/kg.



Latent heat 20000 J/kg



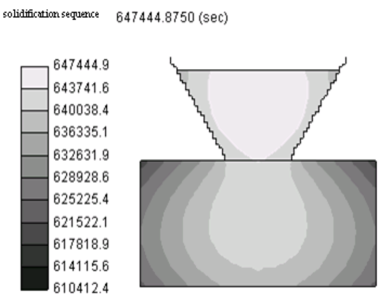
Latent heat 32125 J/kg



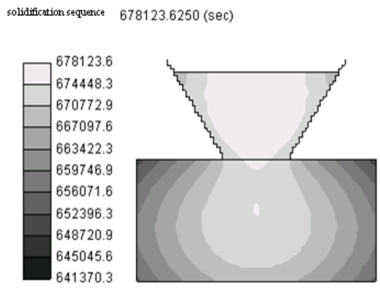
Latent heat 34760 J/kg

Figure 1. Solidification sequence of the casting system when the bottom center of riser solidified

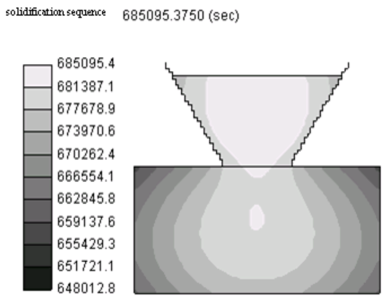
Seen from Fig .2, when the melt at the center of cast solidified, the solidification time of the casting system increased from 647445sec to 685095 sec with the increase of the latent heat. The solidification sequence of the cast at different latent heat is the same correspondingly explained above.



Latent heat 20000 J/kg




Latent heat 32125 J/kg




Latent heat 34760 J/kg

Figure 2. Solidification sequence of the casting system when the center of cast solidified

Comparing Fig .1 with Fig .2, we can get the solidification time of the riser. When the latent heat is 20000 J/kg, 32125 J/kg or 34760 J/kg respectively, the corresponding solidification time of the riser is 3704 sec, 2940 sec or 2966 sec. So the solidification time percentage of the cast is 99.428%, 99.566%, or 99.567% correspondingly in the simulation process. The larger the solidification time percentage of the cast is, the more easily the shrinkage cavity produces at the center of cast.

So, considering the solidification sequence of the casting system, the latent heat of AZS material should be selected less than 20000 J/kg.

## *B. Temperature Gradient*

According to Fig .3, when the bottom center of riser solidifies, the maximum temperature gradient of the casting system lineally decreases with the latent heat of AZS material, from 0.061 to 0.037℃/cm. But when the center of cast solidifies, the maximum temperature gradient of the casting system lineally decreases with the latent heat of AZS material, from 0.015 to 0.012℃/cm. Particularly, when the latent heat of AZS material increases from 20000 J/kg to 26000 J/kg, the maximum temperature gradient of the casting system will be modest value from 0.014 ℃/cm to 0.013 ℃/cm.

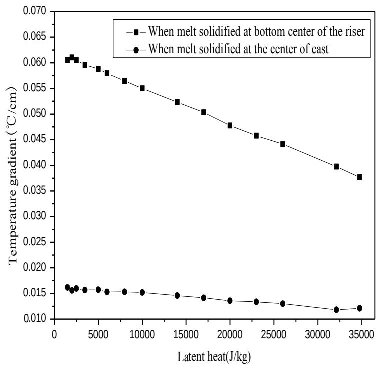



Figure 3. Effects of the latent heat on the temperature gradient

Where the temperature gradient is big, the expansion capability of feeding channel will be strong, and the feeding effect will be good. However, given a big temperature gradient, the thermal stress and the interaction between molecules in cast will also be great, so shrinkage defects will be more likely to appear. As a result, a smaller value of temperature gradient at the bottom center of riser and a bigger value of temperature gradient at the body should be preferable. In this situation, the feeding effect of riser will be advisable. There will be less shrinkage cavity appeared at the center of cast.

So, taking the temperature gradient into consideration, the latent heat should be selected between 20000 J/kg and 26000 J/kg.

## *C. Solidification Time*

As shown in Fig .4, when the latent heat of AZS material increases from 1500 J/kg to 34760 J/kg, the overall solidification time of casting system is prolonged form 604392 sec to 685095 sec. This will lead to the prolonging production process and increase the cost of the cast. Particularly, it increases fast when the latent heat increases from 26000 J/kg to 32125 J/kg. Therefore, taking the solidification time into consideration, latent heat should be selected less than 26000 J/kg.

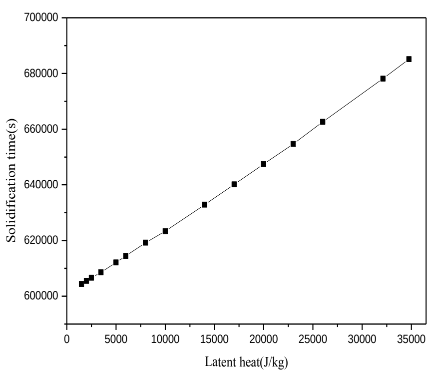



Figure 4. Effects of the latent heat on solidification time

### D. Residual Melt Modulus

As shown in Fig .5, the residue melt modulus at the bottom center of the riser decreases with the increase of latent heat of AZS material. That is to say, the probability of casting defects is reduced there. When the latent heat is less than 15000 J/kg, the residual melt modulus slowly decreases. When the latent heat is 15000 J/kg - 20000 J/kg, the residual melt modulus decreases fast. If the latent heat is 20000 J/kg - 32125 J/kg, the residual melt modulus decreases slowly. Therefore, according to the influence of latent heat on the residual melt modulus, the value of latent heat should be more than 20000 J/kg and the cooling process of cast will get a good result.

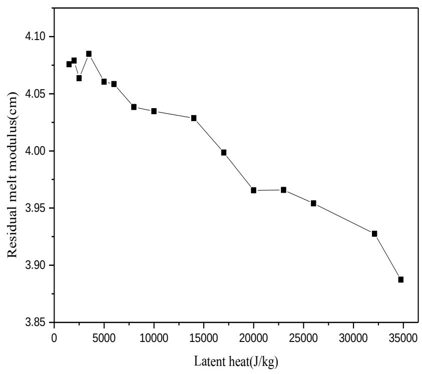



Figure 5. Effects of the latent heat on the residual melt modulus

## IV. CONCLUSIONS

A. When latent heat is less than 20000 J/kg, the casting system solidifies perfectly from bottom to top. With the increase of latent heat, the shrinkage defects will be more likely to appear at the center of cast.

B. The maximum temperature gradient of the casting system lineally decreases with the latent heat. Taking the temperature gradient into consideration, the latent heat should be selected between 20000 J/kg and 26000 J/kg.

C. When the latent heat increases, the solidification time of casting system is prolonged, so the preferable the latent heat should be less than 26000 J/kg.

D. In order to reduce the residual melt modulus to reduce the probability of shrinkage defects at the center of cast, the advisable latent heat should be more than 20000 J/kg.

E. The optimized latent heat of AZS material is20000 J/kg.

## ACKNOWLEDGMENT

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