Study on the Thermal Expansion Performance of Gypsum in the Application of Precision Casting

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Abstract. Gypsum is a very important cementitious material in gypsum-based precision casting. The thermal expansion characteristics of gypsum have great influence on the adjustment of gypsum type precision casting powder formula. In this paper, the thermal expansion properties of different gypsums such as β-gypsum, natural gypsum-based α-gypsum, desulfurization gypsum-based α-gypsum, and the influence of temperature, heating rate/heating mode on the thermal expansion properties of α-gypsum are studied, which can provide references for the application of gypsum in the precision casting.

1. Introduction
Gypsum-type casting originated from 3,000 to 3,500 years ago. China began to use gypsum in the precision casting technology more than 1,500 years ago. In the 1960s, the United States and Japan developed gypsum-type precision casting, which made the gypsum-type casting a leap-forward development [1-4]. Compared with the precision casting methods such as sand type, ceramic type and thin shell type, the gypsum type precision casting process has the following advantages: simple process, short production cycle, high precision of casting, good surface quality, low cost, and simple equipment used [5-6]. The basic process of precision casting is shown in Figure 1.

At present, gypsum-type casting is the first choice for jewellery and glaze at home and abroad. Gypsum-type precision casting powder is mainly consisted of gypsum powder (usually α-type high strength gypsum powder) mixed with admixtures and other fillers having high-temperature expansion characteristics. Gypsum is an important cementitious material in precision casting. And it has a large shrinkage at high temperature, and the selection and addition ratio of the other fillers need to match the shrinkage performance of gypsum. That is to say, the thermal expansion characteristics of gypsum determine the selection and addition ratio of other fillers. In this paper, the thermal expansion properties of different gypsums such as β-gypsum, natural gypsum-based α-gypsum, desulfurization gypsum-based α-gypsum are determined. And the influence of temperature, heating rate/heating mode on the thermal expansion properties of α-gypsum is also studied.
2. Experimental

2.1 Materials

The main physical properties of several gypsum powders are shown in Table 1.

| Type of Gypsum                        | Setting time (min) | Water requirement of normal consistency (%) | Flexural strength for 2h (MPa) | Absolute compressive strength (MPa) |
|---------------------------------------|--------------------|---------------------------------------------|------------------------------|------------------------------------|
| Desulfurization gypsum-based α-gypsum | 9～12               | 35                                          | 6.6                          | 52.6                               |
| Natural gypsum-based α-gypsum          | 5～13               | 39                                          | 6.8                          | 50.8                               |
| β-gypsum                              | 7～16               | 70                                          | 2.75                         | 18.1                               |

2.2 Instruments and determination methods

The thermal expansion properties of the samples were measured using ultra high temperature horizontal dilatometer (PCY-II). The thermal expansion sample was prepared by using the standard consistency water consumption. The sample size was about: Φ20×50 mm. The slurry samples made of gypsum powders were naturally dried at room temperature for 24 h, and then placed in an oven at the temperature of 40 °C to dry to constant weight. Take out and measure the thermal expansion properties.

The heating mode adopted is commonly used in the factories in order to reflect the volume change of gypsum casting powder more accurately. The heating mode curve is shown in Figure 2.
3. Result and discussion

3.1 Deviation analysis of thermal expansion dilatometer

The thermal expansion curves of the corundum rod (calibration sample) and the gypsum powder sample (Z02) under the same heating mode are showed in Figure 3 and Figure 4, respectively. It can be seen from Figure 3 that the two thermal expansion curves of the corundum rod have little difference. As the temperature increases, the expansion rate of the calibration sample increases slowly, and the expansion curves of the two are almost overlapped, and the maximum error is about 0.02%. It can be seen from Figure 4 that the gypsum powders (Z02-1, Z02-2) has the same heating rate and the same heating mode. There is a certain deviation between the two curves. The deviation range is 0.05%-0.15%, which is larger than that of the two curves in Figure 3. Compared with the corundum rod (calibration sample), the gypsum powder (Z02) needs to be prepared by mixing water and then casting. Due to the difference in density of materials, the settling of material is different. It will affect the uniformity of the molded...
sample and has a certain impact on the test accuracy. Therefore, the deviation of the thermal dilatometer should be based on the deviation exhibited by the corundum rod sample test curve.

3.2 Thermal expansion of different gypsoms

The thermal expansion curves of natural gypsum based α-hemihydrate gypsum and desulfurization gypsum based α-gypsum hardened body are shown in Figure 5. The amounts of water demand are all 0.35. And the heating mode adopted is showed in Figure 2. It can be seen from the figures that during the hydration reaction, the growth of the crystals cause the gypsum to expand, and the volume expands when it is dried until 150 °C. At this time, the linear expansion ratio is 0.00264%. The maximum linear expansion rate is up to 0.025% at around 80 °C. From 150 °C to 200 °C, with the increase of temperature, gypsums will gradually lose crystal water, and a negative linear expansion rate will occur. From about 200 °C to 600 °C, the gypsum line expansion rate drops sharply, and the gypsum samples show a significant shrinkage. The linear expansion coefficient of gypsum from 600 °C to 800 °C tends to be stable, indicating that the shrinkage characteristics of gypsum in this temperature range are relatively stable, and all of the crystal water has been lost at this stage. The thermal expansion curve of natural-based α-gypsum is relatively close to that of FGD-based α-gypsum. The shrinkage rate of FGD-based α-gypsum is slightly lower than that of natural-based α-gypsum between 200 °C and 700 °C, but the shrinkage rate of FGD-based α-gypsum increases rapidly from 700 °C to 740 °C. The shrinkage ratio of the two gypsum samples is about the same as -2.8%.

The natural β-gypsum thermal expansion sample has a water addition of 0.8, and the thermal expansion curve is slightly different from that of α-hemihydrate gypsum (Figure 6). The shrinkage of β gypsum is significantly increased at the temperature of 150°C and 400-450°C respectively. And the dimensional change rate is higher than that of α-gypsum. The total shrinkage of β gypsum at 740 °C is higher than the shrinkage of α-gypsum, and the size of β gypsum sample still continues to change during the process of constant temperature, indicating that the strength of β gypsum sample is reducing significantly. When it heats to above 700 °C, the β-gypsum does not have sufficient strength to withstand the pressure of the instrument thimble, which consequently results in a significant rapid shrinkage of β gypsum. This also indicates that the high temperature resistance of α-gypsum is better than that of β gypsum and the precision casting gypsum requires the use of α-high strength gypsum as cementitious material.

3.3 Effect of the heating rate on the expansion property of α-gypsum
The heating rates are set to: 1 °C / min; 2 °C / min; 3 °C / min; 4 °C / min to 900 °C. When the heating rate is 1 °C / min and 2 °C / min, the dimensional change curves are similar (Figure 7 to Figure 8). The α-gypsum sample shows a slow shrinkage below 700 °C, and the expansion ratio is about -0.25% at 710 °C. When the temperature is raised at around 710 °C, the α-gypsum sample shrinks sharply. When the heating rate is 3 °C / min (Figure 9), the inflection point around 710 °C is more gradually slow than the heating rate of 1 °C / min and 2 °C / min. When the temperature is raised to 900 °C, the final dimensional shrinkage of α-gypsum sample is substantially the same at about -6.5%, and the expansion ratio is increased by about 100% compared to the sample using the heating curve I. The cooled gypsum sample undergoes significant softening and bending, which is a cause of a significant increase in shrinkage. When the heating rate is set to 4 °C / min (Figure 10), the sample does not show softening and bending. The thermal expansion curve of the sample is close to that of the sample with heating curve I, and the expansion ratio is about -3%. It can be seen that in the application of gypsum-type precision casting gypsum, the slower the heating rate is, the better result it would not probably get. For example, when the heating rate is too low, and the heating time is too long, they will cause the model to soften and the strength to decrease. Therefore, the appropriate heating rate should be selected to formulate an appropriate heating curve.
| Demand | Condition 1 | Condition 2 | Condition 3 | Condition 4 |
|--------|-------------|-------------|-------------|-------------|
| Heating rate (°C/min) | 1 | 2 | 3 | 4 |
| Original length (mm) | 55.04 | 54.79 | 53.80 | 50.08 |
| Final length (mm) | 48.38 | 47.92 | 47.11 | 45.43 |
| Shrinkage (%) | 12.10 | 12.50 | 12.44 | 10.57 |

4. Conclusions
The thermal expansion curves of natural $\alpha$-hemihydrate gypsum and desulfurization gypsum-based $\alpha$ gypsum hardened bodies are basically the same. The shrinkage rate of FGD-based $\alpha$-gypsum between 200 °C and 700 °C is lower than that of natural-based $\alpha$-gypsum, indicating that in this temperature range, the high temperature resistance of FGD-based $\alpha$ gypsum is slightly better than that of natural gypsum based $\alpha$-gypsum;

The shrinkage rate of $\beta$ gypsum sample is higher than that of $\alpha$-gypsum, and $\beta$ gypsum sample size continues to change during the constant temperature of 740 °C, indicating that when the gypsum sample is heated to 700 °C or higher, the strength of $\beta$-gypsum sample is significantly reduced. It can be concluded that high temperature resistance of $\beta$-gypsum is not as good as that of $\alpha$- high strength gypsum.

As the heating rate decreases, the thermal expansion performance of gypsum changes significantly. When the heating rate is lower than 3 °C/min, the sample softens and bends at 700 °C, showing rapid shrinkage. Therefore, the appropriate heating rate should be selected to formulate an appropriate heating curve.

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