Study on application of gypsum-based self-leveling mortar in floor heating backfill

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Abstract. In this paper, gypsum-based self-leveling mortar is prepared by using desulfurization gypsum-based α-high strength gypsum as the main cementing material, and it is applied to the floor heating backfill. Comparing with cement-based self-leveling mortar, the thermal conductivity coefficient, thermal expansion coefficient, elastic modulus and other performance indexes of gypsum-based self-leveling mortar are studied. The results show that the gypsum-based self-leveling mortar prepared based on α-high strength gypsum has high strength and heat conduction. Good physical performance, good volume stability, low thermal expansion rate are suitable for floor heating. The application of the gypsum-based self-leveling mortar in the floor heating project shows that the gypsum-based self-leveling mortar can simplify the construction process and shorten construction time.

1. Introduction

The structure of the floor heating system is complex, and its temperature variation during use is large. Therefore, the floor heating material with higher performance for the floor system is required. Due to the material properties, traditional stone concrete and cement mortar often have thermal problems such as thermal expansion and volume stability leading to cracking during use [1]. In Europe, especially in Germany, gypsum-based self-leveling mortar is generally used as a filling material for floor heating systems [2-4]. With the increase in production capacity and the lower cost of domestic α-high-strength gypsum, gypsum-based self-leveling mortar will be widely used in floor heating systems and enter a period of rapid development.

In this paper, the physical properties of gypsum-based self-leveling mortar are determined with reference to the relevant performance indexes specified in JC/T 1023-2007 “Gypsum-based self-leveling mortar”. In addition, Self-leveling mortars have differences in thermal conductivity, thermal expansion performance, and the application effect in the floor heating system is also analysed.

2. Experimental

2.1. Materials

It can be seen from Fig.1 that the particle size distribution of the sample is mainly concentrated between 2μm and 30μm. The graph of cumulative distribution shows particles with a particle size of less than 30μm account for approximately 91%. The volume-weighted average particle size is 14.576μm, and the particle size is basically normal distribution. The boundary diameters D10 and D90 are respectively 2.078μm and 29.711μm. The α-high strength gypsum prepared by using
desulfurization gypsum as a raw material has relatively small particle size and much narrower particle size distribution which is the main difference in the comparison of natural gypsum. The main chemical constituents of desulfurization gypsum-based α-high strength gypsum are SO$_3$ and CaO (Table 1).

![Particle size distribution of the gypsum based α-high strength gypsum](image)

**Table 1** The XRF analysis of α-high strength gypsum

| SO$_3$ | CaO | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | Na$_2$O | K$_2$O | Cr$_2$O$_3$ | SrO | Crystal water |
|--------|-----|---------|-------------|-------------|--------|--------|-------------|-----|---------------|
| 57.57  | 40.31 | 1.02 | 0.51 | 0.21 | 0.15 | 0.12 | 0.09 | 0.03 | 5.9 |

2.2. **Method**

Material particle size is analysed using a Malvern laser particle size analyser. According to GB/T 10294, the thermal conductivity coefficient is determined by the protective hot plate method. The setting time of α-high strength gypsum is determined according to the corresponding provisions of GB/T 17669.4-1999; the flexural strength of 2 hours is determined according to the corresponding provisions of GB/T 17669.3-1999. According to the corresponding provisions of JC/T 1023-2007, the fluidity of the gypsum-based self-leveling mortar and the water demand are determined.

3. **Result and discussion**

3.1. **The physical properties of gypsum-based self-leveling mortar**

![Fluidity loss vs. time](image)

| Technical index                  | Standard values$^a$ | Measured value |
|----------------------------------|---------------------|----------------|
| 30 minutes fluidity loss (mm)    | ≤3                  | 2.0            |
| Initial setting time (h)         | ≥1                  | 1.3            |
| Final setting time (h)           | ≤6                  | 2.8            |
| 24h Flexural strength (MPa)      | ≥2.5                | 2.8            |
| 24h Compressive strength (MPa)   | ≥6.0                | 13.7           |
| Absolute dry flexural strength (MPa) | ≥7.5              | 9.6            |
| Absolute dry compressive strength (MPa) | ≥20.0             | 30.3           |
| Absolute dry tensile bond strength (MPa) | 1.0               | 1.7            |
| Shrinkage (%)                    | ≤0.05               | 0.01           |

$^a$ according to the corresponding provisions of JC/T 1023-2007.

The basic physical performance indexes of gypsum-based self-leveling mortar are showed in Table 2. It can be seen from the Table 2 that the gypsum-based self-leveling mortar has a relatively good leveling property, and the fluidity loss in 30 minutes is not more than 2 mm. The 24-hour flexural strength and compressive strength are 2.8 MPa and 13.7 MPa, respectively. The absolute dry flexural
strength and compressive strength are 9.6 MPa and 30.3 MPa, respectively. The bond strength is 1.7 MPa, which is much higher than the specified strength in the standard. The shrinkage ratio is 0.01%, which is much lower than the standard value of 0.05%.

3.2. Study on Thermal Conductivity of Gypsum-based Self-leveling Mortar

| samples                  | coefficient of thermal conductivity W/(m·K) | Bulk density kg/m³ |
|--------------------------|--------------------------------------------|--------------------|
| Ordinary floor mortar    | 0.4980                                     | 2021               |
| Cementitious self-leveling mortar | 0.4851                                   | 1901               |
| Gypsum-based self-leveling mortar | 0.5424                                   | 1849               |

The thermal conductivity is a very important performance factor for the floor heating material. The floor material with higher thermal conductivity will facilitate rapid indoor temperature rise, uniform heat dissipation, and energy saving. In this paper, three common floor materials are tested. The specific results are shown in Table 3. It can be seen from Table 3 that the thermal conductivity of gypsum self-leveling mortar is about 0.5424 W/(M·K), which is about 10% higher than that of floor mortar and cement-based self-leveling mortar, and its bulk density is slightly lower than that of cement-based self-leveling mortar and the ordinary floor mortar, indicating that the gypsum-based self-leveling mortar will have a better heat conduction effect for the floor heating backfill.

3.3. Study on Thermal Expansion Property of Gypsum-based Self-leveling Mortar

![Figure 2. Thermal expansion of the gypsum based α-high strength gypsum (left) and cement self-leveling mortar (right)](image)

In the process of using the heating backfill material, the volume expansion will occur due to the temperature increase. Under the condition of the same elastic modulus, the larger the volume expansion, the greater the stress caused by the volume expansion. When the stress caused by the thermal expansion exceeds the material strength or the bond strength of the floor material to the base layer will cause the floor to be hollow or cracked, so the thermal expansion properties and elastic modulus of the filler material will affect the later quality of the floor system. Figures 1 and 2 show the thermal expansion curves of gypsum-based self-leveling mortar and cement-based self-leveling mortar from room temperature to 100 °C, respectively, and the heating rate is 1°C / min. The linear expansion of the two is about 0.03-0.035% during the temperature rise to 100 °C. The thermal expansion curve of the gypsum self-leveling mortar is rising gentler than that of the cement self-leveling mortar.
3.4. Elastic modulus of gypsum-based self-leveling mortar

![Stress-strain curve of the gypsum based high strength gypsum](image)

Figure 3. Stress-strain curve of the gypsum based α-high strength gypsum

The stress-strain curve of the gypsum-based self-leveling mortar during the test of elastic modulus is showed in Figure 3. It can be calculated that the elastic modulus of the gypsum-based self-leveling mortar is about 1528.6 MPa. Commonly, the elastic modulus of concrete and cement mortar is about 14000MPa ~ 26000MPa. The elastic modulus of gypsum-based self-leveling mortar is much lower than that of ordinary concrete and cement mortar. It can be concluded from the analysis of Figure 2 that the thermal expansion of gypsum-based self-leveling mortar is basically the same as that of cement self-leveling mortar. Therefore, under the same environment, the stress generated by gypsum-based self-leveling mortar due to thermal expansion is much lower than that of cement mortar. Lower thermal expansion stress of gypsum-based self-leveling mortar will reduce the risk of emptying and cracking of the floor during use. In addition, when men walk indoors, they can feel the better elasticity of the floor, obtain a comfortable foot feeling, and increase the comfort level of the living.

4. Engineering application

![Application of gypsum-based self-leveling mortar](image)

Figure 4. The application of gypsum-based self-leveling mortar in floor heating backfill

Figure 4 shows an application case of using gypsum-based self-leveling mortar for floor heating backfill in a project in Beijing. The backfill area of the project is about 70 m², and the backfill thickness is about 4 cm-6 cm, and the maximum area of the single block is about 30 m². Because of the manual pouring in the pouring process, and the thickness of the backfill is large, it is difficult to reach the working surface in one-time pouring. Therefore, the two-time pouring is used, and the interface agent is used for the two constructions. After the completion of the project and during a heating cycle, the floor effect is very good and no hollow or cracks.
5. Conclusion
High-performance gypsum-based self-leveling mortar with a compressive strength exceeding 30 MPa and a shrinkage not exceeding 0.02% can be produced by using desulfurization gypsum-based alpha gypsum. Compared with cement self-leveling mortar, the gypsum-based self-leveling mortar has advantages as follows:

Gypsum-based self-leveling mortar has good thermal conductivity. Under the same bulk density, the thermal conductivity of gypsum-based self-leveling mortar is about 11% higher than that of cement-based self-leveling mortar.

The thermal expansion value of gypsum-based self-leveling mortar is basically the same as that of cement-based self-leveling mortar. When the temperature rising from 20℃ to 100℃, the thermal expansion value is about 0.03%. Moreover, the expansion curve of gypsum-based self-leveling mortar is smoother than that of cement-based self-leveling mortar during the heating process.

The elastic modulus of gypsum-based self-leveling mortar is much lower than that of cement mortar and concrete. Therefore, in the application of gypsum-based self-leveling mortar in the heating process of the floor heating system, the stress caused by thermal expansion is small; the floor system will not be damaged due to the thermal stress.

References
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