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Performance and hydration study of ultra-fine sulfoaluminate cement-based double liquid grouting material

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HIGHLIGHTS

- A novel double liquid grouting material was prepared.
- Anhydrite and lime content had influence on the properties and hydration process.
- The mechanical strength first increased then decreased as quicklime amount increased.
- The higher the quicklime content, the larger the early expansion ratio.
- Besides ettringite, the relative amount of aluminum hydroxide was another key factor.

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ABSTRACT

This paper prepared a novel double liquid grouting material (ultra-fine sulfoaluminate cement-based grouting material). Slurry A was composed of ultra-fine sulfoaluminate clinker, and slurry B was made from ultra-fine anhydrite and ultra-fine quicklime in accordance with a certain proportion. The properties and hydration process of the double liquid grouting material were studied in the process of adding quicklime from 0 wt.% to 30 wt.%, and the double liquid grouting material was studied with microcalorimeter, thermal-thermogravimetric (DTA-TG) analysis, scanning electron microscopy and energy spectrum technique (SEM-DES), marsh cone flow time, setting time, compressive strength and expansion/shrinkage tests. The results showed that the double liquid slurry had a short setting time when quicklime was added, causing the rapid development of mechanical strength. The more the quicklime content, the longer the flow time of slurry B. The early expansion ratio increased gradually with the increase of the quicklime content. The DTA-TG and SEM-DES test results indicated that the ettringite and aluminum hydroxide are the main hydration products. And the research also found that the mechanical strength of the double liquid grouting material not only depended on the ettringite concentration, but the aluminum hydroxide content was another important influence factor.

1. Introduction

Grouting technology is a special engineering method that the slurry having condensation hardening property is injected into the fracture that existing in the matrix to be strengthened, achieving the purpose of reinforcement [1–5]. For grouting reinforcement, the performance of the grouting material has a decisive influence. In fact, grouting material is a special kind of slurry. However grouting material usually has higher fluidity, injection performance and early strength compared with the conventional slurry in order to meet the needs of the actual project. Besides, the ideal grouting material should also have the following basic characteristic: relatively shorter setting time, micro-expansion property, etc [6].

Cement-based grouting materials have been widely used in various engineering fields. Compared with the chemical slurry, cement-based grouting materials have many advantages, such as low price, non-toxic, higher strength, etc [7–10]. And in order to increase the injection performance of cement-based grouting material, the ultra-fine cement-based grouting material is made by grinding [11–13]. Researches have showed that the injection performance of ultra-fine cement-based grouting material can be compared with that of chemical slurry. At present, most of cement-based grouting materials are mainly prepared on the basis of Portland cement [7,14–16,8]. This has produced some difficult problems, such as longer setting time, lower early strength, easy shrinkage of hardened body, etc [17]. These defects are detrimental

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to the process of grouting reinforcement. Even worse, these defects are mainly determined by the properties of Portland cement itself and it is difficult to effectively improve through certain technical means. Therefore, it is imperative to find and develop a new type of high performance grouting material for green environmental protection.

In 1970s, China invented a special kind of cement, which is sulfoaluminate cement (CSA cement). The main mineral composition of CSA cement clinker includes $C_4A_3\bar{S}$ (ye'elimite) and β-C_2S. In addition, it also contains some other minor phases, such as $C_{12}A_7$, C_4AF, CA, etc. Compared with Portland cement, CSA cement has shorter setting time, higher early strength, micro-expansion property, etc [18,19]. The hydration process of CSA cement is completely different from that of Portland cement. In CSA cement, ettringite is one of the main hydration products [20–22]. The reason why CSA cement has the higher early strength and expansion performance, mainly due to the large number of ettringite exists.

In the presence of calcium sulfate resource, ye'elimite hydrates to form ettringite and aluminum hydroxide according to Eq. (1). When calcium sulfate is insufficient, ye'elimite reacts to form monosulfate and aluminum hydroxide (Eq. (2)). Besides, calcium oxide or calcium hydroxide can react with aluminum hydroxide and calcium sulfate to form ettringite, accelerating the hydration of ye'elimite to increasing the promote precipitation of ettringite (Eq. (3)) [23,24].

$$C_4A_3\bar{S} + 2C\bar{S} + 38H \rightarrow C_3A \cdot 3C\bar{S} \cdot 32H(\text{ettringite}) + 2AH_3(\text{aluminum hydroxide}) \quad (1)$$

$$C_4A_3\bar{S} + 18H \rightarrow C_3A \cdot C\bar{S} \cdot 12H(\text{monosulfate}) + 2AH_3 \quad (2)$$

$$3CH + AH_3 + 3C\bar{S} + 26H \rightarrow C_3A \cdot 3C\bar{S} \cdot 32H \quad (3)$$

According to the characteristics of hydration reaction of ye'elimite – calcium sulfate –calcium hydroxide ternary mixture, it may be able to prepare a kind of grouting material with excellent performance. As stated in the previous, reducing the particle size can effectively increase the performance of cement- based grouting material. Thus a novel double liquid grouting material (ultra-fine CSA cement based double liquid grouting material based on CSA clinker – anhydrite – quicklime) is prepared in this paper. However, the calcium sulfate and calcium hydroxide content can seriously affect the process of hydration of ye'elimite, effecting the change of performance of the material. At present, the research on this aspect has not been reported extensively. So this paper focuses on the effect of quicklime and anhydrite content on the performance and hydration process of ultra-fine CSA cement based double liquid grouting material. The fluidity, setting time, mechanical property and expansion – shrinkage property of ultra-fine CSA cement-based grouting material are studied. Moreover, microcalorimeter, DTA-TG and SEM-DES are used to research the hydration process of ultra-fine CSA cement-based grouting material. Through this study, some theoretical basis and guidance for the future application of the ultra-fine CSA cement-based material in grouting engineering field may be provided.

2. Materials and test methods

2.1. Materials

Sulfoaluminate cement clinker and anhydrite were purchased from Hua yan cement plant. The quicklime was brought from Tai hang lime Factory. A commercial ultra-fine Portland cement grouting material was purchased from Dinghao Technology Co. Ltd. Polycarboxylate Superplasticizer was purchased from Sobute New Materials Co, Ltd, and its active matter was 25 wt.%. FDN reducer agent was brought from Shandong Entac Building Material Technology Co, Ltd. CSA clinker, anhydrite and quicklime were pulverized by fluidized bed-type jet mill, preparing the ultra-fine powers. The effective content of calcium sulfate in ultra-fine anhydrite was 85.19 wt.%. The calcium oxide content in ultra-fine quicklime was 70.3 wt.%, also including 7.35 wt.% calcium carbonate. The mineralogical or chemical composition of ultra-fine CSA cement clinker and ultra-fine anhydrite were shown in Table 1, Table 2 and Table 3. Fig. 1 gave the particle size distribution of the three kinds of ultra-fine power.

Table 1
Chemical composition of the ultra-fine CSA clinker/wt.%.

Loss	SiO_2	Fe_2O_3	TiO_2	Al_2O_3	CaO	MgO	SO_3
0.17	6.36	1.27	1.77	38.27	40.23	1.15	8.88

Table 2
Mineralogical composition of the ultra-fine CSA clinker/wt.%.

$C_4A_3\bar{S}$	β-C_2S	C_4AF	f-SO_3	f-CaO	CaO·TiO_2
74.54	18.25	3.86	0.81	2.02	3.01

Table 3
Chemical composition of the ultra-fine anhydrite/wt.%.

Loss	SiO_2	Fe_2O_3	MgO	Al_2O_3	CaO	SO_3	Alkali
6.14	1.04	0.18	2.64	0.23	38.63	50.11	0.12

2.2. Test methods

2.2.1. Marsh cone flow time and setting time test

The double liquid grouting material included A and B two kinds of slurries. According to the basis mix proportion shown in Table 4, the slurry A and slurry B were prepared by mixing machine about 3 min. The flow time of slurry A and slurry B were measured by Marsh cone method. The setting time of the blended pastes were measured by inverted cup method.

2.2.2. Compressive strength and expansion-shrinkage test

According to the basis mix proportion shown in Table 4 and 40 mm × 40 mm × 40 mm and 40 mm × 40 mm × 160 mm standard sample were prepared by using mixed slurry.

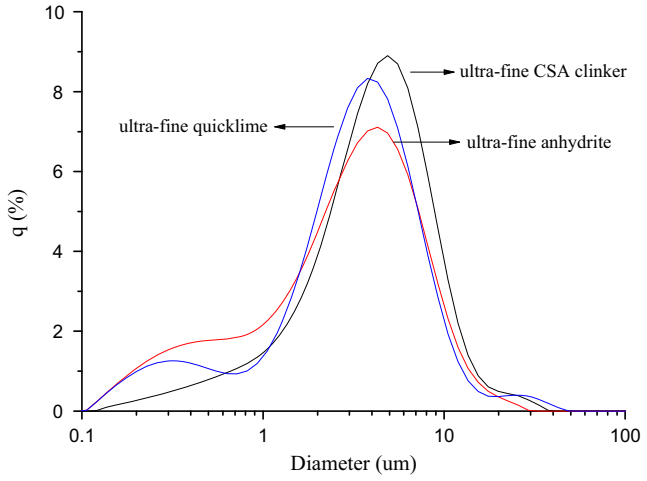

Fig. 1. Particle size distribution of raw materials used in all experiments.