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Effects of mineral admixtures and additional gypsum on the expansion performance of sulphoaluminate expansive agent at simulation of mass concrete environment

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HIGHLIGHTS

- Mineral admixtures and sulphoaluminate expansive agent were used simultaneously.
- Simulated mass concrete curing condition was used.
- The expansion effects were influenced by mineral admixtures.
- Both strength and expansion effects of GGBS samples were enhanced by adding gypsum.

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ABSTRACT

Shrinkage cracks are easily occurred in mass concrete. To compensate the shrinkage, the sulphoaluminate expansive agent is usually used. Besides, high volume mineral admixtures are usually used to decrease the hydration thermal and delay the appearing of temperature peak of mass concrete. However, the expansion effect and compressive strength were probably affected by the mineral admixtures and expansive agent interactively. In this study, the effects of GGBS and FA on the expansion performance at the simulated mass concrete temperature were investigated, and moderate additional gypsum was used to eliminate these negative effects. Besides, XRD, TG-DTG and SEM were used to analyze the hydration process, hydration products and the morphology of products. The results show that the expansion effect and compressive strength were decreased by the addition of GGBS and FA at simulated curing condition. Both expansion effect and compressive strength of samples blended with GGBS were increased by gypsum, because of the gypsum promoted the generation of AFt and stimulated the hydration of GGBS. But for samples blended with FA, the gypsum promoted the generation of AFt but seriously prolonged the setting time of samples, resulted in the consuming of expansion energy in the plastic deformation.

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1. Introduction

The mass concrete possesses large volume and high thermal release [1–3]. Due to its large volume and poor thermal conductivity, the accumulated internal heat produced by the hydration of cement is not easy to dissipate, and the fast dissipate of external heat easily lead to temperature shrinkage [4,5]. Besides, chemical shrinkage and air shrinkage are inescapable in late ages for concrete due to its nature [6,7]. The shrinkage above results in tensile stress easily, and once the tensile stress is greater than the tensile strength of the concrete, the concrete will crake [2,8–10].

To compensate the shrinkage, the expansive agent is usually used [6,11–13]. At present, the most common used expansive agent is sulphoaluminate expansive agent, with the composition of calcium sulphoaluminate, gypsum, and alunite [14–16]. The volume expansive is because of the generation of ettringite (AFt), which was a hard rod-like crystal, processing the high strength. The formation of AFt is according to the following reactions (Eqs. (1) and (2)) [17,18].

$$C_3A + 3(CaSO_4 \cdot 2H_2O) + 26H_2O \rightarrow C_3A \cdot 3CaSO_4 \cdot 32H_2O \quad (1)$$

$$C_4A_3\bar{S} + 6Ca(OH)_2 + 8CaSO_4 + 90H_2O \rightarrow 3(C_3A \cdot 3CaSO_4 \cdot 32H_2O) \quad (2)$$

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In addition, to decrease the thermal of mass concrete, large volume mineral admixtures are usually added, such as ground granulated blast furnace slag (GGBS) and fly ash (FA). The hydration of mineral admixtures possesses lower thermal release, and can delay the appearing of temperature peak of mass concrete [19–22].

However, the effect of expansive agent and the amount of hydration of cement are very relevant, for the generation and growth of AFt significantly affected by the concentration of Ca^{2+}, SO_4^{2-} and OH^- [6,23–25]. After cement substituted by high volume mineral admixtures, because of the cement content reduced, the production of AFt in expansive agent probably affected by the insufficient of $Ca(OH)_2$ at the early stage. Hence, the development of expansive effect is limited. Moreover, at late stage, although the amount of $Ca(OH)_2$ is abundant, the secondary hydration of mineral admixtures also need to consume partial of $Ca(OH)_2$, and the development of expansive effect would be restrained again. On the other hand, if the $Ca(OH)_2$ consumed by the generation of AFt, the $Ca(OH)_2$ for stimulating secondary hydration of mineral admixtures is insufficient. Probably, the compressive strength will be decreased, because of the incompletely stimulate of due activity of mineral admixtures. To address this problem, adding moderate gypsum may be an effective and convenient way. Gypsum can not only stimulate the activity of mineral admixtures, but also participate in the reaction of generation of AFt [26].

Moreover, at high temperature of mass concrete, the effect of reaction was complex, which was benefit and harmful to the development of strength simultaneously [27–29]. High temperature promote the hydration of cement, benefit to the development of strength; however, if the temperature as high as 70 °C, the ettringite, one of the mainly source of strength, would decompose. At the same time, calcium aluminate sulfate hydrate (AFm) with low strength generated, and the reaction is as follow (Eq. (3)) [28–31]. For the binder containing expansive agent and mineral admixtures simultaneously at mass concrete environment, effect of the superposition of the opposite two does not known.

$$C_3A \cdot 3CaSO_4 \cdot 32H_2O \rightarrow C_3A \cdot CaSO_4 \cdot 12H_2O + 2(CaSO_4 \cdot 2H_2O) + 16H_2O \tag{3}$$

In view of this, mass concrete temperature was simulated in this study. Under this curing condition, the effect of two mineral admixtures (GGBS and FA) on the expansive effect and strength of mortars was investigated. Besides, to compensate the negative effects of mineral admixtures on expansive effect, moderate gypsum was added. Furthermore, the hydration process, hydration products and morphology of products were examined by the techniques of X-ray Diffraction (XRD), thermogravimetry (TG) and Scanning Electronic Microscopic (SEM), which would help to explain the mechanisms of this blended cementitious system.

2. Experimental

2.1. Raw materials

The chemical compositions of Portland cement (PC), ground granulated blast furnace slag (GGBS), flay ash (FA) and expansive agent are listed in Table 1. In present study, the sulphoaluminate expansive agent was used, and the performance index of the expansive agent is shown in Table 2. Besides, the gypsum with the purity of 99.0% and liquid commercial pumping agent with the solid content of 40 wt% were used.

Table 1
Chemical composition of raw materials (wt%).

Components	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	Loss
Expansive agent	15.82	13.75	0.58	34.58	3.05	0.09	0.05	25.32	2.55
PC	22.32	5.84	3.15	61.23	2.02	0.39	0.15	2.00	1.66
GGBS	32.56	25.77	0.62	42.08	5.63	0.96	1.22	1.01	0.93
FA	51.42	36.00	5.21	2.60	0.18	1.36	0.46	0.32	2.25

Table 2
Performance index of the expansive agent.

Items		Ages	Index value	Measured value
Restrained expansion rate	Water curing	7 days	⩾0.025	0.032
	Water curing	28 days	⩾0.100	0.037
	Air curing	21 days	⩾-0.020	−0.017
Compressive strength (MPa)		7 days	⩾20.0	35.5
		28 days	⩾40.0	47.8
Flexural strength (MPa)		7 days	⩾3.5	7.2
		28 days	⩾3.5	9.4

2.2. Mix proportions

In the current study, mix proportions are listed in Table 3. The expansive agent partially replaced total cementitious material for the content of 10 wt%. The contents of two mineral admixtures are 0 wt%, 20 wt%, 30 wt%, 40 wt% and 50 wt%, respectively. The contents of gypsum are calculated according to the loss of SO_3 due to the partial substitution of mineral admixtures. They were 0.4 wt%, 0.6 wt%, 0.9 wt%, 1.1 wt% for mortars blending with GGBS at the content of 20 wt%, 30 wt %, 40 wt% and 50 wt%, respectively, and 0. 7 wt%, 1.1 wt%, 1.5 wt%, 1.9 wt% for mortars blending with FA at the content of 20 wt%, 30 wt%, 40 wt% and 50 wt%, respectively. The ratio of powders to sand and water to powders was 2: 1 and 0.35. Besides, 2.0 wt% pumping agent was used.

2.3. Curing and testing

In present study, mass concrete environment was simulated. For the mass volume of mass concrete, the internal hydration thermal could not distribute quickly due to its poor thermal conductivity. Hence, the internal temperature always up to 60–70 °C at 2–3 days, and then decreased slowly [5]. According to this, the curing condition was simulated and is shown in Table 4. To reduce the influence factors, the model was simplified and the curing schedules used for all the samples, neglecting the effect of mineral admixtures on the hydration thermal.

Samples for compressive strength testing (40 mm × 40 mm × 160 mm) and for restrained expansion rate testing (40 mm × 40 mm × 140 mm) according to the mix proportions above were prepared. They were cast at temperature of 20 ± 2 °C. The compressive strength of samples was measured with hydraulic universal testing machine. Each proportion was measured as a set of 3 samples. Samples were tested for compressive strength after 3 days, 7 days and 28 days. For restrained expansion rate, the test method and calculation were according to the Chinese standard GB23439-2009 [32]. The length of samples was tested every day during 2–14 days and then tested every 3 days during 14–35 days by expansion gauge, with the minimum scale of 0.001 mm. Besides, cement pastes without sand was prepared for examine XRD, TG and SEM. The hydration of paste was stopped by ethanol at certain ages. After washing and filtering by ethanol several times, the samples were dried in vacuum at 40 °C for 48 h.

3. Results and discussions

3.1. Effects of mineral admixtures on the expansive effect and compressive strength

The effects of mineral admixtures content at simulated mass concrete environment are shown in Fig. 1(a and b). Fig. 1 (a) and (b) are corresponding to the samples with mineral admixtures of GGBS and FA, respectively.

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