Pergamon

Cement and Concrete Research 31 (2001) 335–337

CEMENT AND CONCRETE RESEARCH

Technical note

The effect of expansive agent and possibility of delayed ettringite formation in shrinkage-compensating massive concrete

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Received 29 March 2000; accepted 10 October 2000

Abstract

The effects of expansive agent and possibility of delayed ettringite formation (DEF) were determined using a temperature match condition (TMC) system in the simulated condition of shrinkage-compensating massive concrete. The expansive agent used in massive concrete cannot give full play to its shrinkage-compensating effect when curing temperature is higher than 70°C. The harmful delayed expansion due to DEF might occur in hardened concrete. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Delayed ettringite formation; Expansive agent; Shrinkage-compensating massive concrete

1. Introduction

Sulfoaluminate-type expansive agent, supplanting 8–12% of cement in the mixture, is commonly used to prepare massive concrete for foundation construction of high-rising buildings. Shrinkage-compensating massive concrete foundations, whose volume can be over 10 000 m^3 and thickness be over 5 m, are cast continuously without postcast construction joints [1]. The temperature in the core of massive concrete may rise higher than 70°C. Even as high as 90°C was recorded in a case in Shanghai, China [2]. Such high temperature in the shrinkage-compensating massive concrete may result in delayed ettringite formation (DEF), which was recognized first by Heinz and Ludwig [3] in the case of steam-curing precast concrete product and then studied intensively by other researchers [4–6].

Many of previous research works about DEF focused on the steam-curing precast concrete products, which were cured normally under water after heat treatment. Their deterioration begins mainly in their unconfined parts, such as tips and edges. There is some difficulty for the water supply in the core of massive concrete. There is also strong confinement in the foundation concrete. Therefore, there may be different phenomena of DEF in the shrinkage-compensating massive concrete. In this work, the alternation of hydrate and the longitudinal variance of confined shrinkage-compensating mortar were investigated under the temperature match condition (TMC), simulating shrinkage-compensating massive concrete to identify the possibility and effect of DEF.

2. Experiment

The materials used in the study included PO-525 ordinary Portland cement and an expansive agent. Their chemical compositions are shown in Table 1. The phase compositions of the expansive agent are mainly silica–aluminate clinker, alumina and gypsum. The mortars with binder-to-sand ratio of 2 were prepared (Table 2). The mortars were cast into $40 \times 40 \times 140$-mm molds, with 4-mm diameter steel limiting frame and kept in humid air at 20 ± 2°C for 18 h. After demolding, the initial length of the restrained mortar prisms was measured. Then, the samples were cured at the different conditions listed in Table 2.

A TMC system was developed to simulate the temperature development in the core of fresh massive concrete. The temperature in the curing bath rose from ambient temperature to 70°C in 48 h and was kept over 70°C for 72 h. The highest temperature was 80°C. The relative humidity (RH) in the curing bath was higher than 95%. After cooling down to 60°C in 48 h, the temperature was not controlled and fell down to ambient temperature in 3 h. After TMC curing, samples were cured in ambient temperature but different

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PII: S0008-8846(00)00453-1

Table 1
Chemical composition of Portland cement and expansive agent

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	TiO_2	P_2O_5	Loss
Portland cement	22.17	5.43	3.16	60.87	1.67	1.10	0.07	2.30	0.25	0.11	4.18
Expansive agent	23.93	12.55	1.65	19.59	2.40	0.73	0.11	31.75	0.49	0.19	6.15

Table 2
Composition and curing condition of the mortars and pastes

No.	Expansive agent (%)	W/B	Curing temperature during the first 7 days	Curing RH during the first 7 days	Curing temperature and RH after 7 days
1	0	0.44	TMC	Steam-curing	Ambient temperature, > 90%
2	10	0.44	Ambient temperature	>90%	Ambient temperature, >90%
3	10	0.44	TMC	Steam-curing	Ambient temperature, >90%
4	0	0.33	TMC	In water	Ambient temperature, in water
5	10	0.33	Ambient temperature	In water	Ambient temperature, in water
6	10	0.33	TMC	In water	Ambient temperature, in water
7	0	0.38	TMC	Sealed	Ambient temperature, 85%
8	10	0.38	Ambient temperature	85%	Ambient temperature, 85%
9	10	0.38	TMC	Sealed	Ambient temperature, 85%

RH. Parts of samples were cured without TMC, only in ambient temperature but different RH.

The longitudinal measure of restrained mortars was done at the scheduled ages. The semi-quantitative assessment of AFt and AFm in mortars was done by the means of the step scanning of X-ray diffraction with Cu K_α target in the 2θ range of 8.5–10°. The intensities of peak of AFt (100) and AFm (003) were measured.

3. Results and discussions

Figs. 1, 2 and 3 show the longitudinal variance of confined mortar prism nos. 1–3, 4–6 and 7–9, respectively. Lengths of prism nos. 1, 3, 4, 6, 7 and 9, which were subjected to TMC process, reached the maximum values on the third day because of the combined effect of expansive agent and the thermal expansion. The prism nos. 2, 5 and 8, which contain 10% of expansive agent and were not subjected to TMC process, gained some expansion in the initial hydrating period. The expansion can be maintained after 1 year in the range of 0.01–0.04%; values expected to compensate shrinkage of concrete.

Prism nos. 3, 6 and 9, which contained expansive agent and were subjected to TMC process, had the similar 7-day longitudinal variance with prism nos. 1, 4 and 7, which did not contain expansive agent but were also subjected to TMC process. Their expansions were smaller than those of prism nos. 2, 5 and 8, which had the same composition but were not subjected to TMC process. This shows that the effect of the expansive agent was counteracted due to the high curing temperature. In the later age, the longitudinal variance of the samples 3, 6 and 9 exhibited a different magnitude according to the different W/B and subsequent humidity of curing environment.

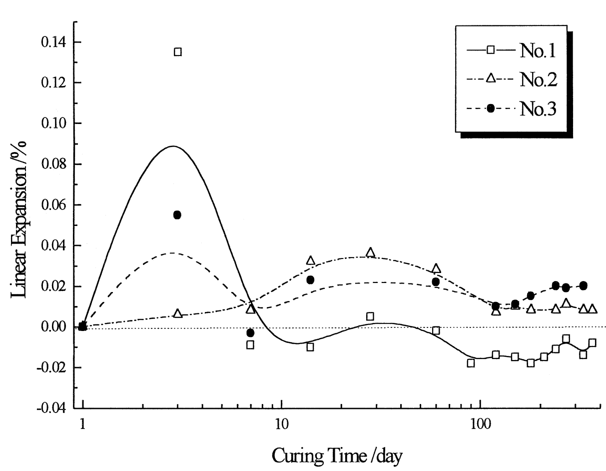

Fig. 1. The restrained expansion of sample nos. 1–3 at different times.

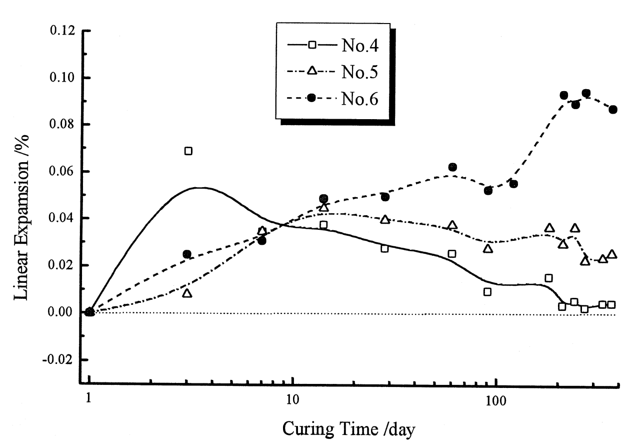

Fig. 2. The restrained expansion of sample nos. 4–6 at different times.

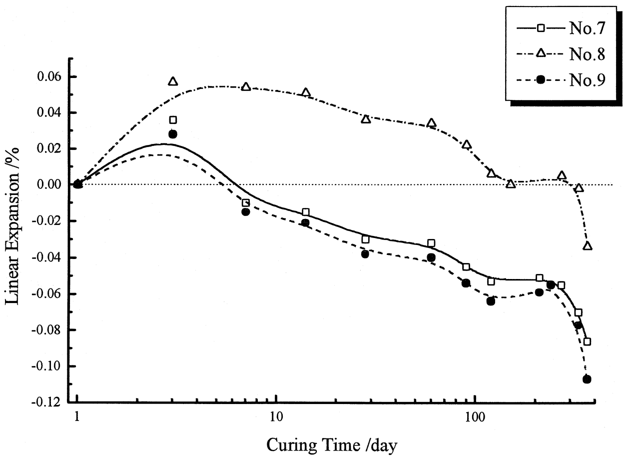

Fig. 3. The restrained expansion of sample nos. 7–9 at different times.

The expansion of prism no. 3, cured in humid air in later age, is not larger than zero (Fig. 1). It has a trend of expansion in the later period. If the expansion develops continuously along with the prolongation of hydration time, there is a potential danger of cracking of concrete.

The samples cured under water show intensive and fast expansion (Fig. 2). The expansion of prism no. 6 surpasses that of prism no. 5 after 7 days and gradually increases to 0.1% after half a year. Such high expansion can introduce cracking and is dangerous for the concrete structure in service. There is obvious danger of DEF for the shrinkage-compensating massive concrete under conditions of water saturation.

The expansion of prisms is limited when there is no abundant water supply (Fig. 3). Prism no. 9 always had greater shrinkage than the prism no. 7, which contained no expansive agent. It undergoes 0.04% of shrinkage, which is the critical limit of concrete cracking after 30 days. There is no possibility of DEF, but the expansive agent creates no shrinkage-compensating effect in the dry condition, which puts the concrete structure at a disadvantage. Therefore, internal and external water supply plays an important role in the expansive characteristics of the shrinkage-compensating massive concrete.

The semi-quantitative assessment of AFt and AFm in paste nos. 2, 3, 8 and 9 shows that AFt has formed intensively in the first day. The quantities of AFt in paste nos. 3 and 9 decrease to the minimal value, and some AFm forms on the seventh day after the curing temperature falls down to ambient temperature. This decrease weakens the compensating capability to cooling shrinkage of concrete. As a result, there is an obvious decline of the linear expansion of prism nos. 3 and 9 from the third to seventh day. The quantity of AFt in paste no. 3 changes a little after 14 days. AFm does not transform into AFt again. Therefore, its longitudinal variance is not obvious in the later period. In paste nos. 8 and 9, the formation of AFm precedes the formation of AFt because of the lack of water supply. Therefore, they shrink continuously.

4. Conclusion

Expansive agent used in massive concrete cannot give full play to its shrinkage-compensating effect because of the decomposition of ettringite when the curing temperature is higher than 70°C in early age. Harmful delayed expansion would occur due to DEF at a later age in shrinkage-compensating massive concrete. It appears most severe when prisms are cured under water and mild temperatures in humid air. But prisms cured in dry air undergo shrinkage. Those possess potential danger for the durability of concrete structures in service.

Acknowledgments

The authors would like to acknowledge the financial support of the NSFC grant no. 59878027 and the testing fund of Tsinghua University.

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