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Study on early-age cracking of cement-based materials with superplasticizers

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Abstract

The addition of superplasticizers is an important approach to prepare high performance cement-based materials. The effect of polynaphthalene series superplasticizer (PNS) and polycarboxylate type superplasticizer (PC) on early-age cracking and volume stability of cement-based materials was investigated by means of multi-channel ellipse ring shrinkage cracking test, free shrinkage and strength test. The general effect of PNS and PC is to increase initial cracking time of mortars, and decrease cracking sensitivity of mortars. As for decreasing cracking sensitivity of mortars, PC > H-UNF (high-thickness-type PNS) > C-UNF (common-thickness-type PNS). To incorporate superplasticizers is apparently to increases free shrinkage of mortars when keeping the constant W/B ratio and the content of cement pastes. As for the effect of controlling volume stability of mortars, PC > C-UNF > H-UNF. Maximum crack width of mortars with PC is lower, but the development rate of maximum crack width of mortars with H-UNF is faster in comparison with control mortars. Flexural and compressive strength of mortars and concretes at 28 days increased with increasing superplasticizer dosages under drying conditions. C-UNF was approximate to H-UNF, but PC was superior to PNS in the aspect of increasing strength of cement-based materials.

Keywords: Superplasticizers; Early-age cracking; Volume stability; Ellipse ring; Initial cracking time

1. Introduction

The problem of early-age cracking and volume stability is a popular subject in the field of high performance cement-based materials research all along. The deterioration of volume stability can directly result from the occurrence of cracking. Cracking is a main source of premature deterioration of the structure of cement-based materials, which shortens the service life of the structure [1]. Superplasticizer is an indispensable ingredient in high performance cement-based materials. According to chief constituents, superplasticizers can be divided into four types: polynaphthalene series, melamine series, sulfamic acid series and polycarboxylate type. Polynaphthalene series superplasticizer (PNS) is a representative of the second-generation superplasticizers. According to sodium sulfate content, PNS can be separated into two kinds: high-thickness-type PNS and common-thickness-type PNS. Common-thickness-type PNS contains 15–25% sodium sulfate, whereas high-thickness-type PNS only contains 5% sodium sulfate and even lower. Polycarboxylate type superplasticizer (PC) is the third-generation high performance water-reducing agent, and its molecular structure exhibits comb-shape. PC can prevent slump loss of concrete, which has hardly any slump loss within 90 min, and do not obviously brings retarding effect. Thus, PC is one of the research and development focuses in chemical admixtures both at home and abroad [2,3].

Previous studies on superplasticizers tended to improve rheological properties and mechanical properties of cement-based materials [4–7]. To the knowledge of the

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authors, there was lack of studies on the effect of superplasticizers on early-age cracking and volume stability of cement-based materials. The objective of the present investigation was determine the effect superplasticizers, namely, PC and PNS, on early-age shrinkage cracking and volume stability of cement-based materials cured under drying conditions.

2. Experimental

2.1. Materials, mix proportions and specimen preparation

All mixtures were made with the same Portland cement (Lafarge). The cement has a Blaine fineness of 351 m^2/kg and a Bogue calculated phase composition of 62.1% C_3S, 10.9% C_2S, 8.8% C_3A, and 10.9% C_4AF. Fly ash has a specific surface of 350 m^2/kg. Silica fume has a specific surface of 2.0×10^4 m^2/kg and density of 2.2 g/cm^3. The chemical compositions of these three materials are presented in Table 1. Physical properties of this cement are given in Table 2. The fine aggregate was natural river sand with fineness modulus of 2.5. The coarse aggregate was crushed stone with the maximum diameter of 20 mm.

Superplasticizers used in this study include PNS and PC. PNS called UNF was a powder product, which had common-thickness-type UNF (C-UNF) contained 16% sodium sulfate and high-thickness- type UNF (H-UNF) contained 0.5% sodium sulfate. C-UNF and H-UNF had water-reducing ratio of 15–25%. PC called GLENIUM SP-8N was a liquid product with a solid content of 18%, which had water-reducing ratio of over 30%.

In terms of previous study on the optimized compositions of binders [8], the binder contained cement, fly ash and silica fume, which is in proportion to 55%, 40% and 5% by mass. All mortars were designed at a fixed water-to-binder (W/B) ratio of by weight of 0.35 and binder-to-sand ratio by weight of 1:2. The type and dosage of superplasticizers in mortars are given in Table 3. For each mortar mixture, its fluidity was controlled over 120 mm. All concretes were prepared with a fixed W/B ratio of by weight of 0.30. The mix proportions of concretes are given in Table 4. The dosages of superplasticizers in mortars and concretes are the percent of binders by mass which contain cement, fly ash and silica fume.

Table 1
Chemical composition of cementitious materials

Components	Cementitious materials (%)		
	Cement	Fly ash	Silica fume
SiO_2	20.1	50.11	91.63
Al_2O_3	5.60	29.58	0.90
Fe_2O_3	3.58	6.20	0.93
CaO	63.43	3.92	0.13
MgO	1.06	1.79	1.78
SO_3	2.05	2.70	–
f-CaO	0.46	–	–
LOI	2.74	6.30	2.93

Table 2
Physical properties of cement

Setting time (min)		Flexural strength (MPa)		Compressive strength (MPa)	
Initial	Final	3 d	28 d	3 d	28 d
157	250	6.0	9.0	30.1	53.2

2.2. Methods

Initial cracking time of cement-based materials is directly reflected the ability of early-age shrinkage cracking resistance. Multi-channel ellipse ring shrinkage cracking test was used to measure initial cracking time of mortar in the present investigation, which schematic is shown in Fig. 1. Theoretical and modeling aspects of this ellipse ring-type specimen can be found elsewhere in literatures [9,10]. The dimension of the steel ellipse ring is shown in Fig. 2.

For the present study, the ellipse ring specimens were cast with mortars at 20 ± 2 °C and over 50% relative humidity (RH) and vibrated for 30 s on the vibrator, and then moist-cured at 20 ± 1 °C and over 90% RH. After 18 h, the outer molds of ring specimens were stripped off, and the top surface of the ring specimens was sealed with polyurethane so that drying would be only allowed from the lateral face. Then the specimens were placed in the drying chamber at 20 ± 3 °C and 50 ± 4% RH. Along the circumferential surface of the ellipse ring specimen, a strip of conducting layer was coated to connect the circuit that monitored initial cracking time. A curing period of 18 h was selected to simulate minimal field-curing conditions, and also to accelerate the onset of cracking.

Because multi-channel ellipse ring shrinkage cracking test can simultaneously monitor five specimens and exactly record initial cracking time, it greatly improves the accuracy and efficiency of measuring cracking sensitivity of cement-based materials.

Crack width of the mortar-ellipse-ring specimen was observed through the use of a magnifying microscope. Maximum crack width was determined once per week, and observed its development.

Table 3
Type and dosage of superplasticizers in mortars

Mix no	J1	C1	C2	H1	H2	G1	G2	G3
Type of superplasticizers	–	C-UNF	C-UNF	H-UNF	H-UNF	PC	PC	PC
Dosage of superplasticizers (%)	–	0.5	1.0	0.5	1.0	0.5	1.0	1.5