DURABILITY PROPERTIES OF CONCRETE WITH EXPANSIVE ADDITIVE

Nguyen Trong Lam[1], Taweechai Sumranwanich[2], Pitisan Krammart[3], Dujthep Yodmalai[4], Raktipong Sahamitmongkol[5] and Somnuk Tangtermsirikul[6]

[1]Sirindhorn International Institute of Technology, Thammasat University, e-mail: ntlamce@siit.tu.ac.th

[2]Department of Civil Engineering, Faculty of Engineering, Burapha University, e-mail: twc@buu.ac.th

[3]Department of Civil Engineering, Faculty of Engineering, Rajamangala University of Technology Thanyaburi, e-mail: pitisan.k@en.rmutt.ac.th

[4] Sirindhorn International Institute of Technology, Thammasat University, e-mail: dujthep_y@hotmail.com

[5] Construction and Maintenance Technology Research Center (CONTEC), e-mail: sahamit@siit.tu.ac.th

[6]Construction and Maintenance Technology Research Center (CONTEC), Sirindhorn International Institute of Technology, Thammasat University, e-mail: somnuk@siit.tu.ac.th

Abstract

This paper presents a study on durability properties of concrete using an expansive additive. In this research, the effect of expansive additive (EA) content, fly ash (FA) content and water to binder ratio (W/B) on durability such as carbonation resistance of concrete, sulfate resistance of mortar, chloride penetration and chloride binding capacity of paste were studied. The results indicate that, when EA content is controlled at not over 30 kg/m^3, carbonation resistance of both cement-only expansive concrete and fly ash expansive concrete are better than that of concrete without expansive additive. But when amount of EA is higher than 30 kg/m^3, carbonation resistance of fly ash expansive concrete becomes worse. Expansive additive has a negative effect on sulfate resistance and chloride binding capacity of concrete but tends to reduce chloride permeability.

Keyword: Expansive concrete, Fly ash, Carbonation resistance, Sulfate resistance, Chloride penetration, Chloride binding capacity.

1. Introduction

Shrinkage and low tensile strength are two major unpreferable properties of concrete. Therefore, under restrained condition, concrete structures may crack due to shrinkage. Application of expansive concrete is one of the effective solutions for shrinkage cracking problem of concrete. In restrained condition, when expansive concrete expands, it produces compressive stress in the restrained expansive concrete. The compressive stress in the concrete will reduce or eliminate tensile stress which occurs when concrete shrinks in restrained condition.

The mechanical properties of expansive concrete such as expansion and compressive strength in free and restrained condition were reported in previous research [1]. However, these results were not enough to apply the expansive concrete in practice. In order to apply expansive concrete effectively, it is needed not only to make sure that the compressive but also durability of the concrete is sufficient.

Some durability properties which are carbonation, sulfate resistance, chloride binding capacity and chloride penetration have been studied since early years of last century. But up to now, a few researches on durability of

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expansive concrete are carried out, especially, durability of expansive fly ash concrete.

Expansive additive which contains mostly free calcium oxide produces additional amount of calcium hydroxide in the concrete. This may result in higher carbonation resistance and lower sulfate resistance, especially in the case of sodium sulfate, of concrete. On the other hand, when cement is partly replaced by expansive additive, the C_3A and C_4AF content which can react with chloride ion [2,3] will reduce. Therefore, expansive additive may has negative effect on chloride binding capacity of concrete.

The objective of this work is to investigate the effect of expansive additive on durability of cement-only concrete and fly ash concrete such as carbonation resistance, sulfate resistance, chloride penetration and chloride binding capacity.

2. Experimental Program

2.1. Materials and mix proportion

2.1.1. Materials

Cement type 1 (C1), cement type 5 (C5), fly ash (FA) and expansive additive (EA) were used as binders. Chemical composition and physical properties of these materials are given in Table 1. River sand and crushed lime stone were used as fine and coarse aggregates, respectively. Their physical properties are shown in Table 2. The maximum size of coarse aggregate is 19 mm. The fine and coarse aggregates used in the experiments comply with ASTM C33-97 [4].

2.1.2. Mix proportion

Cement-only concrete and fly ash concrete (FA=30%) containing different amount of EA (0; 15; 30 and 40 kg/m^3) were used in carbonation test. These mix proportions are the same as the mix proportions used for compressive strength and expansion tests in our previous study [1]. The details of mix proportions of concrete are given in Table 3.

Cement type 5 mortars containing different EA content (0, 10%) and different W/B (0.4, 0.55) as well as cement type 1 mortars containing different FA content (0, 30%), EA content (0, 10%) and different W/B (0.4, 0.55) were used in sulfate resistance test. The details of mix proportions of the mortars are given in Table 4.

Pastes containing 0% and 10% EA were prepared for cement-only and cement with 30% FA with W/B equal to 0.4 and 0.5. They were used for chloride penetration and chloride binding capacity test.

2.2. Method of testing

2.2.1. Carbonation test

Accelerated carbonation test was conducted. Concrete specimens with the size of 100x100x100 mm were used in the accelerated carbonation test. These specimens were seal-cured for 7 days before being carbonated in the chamber. The temperature and relative humidity in the carbonation chamber were controlled at 40^{o}C and 55%, respectively. The CO_2 concentration was 4% [5].

Carbonation depth was measured 28 days after the specimens were placed in the carbonation chamber. The specimens were split and cleaned. The depths of carbonation were determined by spraying on freshly broken surfaces with 1% of phenolphthalein in the solution of 70% ethyl alcohol (Figure 1).

2.2.2. Sulfate resistance test

Sodium sulfate (Na_2SO_4 or N$\underline{S}$) was used in this research. N$\underline{S}$ solution was prepared according to ASTM C1012 [6]; the solution contained 50g of Na_2SO_4 dissolved in 1.0 liter of the solution. The solution was mixed one day before use, and stored at a constant temperature of 30 $\pm$ 2°C.

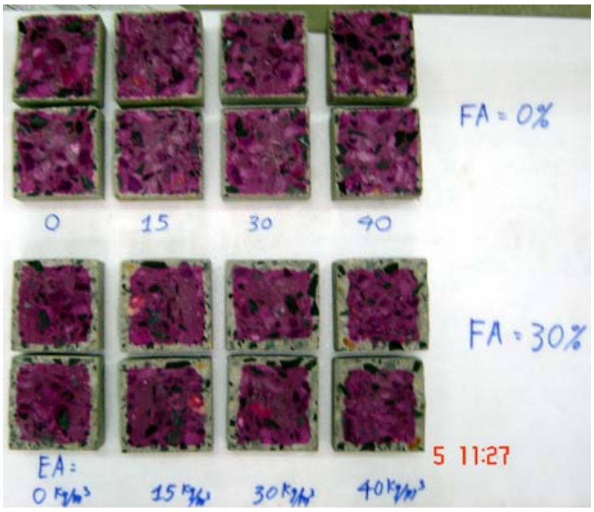

Figure 1 Broken surfaces of specimens after spraying with phenolphthale

Volume ratio of sulfate solution to specimens in each storage container was approximately 4 to 1.

The mortar specimens with the size of 25x25x285 mm (Figure 2) were prepared in accordance with ASTM C 157 [7]. These specimens were water-cured for 28 days before being exposed to the prepared test solution. The specimens were immersed in plastic tanks containing NS solutions. The solutions were changed after 1, 2, 4 weeks and every two months of exposure.

The expansion of specimens was measured according to ASTM C1012 [6]. The initial length of specimens was measured after 28 days of curing in saturated limewater. Subsequently they were placed in the sulfate solution and the length change was measured at 2, 3, 4, 8, 13, and 16 weeks of exposure. After 16 weeks, the measurements were made every two months of exposure. The expansion of specimens was obtained from the average of three specimens.

2.2.3. Chloride binding capacity and chloride penetration test

The paste specimens with the size of 50-mm in diameter and 10-mm thick (Figure 3) were used for chloride binding capacity and chloride penetration tests. Thirteen specimens were prepared for each mixture, ten for expressing the pore solution and three for determining the evaporable water content.

Figure 2 Mortar specimens using for sulphate resistance test

The specimens were water-cured for 7 days before being exposed to chloride by submerging in saline water with 3.0 % of chloride ion concentration.

At the end of chloride exposure period (91 days), specimens were removed from salt water. Surfaces of specimen were immediately dried by using tissue paper. Pore solution inside the specimens was obtained by using a pore expressing apparatus (Figure 4). The maximum loading pressure for expressing the pore solution was about 500 MPa.

Figure 3 Paste specimens for chloride binding capacity and chloride penetration test

Two or three cycles of loading and unloading were performed in order to get 3 to 5 cm^3 of pore solution.

The evaporable water content of each specimen was immediately tested for being used in the determination of free chloride in the specimen. The evaporable water content is determined from weight loss of specimen after being dried in an oven at temperature of 105°C for 24 hours.

Figure 4 Pore expressing apparatus

Table 1: Chemical compositions and physical properties of binders

Material	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	SO_3 (%)	Na_2O (%)	K_2O (%)	LOI (%)	Fineness* (cm^2/g)	Specific gravity
C1	20.20	4.70	3.73	63.40	1.37	1.22	-	0.28	2.72	3430	3.15
C5	20.97	3.49	4.34	62.86	3.33	2.12	0.12	0.47	2.30	3330	3.18
EA	9.60	2.50	1.30	67.30	0.40	18.00	-	-	0.40	3500	3.04
FA	36.10	19.40	15.10	17.40	2.97	0.77	0.55	2.17	2.81	2460	2.27

*Using Blaine's air permeability method.

Table 2: Physical properties of aggregates

Aggregate type	Specific gravity	Water absorption, (%)	Fineness modulus	Unit weight, (g/cm^3)	Void ratio, (%)
Sand	2.60	0.89	2.13	1.63	38.5
Gravel	2.68	0.46	-	1.62	40.0

Table 3: Mix proportions of concrete

Type of binder	No.	Designation	W/B	C (kg)	FA (kg)	EA (kg)	S (kg)	G (kg)	W (kg)	SP (%)
Cement only	1	C1FA0EA0	0.5	350	0	0	824	1038	175	0.8
	2	C1FA0EA15	0.5	335	0	15	823	1037	175	0.8
	3	C1FA0EA30	0.5	320	0	30	823	1037	175	0.8
	4	C1FA0EA40	0.5	310	0	40	823	1037	175	0.8
Cement and 30% FA	5	C1FA30EA0	0.5	245	105	0	808	1018	175	0.5
	6	C1FA30EA15	0.5	234.5	100.5	15	809	1019	175	0.5
	7	C1FA30EA30	0.5	224	96	30	809	1020	175	0.5
	8	C1FA30EA40	0.5	217	93	40	810	1020	175	0.5

Table 4: Mix proportions of mortar

No.	Designation	FA (% by wt)	EA (% by wt)	Mix proportion (ratio by weight)					
				Cement type		Additive		Sand	Water
				I	V	FA	EA		
1	C1	-	-	1	-	-	-	2.75	0.40
2	C5	-	-	-	1	-	-	2.75	0.40
3	C1FA30	30	-	0.70	-	0.30	-	2.75	0.40
4	C1EA10	-	10	0.90	-	-	0.10	2.75	0.40
5	C5EA10	-	10	-	0.90	-	0.10	2.75	0.40
6	C1FA30	30	10	0.63	-	0.27	0.10	2.75	0.40
7	C1	-	-	1	-	-	-	2.75	0.55
8	C5	-	-	-	1	-	-	2.75	0.55
9	C1FA30	30	-	0.70	-	0.30	-	2.75	0.55
10	C1EA10	-	10	0.90	-	-	0.10	2.75	0.55
11	C5EA10	-	10	-	0.90	-	0.10	2.75	0.55
12	C1FA30	30	10	0.63	-	0.27	0.10	2.75	0.55

3. Results and Discussions

3.1. Carbonation

Figure 5 shows the effect of EA content on carbonation depth of fly ash concrete and cement-only concrete. It is found that; in case of concrete without fly ash, when EA content increases up to 40 kg/m^3, carbonation depth of EA concrete is lower than that of non-EA concrete. In case of fly ash concrete, when EA content is lower than 30 kg/m^3, carbonation resistance of EA fly ash concrete is better than that of non-EA fly ash concrete. But when EA content exceeds 30 kg/m^3, carbonation resistance of EA fly ash concrete is worse than that of non-EA fly ash concrete.

The improvement of carbonation resistance (when EA < 30 kg/m^3) is mainly because of the formation of higher amount of $Ca(OH)_2$ in expansive concrete than in cement-only concrete. In addition, the presence of EA with a suitable content in concrete makes its structure denser, so it can prevent CO_2 from penetrating into concrete. But, when too much EA (EA > 30 kg/m^3) is used, higher porosity and micro cracking in concrete maybe formed, so CO_2 can penetrate into concrete more easily.

3.2. Sulfate resistance

Figure 6 and Figure 7 show the relationship between expansion and period of immersion in sodium sulfate solution of mortars with W/B of 0.4 and 0.55, respectively. It can be seen that, mixtures with W/B=0.4 and W/B=0.55 show the same tendency. In case of cement-only mortar (no fly ash), the expansions of cement type 5 mortar specimens are slightly smaller than those of cement type 1 mortar specimens.

In case of fly ash mortar, the mixtures with no EA show reduction of expansion, but with EA, the mixtures with fly ash show the highest expansion.

The explanation can be made as follows. Since expansive additive used in this research is CaO type, a large amount of $Ca(OH)_2$ was formed in the reaction of EA together with the formation of monosulfate and ettringite at early age.

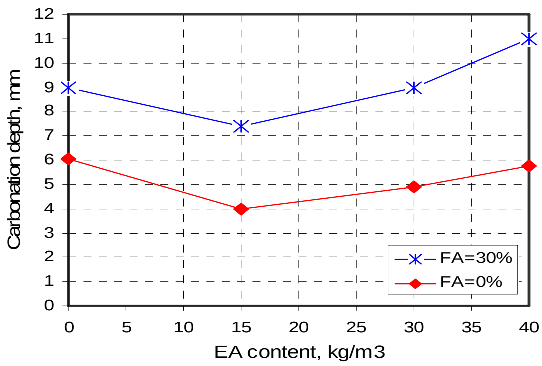

Figure 5 Effect of EA content on carbonation depth of fly ash and cement-only concrete

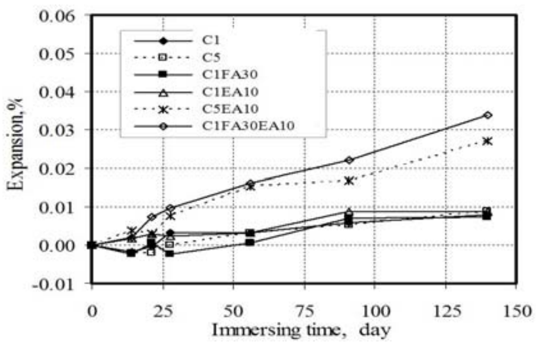

Figure 6 Effect of type of binder on expansion of mortars with W/B=0.4 in sodium sulfate solution

This makes mortar specimens with EA have higher expansion.

In addition, when cement was partially replaced by fly ash, in case of no EA, this replacement reduces not only C_3A content of binder but also produces less amount of $Ca(OH)_2$. But, in case of EA, the presence of fly ash gives much higher expansion by itself [1]. So, finally this mixture shows the highest expansion.

For this reason, it is suggested that the use of expansive additive should be carefully managed in sodium sulfate environment.

3.3. Chloride binding capacity and chloride penetration resistance

Figure 8 and Figure 9 show the effect of type of binder on chloride penetration resistance and chloride binding

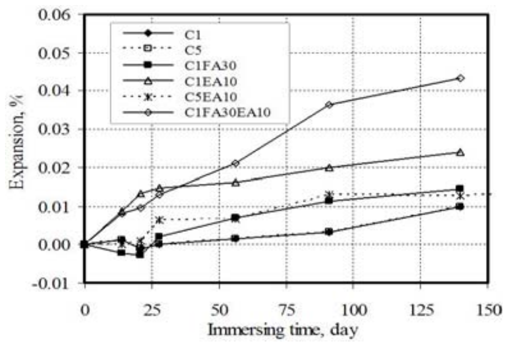

Figure 7 Effect of type of binder on expansion of mortars with W/B=0.55 in sodium sulfate solution

capacity of pastes with W/B=0.4 and W/B=0.5, respectively. Figure 10 shows the effect of type of binder on fixed chloride ratio of paste with different W/B (0.4, 0.5). Mixtures with W/B=0.4 and W/B=0.5 show nearly the same tendency.

In both cases of mixtures with and without EA, fly ash results in reduction of chloride penetration resistance of pastes (Figure 8 and Figure 9). These results are different from the previous research [10]. This difference is because of short curing period of specimens (7 days) before exposing to chloride environment. So at that time, porosity of fly ash paste is higher than that of the cement-only paste. In case without EA, fly ash improves chloride binding capacity of paste (Figure 10). In case with EA, chloride binding capacities of specimens with and without fly ash are nearly the same (Figure 10).

The presence of EA results in reduction of chloride binding capacity (Figure 10) but improves chloride penetration resistance of pastes (Figure 8 and Figure 9). Since by the use of expansive additive to partially replace cement, the C_3A and C_4AF content of binder, which can react with chloride ion, reduces. It results in reduction of chloride binding capacity of paste. But when EA was used with a suitable content, it produces denser paste, resulting in improvement of chloride penetration resistance of paste.

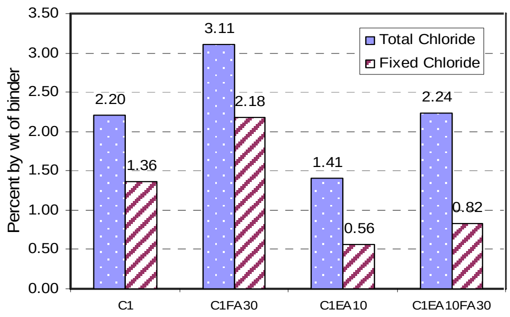

Figure 8 Effect of type of binder on chloride diffusion and chloride binding capacity of pastes with W/B=0.4

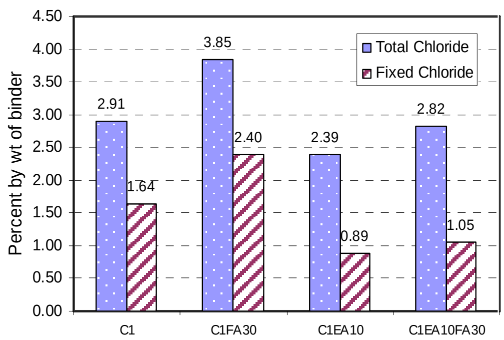

Figure 9 Effect of type of binder on chloride diffusion and chloride binding capacity of pastes with W/B=0.5

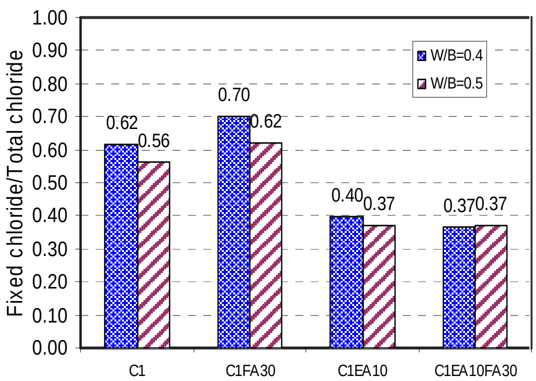

Figure 10 Effect of type of binder and W/B on fixed chloride ratio of pastes

4. Conclusions

From the test results, the following conclusions can be drawn:

1. When EA content is lower than 30 kg/m^3, carbonation resistance of both fly ash concrete and cement-only concrete is better than that of the concrete without EA. But when EA content is higher than 30 kg/m^3, lower carbonation resistance of fly ash concrete can be obtained.
2. Expansive additive causes higher expansion of mortar in sodium sulfate environment.
3. Expansive additive improves chloride penetration resistance of paste.
4. Expansive additive reduces chloride binding capacity of paste

5. Acknowledgement

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