

Expansion and Compressive Strength of Concrete with Expansive Additive

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Abstract

This paper presents a study on expansion and compressive strength of concrete with expansive additive. In this research, the effect of amount of expansive additive (EA), type of binder, water to binder ratio, curing temperature, curing condition and restraining ratio on expansion and compressive strength of expansive concrete were studied. The results show that, expansive additive is more effective on free expansion and restrained expansion of fly ash concrete than concrete with other types of binders. Expansion of expansive concrete developed within 3 days, after that it is constant or reduces slightly due to shrinkage. Under free condition, when incorporating high EA content strength drop problem of expansive fly ash concrete is more severe than cement-only concrete. But this problem becomes less severe when concrete is restrained.

Keyword: Free expansion, Restrained expansion, Expansive concrete, Compressive strength, Expansive additive, Fly ash concrete.

1. Introduction

Concrete has two major unpreferable properties which are shrinkage and low tensile strength. Therefore, under restrained condition, concrete structure may crack due to autogenous shrinkage and drying shrinkage. In order to surmount this cracking problem, expansive concrete has been utilized as one of the solutions. Although expansive concrete has

been developed since 1930s, its behaviors are still not fully understood.

There are two methods to make expansive concrete. The first one is to use expansive cement to make expansive concrete. This method has been extensively used in America and Europe. The other is to add expansive additive at the time of mixing concrete to make expansive concrete. This method is a general method in Japan.

Expansive additive can be classified into two main types i.e. C-S-A type which contains mainly calcium sulfo aluminate ($3\text{CaO}\cdot 3\text{Al}_2\text{O}_3\cdot \text{CaSO}_4$) and CaO type which contains mainly free calcium oxide (CaO) [6]. The C-S-A type causes concrete to expand mainly by the transformation of a mixture of calcium sulfo aluminate ($\text{C}_4\text{A}_3\text{S}$), lime (CaO) and anhydrite (CaSO_4) into ettringite, whereas the CaO type causes concrete to expand mainly by the transformation of free calcium oxide into calcium hydroxide and the formation of ettringite. The CaO-type expansive additive was used in this research.

Expansive concrete can be used for two purposes i.e. shrinkage-compensating and chemical prestressing. With the purpose to manufacture shrinkage-compensating concrete, the authors narrow the scope to study the expansive additives with amount of 15 to 45 kg/m^3 in cement-only concrete, fly ash concrete with various fly ash contents and concrete containing limestone powder under sealed curing, water curing and air curing conditions.

2. Experimental Program

2.1. Materials and mix proportion

Ordinary Portland cement type 1 (OPC1), high early strength cement (HESC3), limestone powder (LP) and fly ash (FA) were used as binders. Chemical composition and physical properties of these materials are given in Table 1. River sand and a crushed stone were used as aggregates. 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 [7]. The mix proportions are given in Table 3. The designation of mixtures in Table 3 can be explained as follows: OPC1- ordinary Portland cement type 1; HESC3- high early strength cement; FA- Fly ash content (0, 30 and 50%); LP- Limestone powder content (10%) and EA- amount of expansive additive (0, 15, 30, 35, 40 and 45 g/m³).

2.2. Method of testing

Setting time of cement paste containing different type of binder and different amount of expansive additive were determined according to ASTM C187-98 [10] and ASTM C191-99 [11].

Expansion and compressive strength of expansive concrete were tested under free condition and also restrained condition. The restrained test is necessary because shrinkage cracking of concrete only happens under restrained condition. Expansive concrete is applied to relieve cracking problem of concrete structure. Under restrained condition, when expansive concrete expands, it produces tensile stress in steel bar and compressive stress in concrete. The compressive stress in concrete will eliminate or reduce tensile stress which

occurs when concrete shrinks under restrained condition. By measuring restrained expansion, we can calculate the compressive stress in concrete which will be used together with tensile strain capacity and creep in the crack control.

The specimens with the size of 75×75×250 mm were used for free expansion tests. These tests conform to ASTM C157/C157M - 99 [8]. The specimens with the size of 100×100×400 mm were used for restrained expansion test. The cylinder specimens with the size of φ100×200 mm were used for free compressive strength tests [9]. The 100×100×100 mm cube specimens were used for restrained compressive strength test. Restraining ratio for restrained compressive strength test was 1.571%.

For each mix proportion, concrete specimens for testing free expansion and free compressive strength were cast at the same time. These specimens were demoulded at 24 hours after casting. Initial length of the specimens for free expansion test was measured just after demoulding. For restrained expansion test, the strain of specimens was measured by strain gages which were connected to Data logger at 7 hours after casting. The main curing condition was sealed curing but water curing and air curing were also conducted on some mixes for comparison (mixes No.12 and 15). The free expansion of each specimen was measured at the age of 3 days, 7 days, 14 days and 28 days. Compressive strength was tested at the age of 3 days, 7 days and 28 days. Two specimens were used for each mix and the result is the average of their measured values.

Table 1: Chemical compositions and physical properties of binder

Material	SiO ₂ (%)	Al ₂ O ₃ (%)	Fe ₂ O ₃ (%)	CaO (%)	MgO (%)	SO ₃ (%)	Na ₂ O (%)	K ₂ O (%)	LOI (%)	Fineness* (cm ² /g)	Specific gravity
OPC1	20.20	4.70	3.73	63.40	1.37	1.22	-	0.28	2.72	3430	3.15
OPC3	20.73	4.49	3.32	64.89	1.25	2.76	0.24	0.32	1.23	4770	3.22
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
LP	0.06	0.09	0.04	54.80	0.57	-	-	-	43.80	9260	2.70

*Using the Blaine method.

Table 2: Physical properties of aggregate

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 proportion

Type of Binder	No.	Designation	W/B	C (kg)	FA (kg)	LP (kg)	EA (kg)	S (kg)	G (kg)	W (kg)	SP (%)
Cement type 1 only	1	OPC1FA0EA0	0.4	350	0	0	0	865	1089	140	1.7
	2	OPC1FA0EA0	0.5	350	0	0	0	824	1038	175	0.8
	3	OPC1FA0EA0	0.6	350	0	0	0	783	986	210	-
	4	OPC1FA0EA15	0.5	335	0	0	15	823	1037	175	0.8
	5	OPC1FA0EA30	0.5	320	0	0	30	823	1037	175	0.8
	6	OPC1FA0EA35	0.5	315	0	0	35	823	1037	175	0.8
	7	OPC1FA0EA40	0.5	310	0	0	40	823	1037	175	0.8
	8	OPC1FA0EA45	0.5	305	0	0	45	823	1037	175	0.8
Cement type 1 and FA 30%	9	OPC1FA30EA0	0.5	245	105	0	0	808	1018	175	0.5
	10	OPC1FA30EA15	0.5	234.5	100.5	0	15	809	1019	175	0.5
	11	OPC1FA30EA30	0.4	224	96	0	30	850	1071	140	1.5
	12	OPC1FA30EA30	0.5	224	96	0	30	809	1020	175	0.5
	13	OPC1FA30EA30	0.6	224	96	0	30	768	968	210	-
	14	OPC1FA30EA35	0.4	220.5	94.5	0	35	850	1071	175	1.5
	15	OPC1FA30EA35	0.5	220.5	94.5	0	35	809	1020	175	0.5
	16	OPC1FA30EA35	0.6	220.5	94.5	0	35	769	968	210	-
	17	OPC1FA30EA40	0.4	217	93	0	40	851	1072	175	1.5
	18	OPC1FA30EA40	0.5	217	93	0	40	810	1020	175	0.5
	19	OPC1FA30EA40	0.6	217	93	0	40	769	968	210	-
	20	OPC1FA30EA45	0.5	213.5	91.5	0	45	810	1020	175	0.5
Cement type 1 and FA 50%	21	OPC1FA50EA0	0.5	175	175	0	0	798	1006	175	0.5
	22	OPC1FA50EA30	0.5	160	160	0	30	800	1008	175	0.5
	23	OPC1FA50EA35	0.5	157.5	157.5	0	35	800	1008	175	0.5
Cement type 3	24	HESC3FA0EA0	0.5	350	0	0	0	826	1041	175	0.8
	25	HESC3FA0EA35	0.5	320	0	0	30	826	1040	175	0.8
	26	HESC3FA30EA35	0.5	220.5	94.5	0	35	811	1022	175	0.5
OPC1 and LP	27	OPC1LP10EA0	0.5	315	0	35	0	821	1035	175	0.6
	28	OPC1LP10EA35	0.5	283.5	0	31.5	35	821	1034	175	0.6

3. Result and Discussion

3.1. Setting times

The designation of paste mixtures used for setting time test which was shown in Figure 1 is different from that used for concrete in Table 3. It can be explained as follows: OPC1-ordinary Portland cement type 1; FA- Fly ash content (0, 30 and 50%); LP- Limestone powder content (10%) and EA- expansive additive content (0% and 10% of binder which includes EA).

Figure 1 shows the effect of type of binders on setting time of paste. In case of Portland cement paste, the initial and final

setting times of paste containing 10% EA are 17 and 22 minutes, respectively, shorter in comparison with the sample without EA. In case of paste with 30% FA, the differences of initial and final setting times between the sample containing 10% EA and the sample without EA are 18 and 35 minutes, respectively. The initial and final setting times of paste containing 30% FA and 10% EA are shorter than those of paste with cement only. The sample containing 10% LP and 10% EA showed the shortest initial and final setting times.

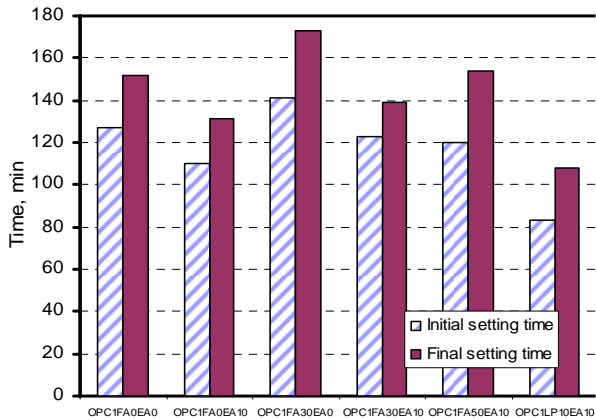


Fig. 1: Effect of type of binder on setting time of paste

Figure 2 shows the effect of EA content on setting time of paste containing 30% FA. With the presence of EA in paste, the initial and final setting times of paste are shortened. When EA content increases, both initial and final setting times of paste containing 30% fly ash become shorter. This result can be explained by the formation of a large amount of expansive products in pastes containing expansive additive [5]. In addition, the hydration reaction rate of EA is faster than that of cement. So, when EA was used with fly ash concrete, it can accelerate the setting time of fly ash pastes.

3.2. Free expansion

3.2.1 Influence of water to binder ratio on free expansion of expansive concrete

Free expansions of expansive concrete containing 30% FA with different water to binder ratios are shown in Figure 3 and Figure 4. With 35 kg/m³ of EA, the free expansion of the mix with W/B = 0.5 is about 1.8 times larger than that of the mix with W/B = 0.4. When W/B is 0.6, the free expansion is about 6.5 and 3.6 times larger in comparison with those of the mixes with W/B = 0.4 and W/B = 0.5, respectively. When using 40 kg/m³ of expansive additive, the difference of free expansion between the mix with W/B = 0.5 and the mix with W/B = 0.6 becomes smaller (about 1.6 times) but the difference between the mix with W/B = 0.6 and the mix with W/B = 0.4 is nearly the same as in the case of using 35 kg/m³ of expansive additive (about 6.8

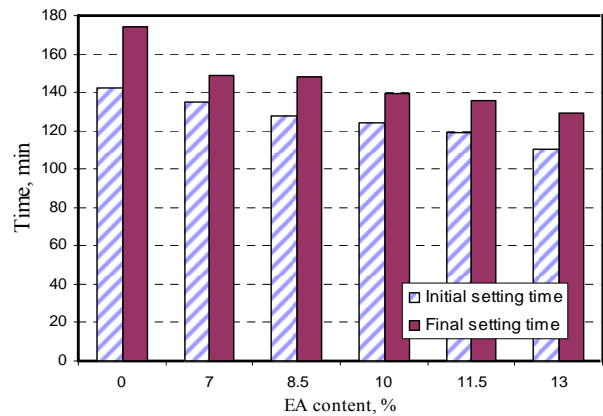


Fig. 2: Effect of EA content on setting time of paste containing 30% FA

times) (Figure 4). When W/B increases, free expansion of expansive concrete increases significantly, but it becomes more difficult to control the expansion, especially when EA content is higher.

3.2.2. Influence of curing condition on free expansion of expansive concrete

Figure 5 and Figure 6 show the free expansion of fly ash concrete (FA = 30%) containing 30 and 35 kg/m³ of expansive additive, respectively.

In case of expansive concrete containing 30 kg/m³ of expansive additive, the free expansions of the mixes under sealed curing and water curing are nearly the same, and are about 3 times larger as compared to the air-cured mix. In the case of specimens cured in water for 7 days and in air afterward, before 7 days their free expansions are equal to those of the specimens cured in water, but after being kept in air their free expansion start to reduce due to shrinkage. However, at the age of 28 days their free expansion are still 2 times larger than the maximum free expansion of specimens cured in air right after demoulding (Figure 5). In case of using 35 kg/m³ of expansive additive, a large difference of free expansion between the mixes under sealed curing and those under water curing was observed. With water curing, free expansion of this mix increases about 46% over the mix with sealed curing (Figure 6). This is because water is necessary for expansive products formation.

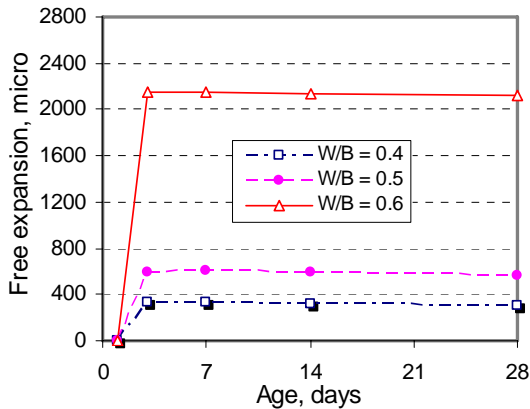


Fig. 3: Effect of W/B on free expansion of expansive concrete containing 35 kg EA/m³

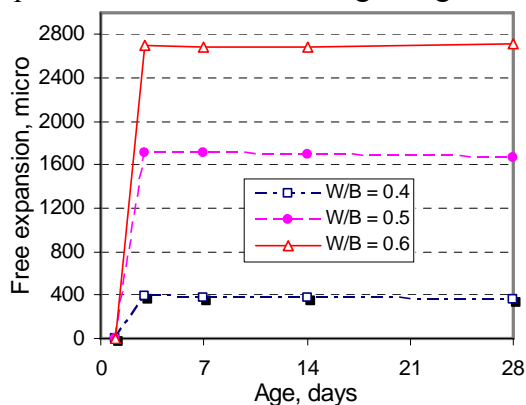


Fig. 4: Effect of W/B on free expansion of expansive concrete containing 40 kg EA/m³

3.2.3. Influence of type of binder on free expansion of expansive concrete

Type of binder greatly affects free expansion of expansive concrete. Mixture with fly ash shows larger free expansion than others. With the same amount of EA, when FA content increases, free expansion of concrete also increases. However, when fly ash content is very high (50%), it becomes difficult to control free expansion of the expansive concrete. Mixture with 10% LP shows about the same free expansion with the mixture with OPC1 only (Figure 7).

3.2.4. Influence of curing temperature on free expansion of expansive concrete

The effect of curing temperature on free expansion of cement-only concrete and fly ash concrete is shown in Figure 8 and Figure 9, respectively. The results show that, free expansion of concrete is very sensitive to

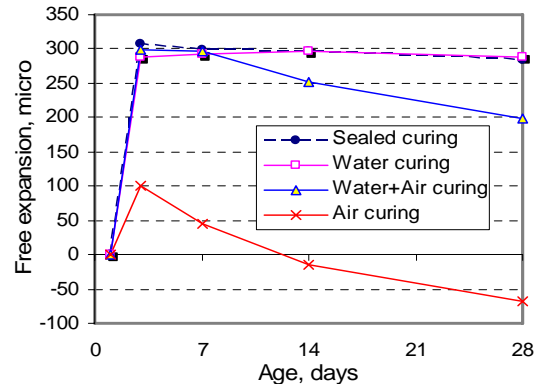


Fig. 5: Effect of curing condition on free expansion of concrete containing 30kg/m³ of EA (W/B=0.5, FA=30%)

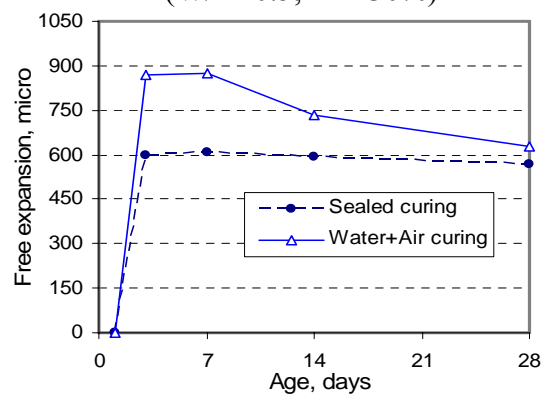


Fig. 6: Effect of curing condition on free expansion of concrete containing 35kg/m³ of EA (W/B=0.5, FA=30%)

curing temperature. When curing temperature increases, free expansion of cement-only concrete and fly ash concrete increases and concrete also achieved the maximum expansion at earlier time. These results can be explained in such a way that, high curing temperature accelerates the expansive reaction. So, a large amount of expansive products were formed at early age when the stiffness of paste is not too high, hence the concrete can expand easier.

3.2.5. Influence of amount of expansive additive and fly ash content on free expansion of expansive concrete

Figure 10 shows the relationship between EA content and free expansion of concrete containing different FA content (0%, 30% and 50%). The results show that, EA is more effective in fly ash concrete than in cement-only concrete.

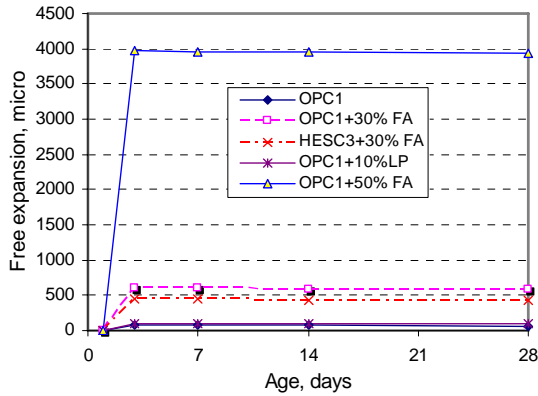


Fig. 7: Effect of type of binder on free expansion of expansive concrete containing 35kg/m³ of EA

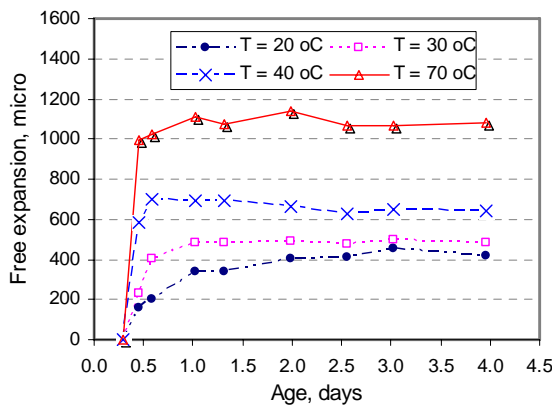


Fig. 8: Effect of curing temperature on free expansion of cement-only concrete containing 30 kg/m³ of EA

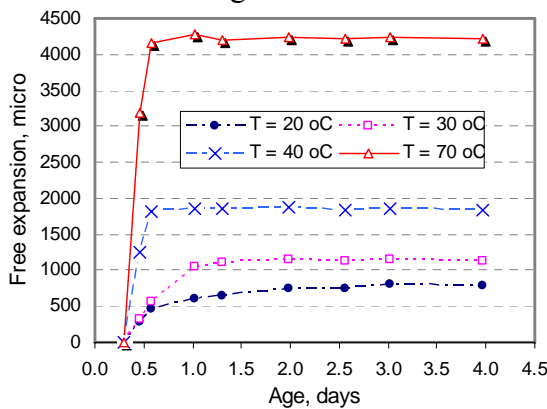


Fig. 9: Effect of curing temperature on free expansion of fly ash concrete containing 30 kg/m³ of EA

In case of fly ash concrete containing 30% FA, when amount of EA increases, free expansion increases gradually. The free expansion of fly ash concrete increases only a little when amount of EA exceeds 40 kg/m³. But, when FA content becomes higher

(50%), free expansion increases tremendously. Figure 11 shows that with the same amount of EA, when FA content increases, the free expansion increases significantly. In the case of cement-only concrete, at amount of EA up to 40 kg/m³, free expansion doesn't change much (see figure 10). However, when amount of EA exceeds 40 kg/m³ the free expansion develops very fast. These results imply that when using fly ash, the behavior of concrete changes, especially the stiffness of paste. Stiffness of fly ash concrete is low and also develops slowly, so fly ash concrete is easier to expand. Hydration products may also be different. In addition, fly ash also contains some substances such as SO₃ and CaO that can join in the expansive reaction to produce expansive products.

3.3. Restrained expansion

3.3.1. Influence of restraining ratio on restrained expansion of concrete

Figure 12 and Figure 13 show the expansion of fly ash concrete and cement-only concrete, respectively at different restraining steel ratios ($\rho = 0\%, 0.785\%, 1.571\%$ and 3.142%). Figure 14 shows the relationship between restraining steel ratio and expansion of fly ash concrete and cement-only concrete.

When restraining steel ratio increases, expansion of both fly ash concrete and cement-only concrete greatly decrease. At $\rho = 0.785\%$, restrained expansion of fly ash concrete and cement-only concrete are only 47% and 55% of their corresponding free expansion (Figure 12 & Figure 13).

With the same amount of EA, restrained expansion of fly ash concrete is still higher than that of cement-only concrete for all restraining ratios. With $\rho = 0.785\%, 1.571\%$ and 3.142% the restrained expansion of fly ash concrete are 35 μ , 39 μ and 29 μ higher than that of cement-only concrete, respectively (Figure 14). This indicates that it is possible to reduce EA content when using FA, and EA is more effective when used with fly ash concrete for crack control.

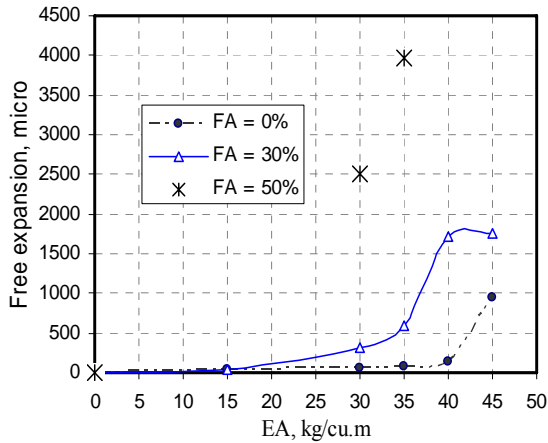


Fig. 10: Relationship between free expansion of concrete containing different FA content and amount of EA at 3 days

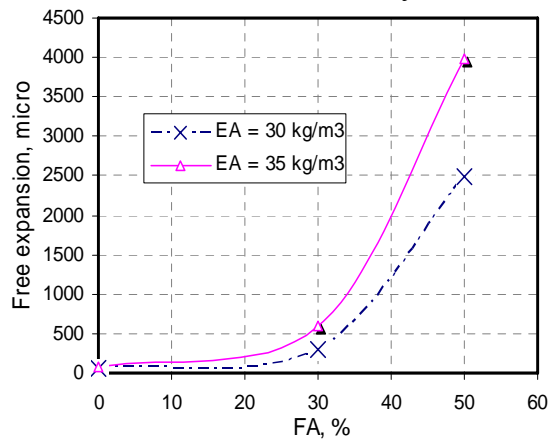


Fig. 11: Relationship between free expansion of concrete containing different amount of EA and FA content at 3 days

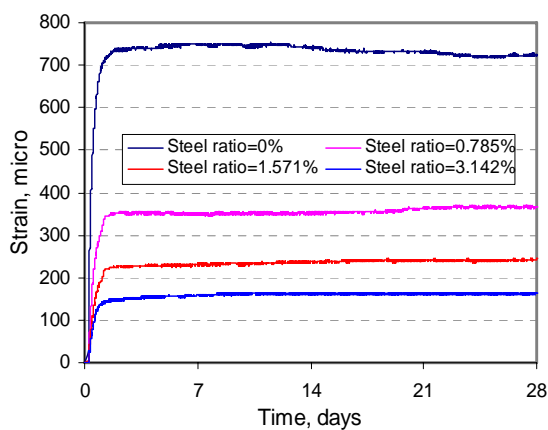


Fig. 12: Effect of restraining ratio on expansion of Fly ash concrete (FA=30%, EA=30 kg/m³, W/B=0.5)

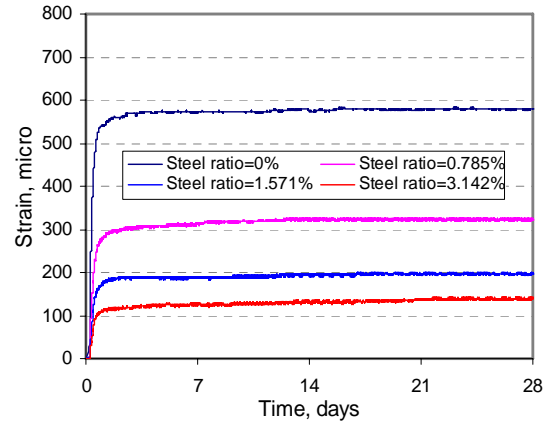


Fig. 13: Effect of restraining ratio on expansion of cement-only concrete (FA=0%, EA=30 kg/m³, W/B=0.5)

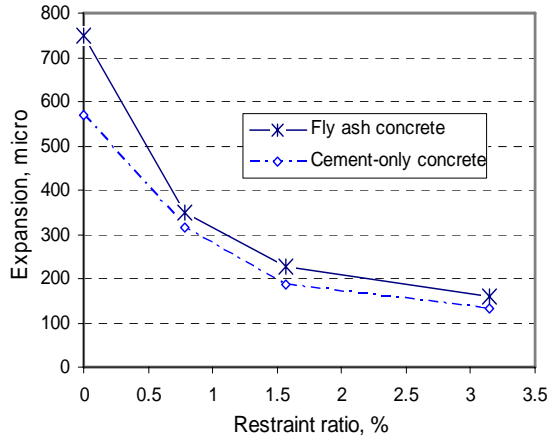


Fig. 14: Relationship between restraining ratio and expansion of concrete at 28 days

3.3.2. Influence of EA content on restrained expansion of concrete

Figure 15 and Figure 16 show the restrained expansion ($\rho=1.571\%$) of fly ash concrete and cement-only concrete containing different EA contents. Figure 17 shows the relationship between restrained expansion ($\rho=1.571\%$) and EA content of fly ash concrete and cement-only concrete.

The results show that, under restrained condition, EA is still more effective in fly ash concrete than in cement-only concrete. When EA content increases, restrained expansion of both fly ash concrete and cement-only concrete increase gradually. The difference between restrained expansion of cement-only concrete and fly ash concrete is smaller than the case of free expansion (Figure 17).

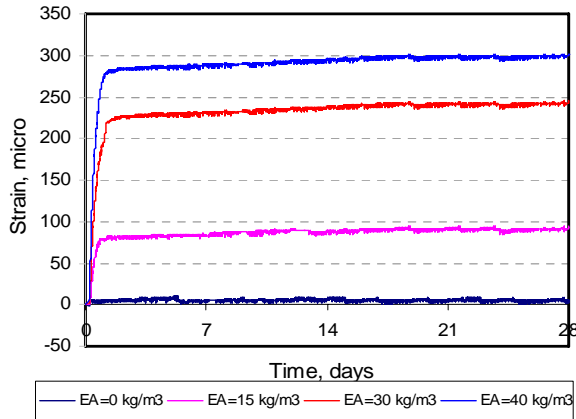


Fig. 15: Effect of EA content on restrained expansion of Fly ash concrete (FA=30%, $\rho=1.571\%$, W/B=0.5)

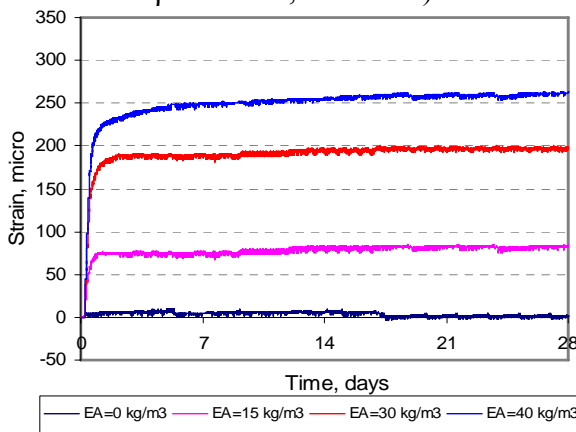


Fig. 16: Effect of EA content on restrained expansion of cement-only concrete (FA=0%, $\rho=1.571\%$, W/B=0.5)

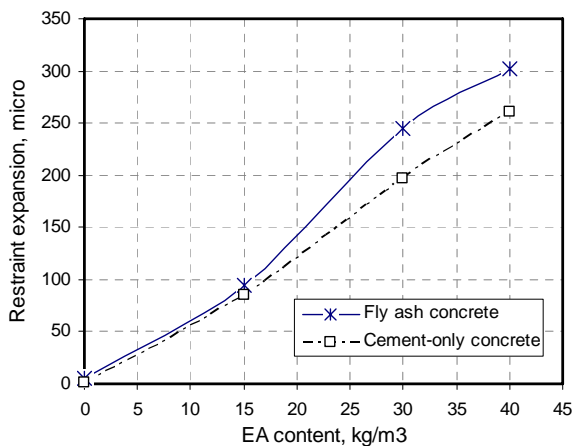


Fig. 17: Relationship between EA content and restrained expansion of concrete at 28 days

3.4. Compressive strength

3.4.1. Influence of amount of expansive additive on compressive strength of expansive concrete without restraint

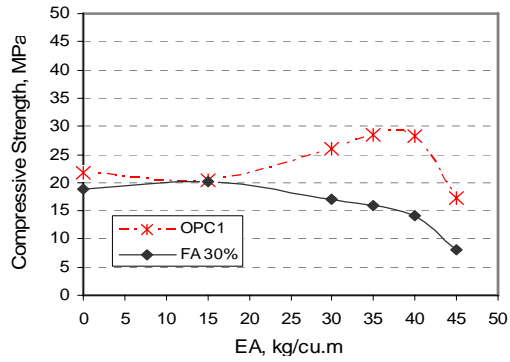
Figure 18 shows that EA has much effect on compressive strength of both cement-only concrete and fly ash concrete. In case of cement-only concrete, when amount of EA increases up to 40 kg/m^3 , compressive strength of concrete also increases. But when amount of EA exceeds 40 kg/m^3 , the compressive strength starts to drop below that of non-EA cement-only concrete. For fly ash concrete, when amount of EA exceeds 30 kg/m^3 , the compressive strength starts to drop below the non-EA fly ash concrete. Especially, when amount of EA exceeds 35 kg/m^3 , the compressive strength of expansive fly ash concrete drops severely.

So, fly ash concrete tends to more severely encounter the problem of strength drop when incorporating high EA content than cement-only concrete.

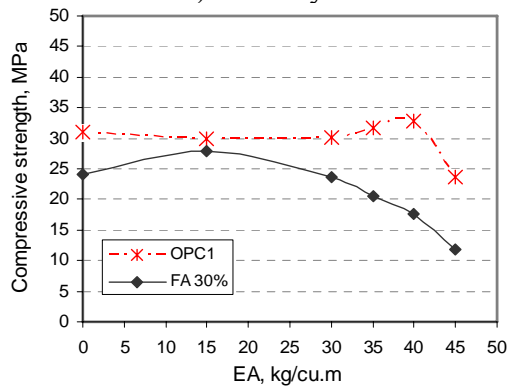
3.4.2. Influence of amount of expansive additive on compressive strength of restrained expansive concrete

Figure 19 shows the effect of EA content on compressive strength of restrained expansive concrete. In case of cement-only concrete, when EA content increases up to 40 kg/m^3 , compressive strength of restrained expansive concrete also increases. In case of fly ash concrete, unlike free condition case, when EA content increases up to 30 kg/m^3 , compressive strength of restrained expansive fly ash concrete is still higher than that of non-EA fly ash concrete. However, when EA content increases to 40 kg/m^3 , compressive strength of restrained expansive fly ash concrete is about 10% lower than that of non-EA mix. So, for the tested restraining ratio, there is no problem about compressive strength drop of expansive concrete in restrained condition if EA content is not higher than 30 kg/m^3 . The dosage of 30 kg/m^3 is generally recommended by the manufacturer.

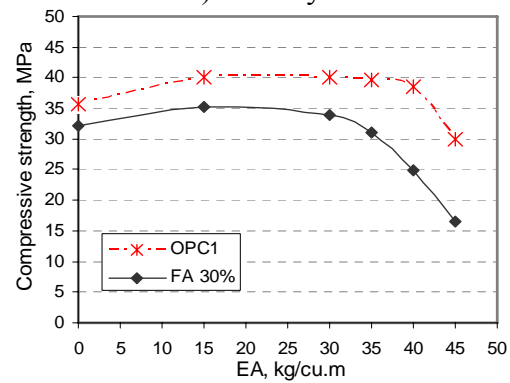
It can be concluded by comparing Fig. 18 and Fig. 19 that the problem of strength drop when incorporating high EA content of fly ash concrete becomes less severe when the concrete is restrained.



a) At 3 days

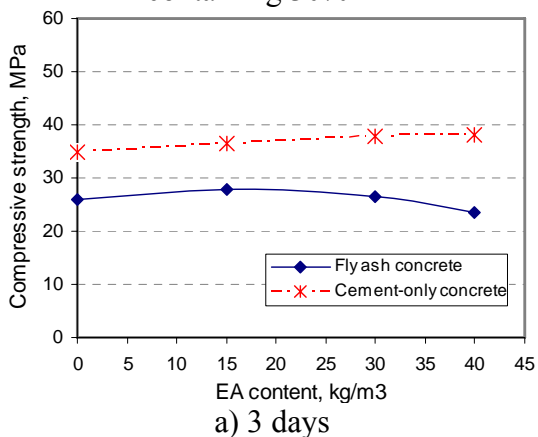


b) At 7 days

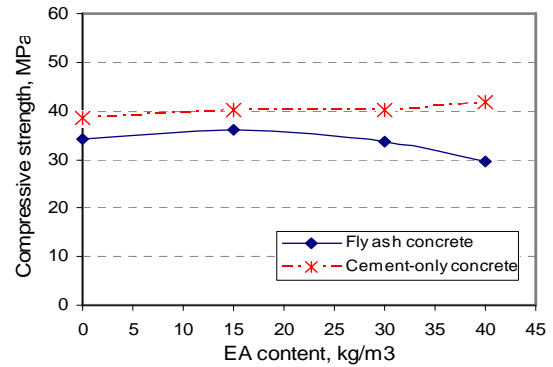


c) At 28 days

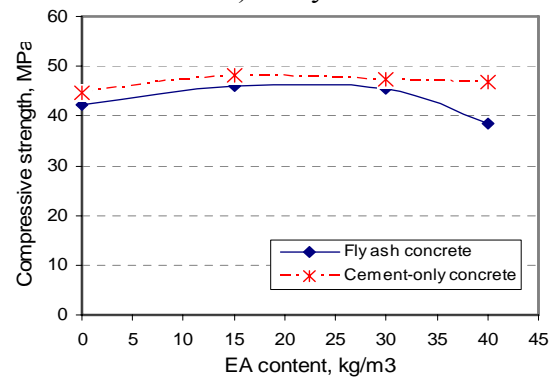
Fig. 18: Relationship between EA content compressive strength in free condition of cement-only concrete and fly ash concrete containing 30% FA



a) 3 days



b) 7 days



c) 28 days

Fig. 19: Relationship between EA content and compressive strength in restrained condition of cement-only concrete and fly ash concrete containing 30% FA

4. Conclusions

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

1. The presence of expansive additive accelerates both initial and final setting time of pastes with and without fly ash.
2. Under both free condition and restrained condition, expansive additive is more effective in fly ash concrete than in cement-only concrete.
3. With the same amount of expansive additive, when fly ash content increases, free expansion of fly ash concrete also increases substantially.
4. Curing condition is important for expansive concrete. Water curing gives higher expansion than the others.
5. When W/B increases, the free expansion of concrete also increases. Especially, in the case of fly ash concrete, when W/B increases the free expansion of concrete increases drastically.

6. Under free condition, when incorporating high EA content strength drop problem of expansive fly ash concrete is more severe than cement-only concrete. But this problem becomes less severe when concrete is restrained.

5. Acknowledgement

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References

[1] Hu Shuguang and Li Yue, “Research on the hydration, hardening mechanism, and microstructure of high performance expansive concrete”, *Cement and Concrete Research*, Vol. 29, Issue 7, July 1999, Pages 1013-1017.

[2] Mario Collepardi, Antonio Borsoi, Silvia Collepardi, Jean Jacob Ogoumah Olagot and Roberto Troli, “Effects of shrinkage reducing admixture in shrinkage compensating concrete under non-wet curing conditions”, *Cement and Concrete Composites*, Vol. 27, Issue 6, July 2005, Pages 704-708.

[3] Cecilie Evju and Staffan Hansen, “The kinetics of ettringite formation and dilatation in a blended cement with β -hemihydrate and anhydrite as calcium sulfate”, *Cement and Concrete Research*, Vol. 35, Issue 12, December 2005, Pages 2310-2321.

[4] Jose Colan Subauste and Ivan Odler, “Stresses generated in expansive reactions of cementitious systems”, *Cement and Concrete Research*, Vol. 32, Issue 1, January 2002, Pages 117-122.

[5] Axel Nørlund Christensen, Torben R. Jensen and J.C.Jonathan C. Hanson, “Formation of ettringite, $\text{Ca}_6\text{Al}_2(\text{SO}_4)_3(\text{OH})_{12}\cdot 26\text{H}_2\text{O}$, AFt, and monosulfate, $\text{Ca}_4\text{Al}_2\text{O}_6(\text{SO}_4)\cdot 14\text{H}_2\text{O}$, AFm-14, in hydrothermal hydration of Portland cement and of calcium aluminum oxide-calcium sulfate dihydrate mixtures studied by in situ synchrotron X-ray powder diffraction”, *Journal of Solid State Chemistry*, Vol. 177, Issue 6, June 2004, Pages 1944-1951.

[6] S. Nagataki and H. Gomi, “Expansive admixtures (mainly ettringite)”, *Cement and Concrete Composites*, Volume 20, Issues 2-3, 1998, Pages 163-170.

[7] ASTM C 33-97, Standard Specification for Concrete Aggregates, ASTM Standard, Vol. 04.02.

[8] ASTM C 157/C 157M-99, Standard test method for Length change of Hardened Hydraulic - Cement Mortar and Concrete, ASTM Standards, Vol. 04.02.

[9] ASTM C 39/C 39M-99, Standard test method for Compressive strength of Cylindrical Concrete Specimens, ASTM Standards, Vol. 04.02.

[10] ASTM C 187 - 98, Standard Test Method for Normal Consistency of Hydraulic Cement, ASTM Standards, Vol. 04.01.

[11] ASTM C 191 - 99, Standard Test Method for time of Setting of Hydraulic Cement by Vicat Needle, ASTM Standards, Vol. 04.01.