Research Article

Effect of Internal Curing on Expansion and Shrinkage of Expansive Concrete

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Abstract

This article presents an experimental study on early age length change of expansive concrete produced by adding expansive additive into concrete and partially replacing fine aggregate with bottom ash in order to investigate the effect of internal curing on the expansion behavior of expansive concrete. To evaluate the length change of the expansive concrete, three experiments were conducted. Free expansion and restraint expansion were tested to confirm the behavior of early age expansion of the expansive concrete. After that free shrinkage was tested to study subsequent shrinkage after the concrete was exposed to a drying environment. It was found, from the experimental results, that bottom ash can increase expansion of expansive concrete with and without fly ash in both free condition and restrained condition. However, the subsequent shrinkage of the expansive concrete is also increased. The experimental findings indicate that the internal curing can potentially be applied to increase the efficiency of expansive concrete however the balance between the enhanced expansion and the subsequent drying shrinkage must be carefully considered.

Keywords: expansive concrete; shrinkage compensating; expansive additive; restraint expansion; free expansion; internal curing; bottom ash; shrinkage; drying

1. Introduction

Shrinkage is one of the main causes of cracking in reinforced concrete structures. Autogenous shrinkage and drying shrinkage are two main subcomponents that induce tensile stress in a hardened concrete if they are restrained [1]. Shrinkage cracks normally take place when the induced tension exceeds tensile capacity of the concrete. Autogenous shrinkage is an intrinsic property of concrete and can occur even when the concrete does not lose any moisture to its environment. This type of shrinkage consists of volume reduction due to chemical reactions (chemical shrinkage) and volume reduction due to ‘self-desiccation’ which is caused by water consumption in hydration and pozzolanic reactions [2,3]. Drying shrinkage,

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on the other hand, involves the loss of moisture from the concrete to the environment. Normally, autogenous shrinkage is more severe when the water to binder ratio of concrete is lower while drying shrinkage is more severe when the concrete has higher water to binder ratio [4].

Applying expansive concrete is one of the techniques that can be used to alleviate the shrinkage cracking problem [5]. Expansive concrete may be produced by adding an expansive additive into the concrete. The concrete must be designed, produced, and cured properly in order to allow an appropriate early age restrained expansion. If sufficient dosage of expansive additive is added to the concrete mixture, tensile stresses produced by both autogenous and drying shrinkages are counter-balanced by the compressive stress produced by early age restrained expansion. The tension in the concrete can then be reduced and cracking can be prevented. This mechanism is called 'shrinkage compensation'.

For real application of the expansive concrete, the concrete mix proportion must be carefully designed. Especially in the case that expansive additive is applied, the suitable dosage of expansive additive must be determined. Insufficient dosage of expansive additive may not be effective for shrinkage compensation. While, an excessive dosage of expansive additive may result in too high cost since the price of expansive additive is still very high (in Thailand, approximately 15 times more expansive than cement). While, an insufficient dosage of expansive additive might not be able to achieve the necessary expansion to compensate for the shrinkage.

Internal curing (IC) is a technique to improve concrete quality. This technique uses water-filled inclusion to provide internal curing water to the cement paste in order to reduce self-desiccation and the risk of early age cracking [6]. The benefits of internal curing is to provide internal moisture to still unhydrated cement in the concrete so that hydration can be more complete. This results in improved strength, reduce autogenous shrinkage and enhance some durability properties of the concrete.

Bottom ash (BA) is a porous material (Figure 1). There is a potential to use it in the concrete as an internal curing material as well as a partial substitution of fine aggregate. It has been reported that 10% of bottom ash replacement in fine aggregate is suitable for reduce both curing sensitivity and the risk of cracking due to long- term shrinkage. However it can be used up to 30% by weight of fine aggregate without negative effect to compressive strength of concrete [7]. In fact, there are various types of internal curing materials such as water absorbent polymer, expanded clay, etc. However, these are manufactured materials, requiring process, energy and high cost of production. On the other hand, bottom ash is a by-product from coal power plants, requiring no costly or complex process to handle, making it very low cost when compared to other kinds of internal curing materials. It also has very high water retaining properties, which are the most significant properties for internal curing materials. Internal curing is not limited to small-scale laboratory application. The use of internally cured concrete was proved to reduce cracking in the field structure. [10,11] This article mainly emphasizes on the effect of internal curing, by using bottom ash as a partial substitution of fine aggregate, on early age expansion of the expansive concrete.

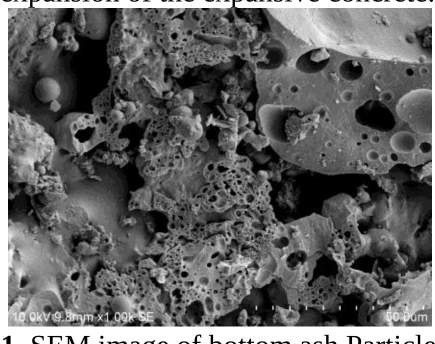


Fig.1. SEM image of bottom ash Particle.

2. Experimental Program

2.1 Materials and Mix Proportion

Concrete mix proportions tested in this study has w/b=0.5, volume of paste to void ratio equal to 1.3, as shown in Table 1. This mix proportion was selected as it is a representative mixture typically used for ready-mixed concrete. Ordinary Portland cement type 1 and a fly ash from Mae Moh generating plant were used as the binders. Specific gravity of the cement was 3.15 and that of the fly ash was 2.29. Since fly ash is widely used in most construction projects in Thailand as a cement replacement material and a common replacement ratio is around 20% by weight of binders. In this study, both concrete with 20% of fly ash and without fly ash were tested. For each type of binder, the mixes with and without bottom ash were tested. River sand with specific gravity of 2.59 and a maximum size of 4.75 mm was used as the fine aggregate. Limestone with specific gravity of 2.69 and a maximum size of 19 mm was used as the coarse aggregate.

In order to ensure the internal curing effect in the mixes with bottom ash, the bottom ash was added to replace 10% by weight of the fine aggregate in the mixes. This dosage of bottom ash was selected based on previous studies [6,7]

Bottom ash from a power plant in Prachinburi province, Thailand was used as an internal curing material in this study. Figure 2 shows the bottom ash preparation by sieving through sieve No.4 to remove over-size particles before use. The maximum size of the bottom ash is then 4.75 mm according to the opening size of the No.4 sieve. Gradations of fine aggregates, both sand and bottom ash, are shown in Figure 3.

The fly ash was obtained from Mae Moh electrical power plant in Lampang province, Thailand. River sand (S) and crushed limestone (G) were used as aggregates. The maximum size of coarse aggregate was 19 mm. Chemical compositions of the cement (C), fly ash (FA), expansive additive (EA), and bottom ash (BA) used in the experiment are shown in Table2

Table1. Mix proportions of the tested concrete.

Designation	OPC1 (kg/m^3)	FA (kg/m^3)	EA (kg/m^3)	BA (kg/m^3)	S (kg/m^3)	G (kg/m^3)	W (kg/m^3)
FA00EA20	345	0	20		806	1024	183
FA20EA20	264	71	20		806	1024	177
FA00EA20BA10	345	0	20	81	725	1024	183
FA20EA20BA10	264	71	20	81	725	1024	177

Table2. Chemical compositions of the tested materials.

Material Name	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	SO_3 (%)	K_2O (%)	Na_2O (%)
OPC1	20.02	5.13	3.21	64.56	2.13	2.90	0.43	0.25
FA	37.05	20.48	13.55	16.26	2.69	2.88	2.30	0.87
EA	3.96	2.01	1.43	66.94	0.64	14.70	0.12	0.12
BA	75.35	8.95	7.41	4.33	1.05	0.03	1.19	0.80

Fig.2. Sieving of bottom ash.

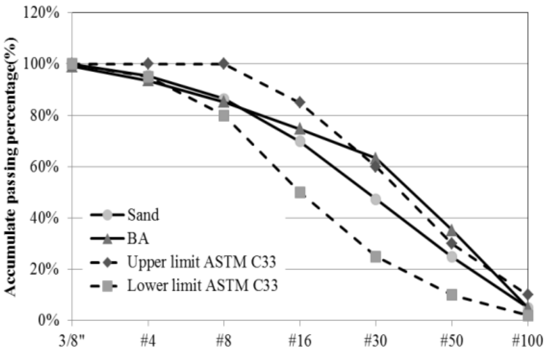


Fig.3. Gradation of fine aggregate.

2.2 Free Expansion/Shrinkage measurement

Specimens with the size of 75×75×250 mm^3 were used for free expansion/shrinkage test. The test conforms to ASTM C157-08. Initial lengths were recorded at 8 hours after mixing. The specimens were cured for 7 days after removing the mould and subsequently exposed to drying environment (28^{o}C and 75% relative humidity) as shown in Figure 4a. Afterwards, the free shrinkage of specimens was periodically measured. Figure 4b shows the specimens and measurement of free expansion/shrinkage.

Three specimens were used for each mix proportion and a test result was obtained from the average of the three specimens.

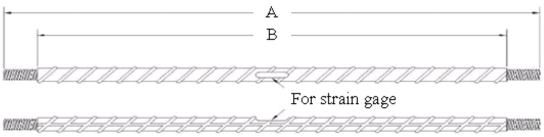
2.3 Apparatus for Restrained Expansion Measurement

A new set of restraining apparatus shown in Figure 5 was designed and employed for the restrained expansion measurement in this study. Conventional deformed bar for construction was used as the restraint. In comparison to other standard tests such as ASTM C878 [8], the usage of the conventional rebar provides similar condition to a real reinforced concrete member and also allows a convenient prefabrication of the apparatus. The restraining ratio in each specimen can also be adjusted by selecting appropriate size and number of steel bars. In this study, a steel ratio of 1.131% (one DB12 rebar) was used in the test program. The end steel plates with a thickness of 15 mm were used to prevent excessive difference in the expansion between the section centre (at the restraining rebar) and near the edge of the section.

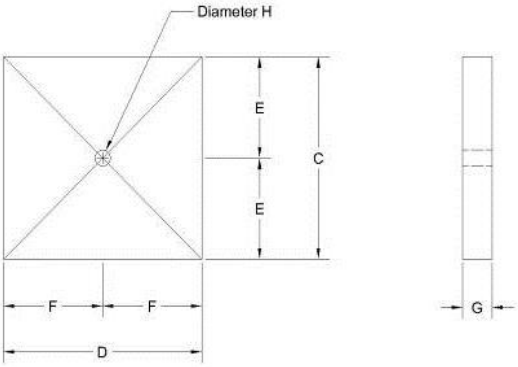
4a) Specimens for free expansion/shrinkage test

(4b) Length measurement

Fig.4. Measurement of free expansion/free shrinkage.

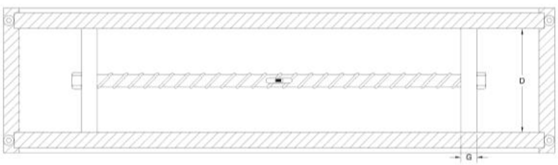


5(a) Steel bar for restraining



Section top view

5(b) End plate



5(c) Installation in the mold

Dimensions	Size(mm)
A	400
B	350
C	100
D	100
E	50
F	50
G	15
H	10

Fig.5. Geometry and size of specimens for measurement of internally restrained expansion.

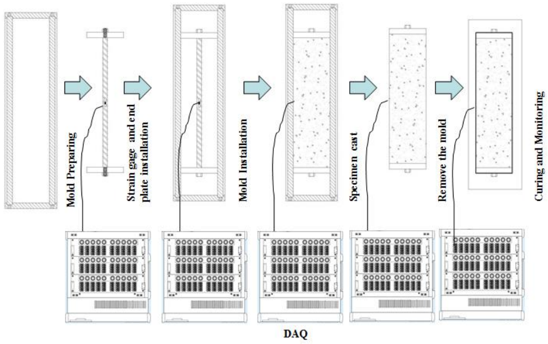
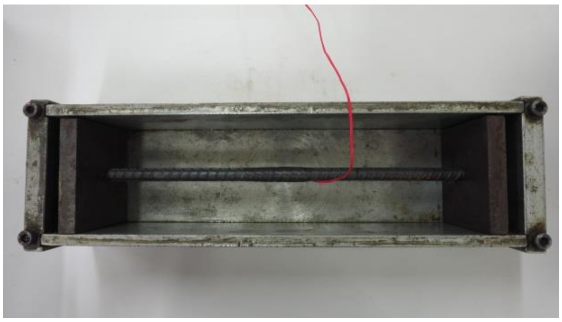


Fig.6. Step of internal retrained expansion test.



7(a) before casting

7(b) curing by wet clothes and plastic sheets until the age of 7 days

Fig.7. Mold preparing and curing.

2.3 Measurement of Restrained Expansion

Concrete specimens with a cross-sectional area of 100x100 mm and 350 mm length were used for the restrained expansion test. The specimens were cast into well-prepared steel formworks in which the apparatus described in the section 2.2 was installed beforehand (see Figure 6 for the prepared formwork and reinforcement before casting).

Electrical wire strain gages were attached in the middle of the steel bar in order to provide continuous reading as shown in Figure 6. The strain gages were then connected to data acquisition equipment (DAQ).

The casting was performed in a gentle manner to prevent any damage that may be induced to the strain gages. Good compaction was provided to eliminate air bubbles and ensure that the concrete can satisfactorily fill the formwork. The formwork was removed at 7 hours after casting. The specimens were then cured in a moist condition (wrapped by wet clothes and then covered with plastic sheets) as shown in Figure 7. The strain measurement was continuously performed. In this study, the specimen expansion from the age of 8 hours after casting will be considered and discussed. Each expansion value was obtained from an average of readings from two strain gages. It was clarified that the difference of the readings of identical samples was, in all cases, less than 10%. During the test process, the environmental temperature was controlled between 27.5 ^{o}C and 30 ^{o}C.

3. Result and discussions

3.1 Free expansion

By adding bottom ash into the normal expansive concrete to induce internal curing, it was found that a replacement of 10% in fine aggregate could increase 7-day free expansion by 14% (Figure 8) when compared to the expansive concrete without BA.

This effect is also observed in fly ash expansive concrete. The results in Figure 9 show that the 7-day expansion increases by 24% in fly ash expansive concrete with BA10% when compared to the fly ash expansive concrete without BA.

For the effect of fly ash on 7-day free expansion of mixtures with no BA, Figure 10 shows that the replacement of 20% fly ash in total binder (FA20EA20) increases the expansion by approximately15% when compared to expansive concrete with no fly ash (FA00EA20).

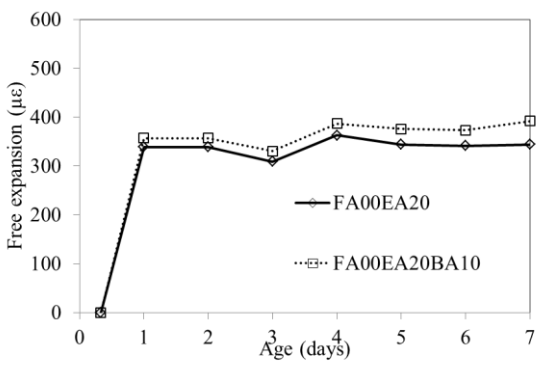


Fig.8. Effect of BA on free expansion of normal Expansive concrete.

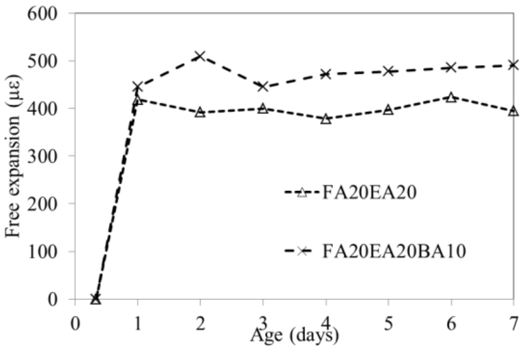


Fig.9. Effect of BA on free expansion of Fly Ash Expansive concrete.

However, for mixtures with BA an increase of 25% expansion over the mixture without fly ash was obtained when using fly ash with BA (Comparing FA20EA20BA10 with FA00EA20BA10). Moreover, the results of mixtures with 10%BA (FA00EA20BA10) and the mixture with 20%FA (FA20EA20), show that the 7-day free expansion can increase about 14% and 15%, respectively when compared to the control mixture with no FA and no BA(FA00EA20).

The synergy between BA and FA significantly improves expansion of the mixture with both BA and FA when compared to the effect of only fly ash or only bottom ash.As can be seen that the tested 7-day expansion of expansive concrete with both BA and FA increases up to 43% when compared to normal expansive concrete with no BA and no FA (Figure 10).

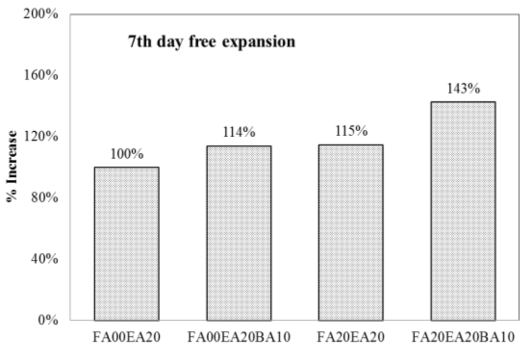


Fig.10. Summary results of 7-day free expansion of expansive concrete with FA and BA.

3.2 Restrained expansion

Internal curing by using bottom ash at 10% replacement in fine aggregate can increase restrained expansion on the 7th day by 9% when compared to normal expansive concrete with no BA (Figure 11). Also, as shown in Figure 12, the expansion increased by about 20% for fly ash expansive concrete with BA.

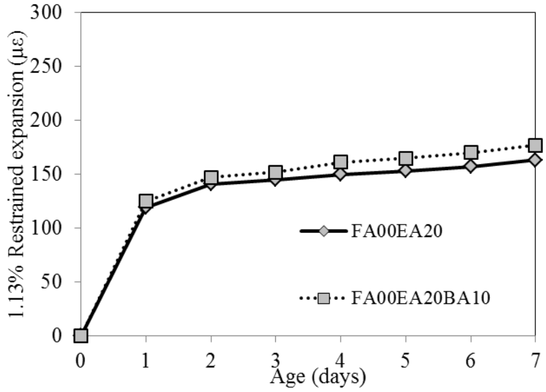


Fig.11. Effect of IC on 7-day restrained expansion of normal expansive concrete.

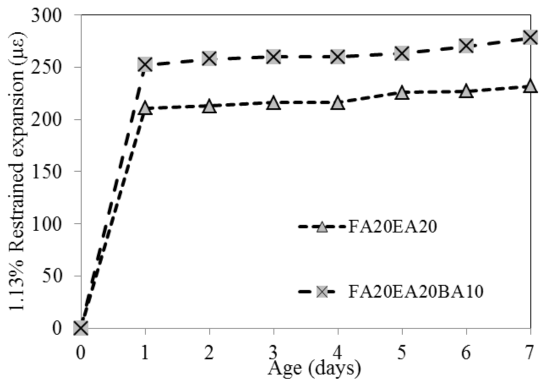


Fig.12. Effect of IC on 7-day restrained expansion of Fly Ash-expansive concrete.

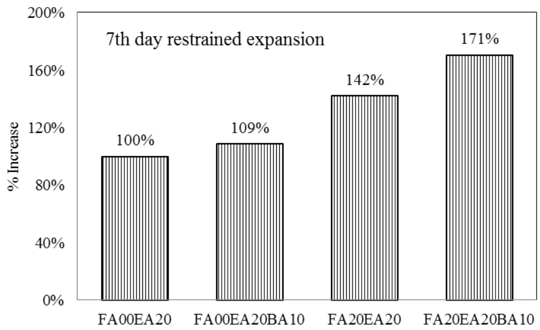


Fig.13. Summary results effect on 7-day restrained expansion of expansive concrete.

Figure 13 shows that using both FA and BA increases 7-day restrained expansion in expansive concrete, similar to the results in free expansion condition. The application of both FA and BA gain more efficiency by increasing the restrained expansion to 71% when compared to the reference mixture with no BA and FA. The reason that bottom ash can increase expansion of the expansive concrete is probably because bottom ash, by internal curing effect, provides water for the reaction of the expansive agent at the inner part of the concrete where curing water is not possible to be supplied from the normal curing from outside.

3.3 Free shrinkage

It is noted that the effectiveness of shrinkage compensation also depends on the amount of shrinkage of the mixture. If expansion of the mixture is improved, but shrinkage of the mixture is on the other hand much higher, the shrinkage compensation may not be so effective. It is therefore necessary to evaluate the shrinkage behavior of the expansive concrete for a more relevant evaluation. As bottom ash is porous with high water retention, it is expected to reduce autogenous shrinkage but may increase drying shrinkage of the concrete. The results in Figure 14 show the subsequent shrinkage after curing (after 7-day expansion). The shrinkage of expansive concrete with internal curing, up to the age of 49 days, is similar to that of the normal expansive concrete. However, at long term, the shrinkage of expansive concrete with internal curing becomes slightly larger than that of normal expansive concrete. This may be because, when the bottom ash which has high porosity is added into the concrete, the microstructure is not as dense as that of the concrete with natural fine aggregate. The moisture can thus evaporate and migrate out of the sample more easily. This is more obvious at long-term.

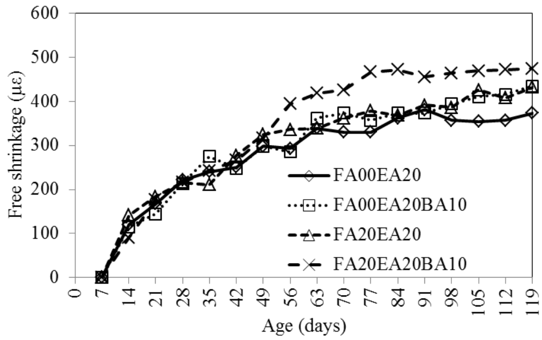


Fig.14. Total shrinkage of expansive concrete with internal curing.

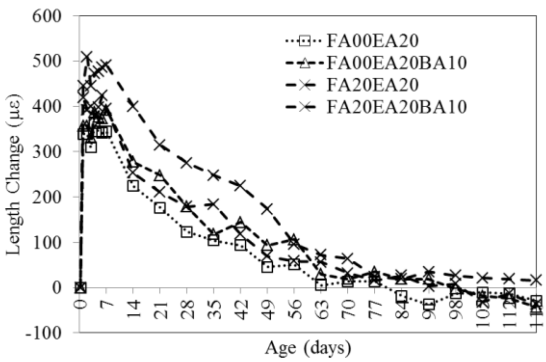


Fig.15. Total length change of expansive concrete with internal curing.

Figure 15 show that total length change at long term of expansive concrete with bottom ash is approximately same as that of the expansive concrete without bottom ash.

Higher expansion of expansive concrete with fly ash was probably due to the delaying effect of fly ash on the reaction of expansive additive and lower stiffness of pastes during expansion period, inducing more opportunity to expand. More expansion of expansive concrete with bottom ash was also found due to mitigating autogenous shrinkage and supply of water for reaction of the expansive additive by internal curing [9]. Future investigations are required for confirmation of these mechanisms.

The experimental findings indicate that internal curing can potentially be applied to increase efficiency of expansive concrete however the balance between the enhanced expansion and the subsequent drying shrinkage must be carefully considered. It should be noted that since there is still no study done on the effect of bottom ash on expansion and shrinkage behavior of expansive concrete, for real application in the future, it is necessary to investigate the mechanisms on how fly ash affects the expansion of expansive concrete as well as the quantitative evaluation of expansion of internally cured expansive concrete under different degrees of restraint for possible design in the future.

4. Conclusions

Internal curing by replacing 10% of fine aggregate with bottom ash can contribute to higher early age expansion in both free condition (up to 14% of the mixture without bottom ash) and restrained condition (up to 9% of the mixture without bottom ash). Synergy between 10% bottom ash replacement in fine aggregate and 20% fly ash replacement in binder can increase more expansion in both free condition and restrained condition, up to 43% and 71% of the mixture without bottom ash, respectively. So it is possible to reduce risk of early age shrinkage cracking when using expansive concrete with internal curing.

After 7 days of expansion, mixtures with bottom ash tends to have larger total shrinkage when compared to the corresponding mixtures without bottom ash. The long-term total length change of expansive concrete with bottom ash is similar to that of the expansive concrete with no bottom ash.

The experimental findings indicate that bottom ash can potentially be applied to increase expansion of expansive concrete however the balance between the enhanced expansion and the subsequent drying shrinkage must be carefully considered.

5. Acknowledgement

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