Effect of Bottom Ash and Mineral Admixtures on the Curing Sensitivity of Concrete

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Abstract

In this paper curing sensitivity of concrete with bottom ash and multiple binders was studied. Bottom ash was used as an internal curing agent and a partial substitution of fine aggregate. Curing sensitivity index was calculated by considering compressive strength as an indicator. Two series of concrete with water to binder ratios by weight (w/b) of 0.35 and 0.55 were produced for compressive strength. The specimens were subjected to two curing conditions which are continuously water-cured and continuously air-cured. The curing sensitivity of concrete with multiple binders such as fly ash and limestone powder with bottom ash was investigated. It was found that for the mixes without bottom ash, the use of fly ash increased curing sensitivity while LP reduced curing sensitivity of concrete. It was also found that the use of bottom ash in concrete reduced the curing sensitivity especially at low w/b ratio. The concrete with limestone powder together with bottom ash were the least sensitive to curing. From autogenous shrinkage results, it was found that bottom ash reduced autogenous shrinkage of mortar significantly. From test results of compressive strength, curing sensitivity and autogenous shrinkage, bottom ash was proved to be one of the effective internal curing agents.

Keyword : Internal curing, bottom ash, fly ash, limestone powder, shrinkage

1. General Introduction

In current practice, effective curing of concrete has become a difficult task especially in a hot country like Thailand. Due to inefficient curing, concrete has low strength development and durability problems. According to ACI 308 [1], the minimum curing periods for Type 1, Type 3 and Type 5 cements should be 7 days, 3 days and 14 days, respectively. EIT 1014 [2] recommended that concrete with Portland cement Type 1 only should be moist-cured continuously not less than 7 days while fly ash concrete requires a longer curing period. Aitcin et al. [3] found 17–22% reduction in compressive strengths of air-cured concrete when compared to the moist cured one. Wood [4] concluded that the compressive strength of moist-cured specimens increased continuously with age over a 20-year period. Though engineers know that good curing enhances quality of concrete, good curing practices are not always implemented. For large structures or mass concrete and for high elevation vertical concrete walls, curing process has been a tremendous task. For high strength concrete (low w/b), there is not enough water inside the concrete then the ultimate

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degree of hydration is not achieved. With poor curing conditions, the problems caused on mechanical and durability properties of concrete cannot be avoided. Autogenous shrinkage is one of the major problems in high strength concrete. During early age, shrinkage sometimes causes more serious problems such as cracking since the concrete still has not gained much strength. Even small stress during the early age can result in shrinkage cracking [5].

Nowadays, water-retaining materials or specific porous materials such as polymer and light-weight aggregate have been studied for being used in concrete for internal curing purpose. Internal curing is the curing of concrete from inside with the help of an internal curing agent. The water retained in these materials provides supplementary water in addition to the originally mixing water for the hydration reaction process. The extra water is gradually consumed in the hydration reaction so that it prolongs the hydration reaction progress and reduces shrinkage. For high performance concrete (HPC) internal curing process had become popular to reduce shrinkage problem [6-8]. It was reported that internal curing helps in avoiding internal micro cracking which may occur in low w/b concrete due to autogenous shrinkage [6]. It was also reported that increase of compressive strength in comparison with normal concrete, especially at later age was observed with internal curing [7, 8].

Bottom ash is a porous material (see Figure 1) which has high water retainability, so it is possible to be used in concrete as an internal curing material and has high potential in real practice. Bottom ash is a waste material from coal power plants. A large amount of the produced bottom ash is dumped or used as a land-fill material. These practices cause some expense for disposing and may cause some environmental problems. As a result, a beneficial way in points of view of economic and environment is to utilize the bottom ash in concrete. Some previous researches have shown improvement on compressive strength with bottom ash replacement up to 10% of fine aggregate [9-12]. It was reported that bottom ash can be used to partially replace fine aggregate up to 30% by weight without detriment of compressive strength of concrete [10-12].

Concrete containing pozzolanic materials such as fly ash and limestone powder is popular since the ready-mixed concrete producers can reduce the cost of the concrete, reduce environmental problem and enhance some performances of the concrete at the same time. These mineral admixtures require different curing periods. So to know the curing sensitivity of these mineral admixtures is of great importance. To respond to the problem of curing, it is useful to develop a concrete which is less sensitive to curing. Internal curing method and the use of multiple binders are some possible ways to develop a minimum curing concrete.

In this research, the curing sensitivity of concrete with multiple binders and with internal curing process by using bottom ash as an internal curing agent was studied. The final objective (in future study) is to develop a low curing sensitive concrete.

2. Experimental program

2.1 Materials

Ordinary Portland cement (OPC), fly ash and limestone powder (LP) were used as cementitious materials. The physical properties and chemical compositions of the cement, fly ash and LP are shown in Tables 1 and 2. The particle size of the LP used in the test was 5 micron. Natural river sand and crushed limestone were used as fine and coarse aggregates, respectively. The mix proportions of concretes are shown in Table 3. In this research, mixtures were designed at two w/b; 0.35 and 0.55. Bottom ash passing

ASTM sieve no 4 was used to partially replace fine aggregate. The water retainability of bottom ash was found according to the test method proposed by Kasemchaisiri and Tangtermsirikul (2006) [6]. After determining the specific gravity of bottom ash in oven dried condition according to ASTM C128, the specific gravity of bottom ash at water reainability was found from the following relationship.

$$\rho_{wr} = \rho_{od} \times (1 + WR) \quad (1)$$

where ρ_{wr} is specific gravity of BA at water retainability (WR), ρ_{od} is specific gravity of BA at oven-dried. For the current research water retainability of bottom ash was found to be 21.14% and ρ_{wr} is equal to 2.35. This value was used instead of specific gravity of saturated surface dry (ρ_{ssd}) in the mix proportions.

Table 1 Basic properties of cement, fly ash and LP

	Cement	Fly ash	Limestone Powder
Specific gravity	3.15	2.29	2.7
Blaine fineness (cm^2/g)	3,350	2,682	6,874

Table 2 Chemical composition of cement, fly ash and LP

Chemical composition	Cement	Fly ash	Limestone powder
SiO_2 (%)	19.87	36.29	0.42
Al_2O_3 (%)	4.87	21.26	0.11
Fe_2O_3 (%)	3.55	13.77	0.08
CaO (%)	65.03	17.50	55.23
MgO (%)	0.73	2.89	0.48
SO_3 (%)	2.52	3.67	0.01
Na_2O (%)	0.02	1.40	0.01
K_2O (%)	0.45	2.10	0.01
LOI (%)	2.26	0.09	44.16

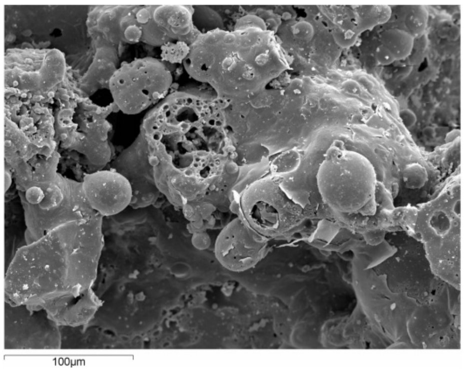

Figure 1 SEM micro graph of bottom ash

2.2 Method

2.2.1 Compressive strength

Mixtures were designed at two w/b ratios; 0.35 and 0.55. Natural river sand was partially replaced by bottom ash (BA) at 10% and 30% by volume. Details of all mix proportions are shown in Table 3. Concrete mixtures were mixed in a pan mixer for 5 minutes. Cube specimens with size 100 × 100 × 100 mm were cast for the compressive strength tests. Plastic sheets were used to cover the specimens to prevent evaporation of water from the specimens. Formworks were removed at the age of 24 hours. All mixes were exposed to two different curing conditions which are water-cured (WC) and air-cured (AC) until testing. Strength tests were carried out at the ages of 28 and 91 days. All air-cured specimens were kept in the room with temperature and RH of 28 ±1^{o}C and 68 ±2%, respectively. To obtain one data, three specimens were tested for their average.

2.2.2 Autogenous shrinkage

For autogenous shrinkage, 25x25x28.5 mm mortar bars were cast. The values of w/b and sand to binder ratio (s/b) were fixed at 0.35 and 1.25, respectively. Bottom ash was used to partially replace sand by volume at 10% and 30%. Fly ash and limestone powder were used as cement replacing materials. Details of the mix proportions are shown in Table 4.

Table 3 Mix design details for concrete

	Ingredients (kg/m^3)						
Mixing code	c	f	LP	w	g	s	BA
w35f0LP0BA0	474	0	0	166	1055	737	0
w35f0LP10BA0	423	0	47	164	1055	737	0
w35f30LP0BA0	315	135	0	157	1055	737	0
w35f20LP10BA0	317	90	45	159	1055	737	0
w35f0LP0BA10	474	0	0	166	1055	663	58
w35f0LP0BA30	474	0	0	166	1055	516	174
w35f0LP10BA10	423	0	47	163	1055	663	58
w35f0LP10BA30	423	0	47	160	1055	516	174
w35f30LP0BA10	315	135	0	156	1055	663	58
w35f30LP0BA30	315	135	0	153	1055	516	174
w35f20LP10BA10	317	90	45	157	1055	663	58
w35f20LP10BA30	317	90	45	154	1055	516	174
w55f0LP0BA0	365	0	0	201	1055	737	0
w55f0LP10BA0	326	0	36	199	1055	737	0
w55f30LP0BA0	245	105	0	193	1055	737	0
w55f20LP10BA0	247	71	35	194	1055	737	0
w55f0LP0BA10	365	0	0	201	1055	663	58
w55f0LP0BA30	365	0	0	201	1055	516	174
w55f0LP10BA10	326	0	36	199	1055	663	58
w55f0LP10BA30	326	0	36	199	1055	516	174
w55f30LP0BA10	245	105	0	193	1055	663	58
w55f30LP0BA30	245	105	0	193	1055	516	174
w55f20LP10BA10	247	71	35	194	1055	663	58
w55f20LP10BA30	247	71	35	194	1055	516	174

Remarks: c: cement, f: fly ash, LP: limestone power, w: water, s: fine aggregate, BA: bottom ash and g: coarse aggregate

Table 4 Mix design details for mortar

	Ingredients (kg/m^3)					
Mixing code	c	f	LP	w	s	BA
w35f0LP0BA0 (M)	636	0	0	223	1450	0
w35f0LP0BA10 (M)	636	0	0	223	1305	131
w35f0LP0BA30 (M)	636	0	0	223	1015	392
w35f30LP0BA0 (M)	410	176	0	205	1484	0
w35f0LP10BA0 (M)	565	0	63	220	1455	0
w35f20LP10BA0(M)	416	119	59	208	1478	0

Remarks: c: cement, f: fly ash, LP: limestone power, w: water, s: fine aggregate, BA: bottom ash and g: coarse aggregate

3. Results and Discussions

3.1 Compressive strength

3.1.1 Effect of Binder on compressive strength

The 28-day and 91-day compressive strengths of water-cured and air-cured concretes with w/b 0.35 and 0.55 are shown in Figures 2 and 3, respectively. As expected, air-cured concrete showed comparatively low strength when compared to water-cured concrete. In this section the mixtures without BA replacement are discussed. In case of water-cured specimens, at the age of 28 days, the highest compressive strength for w/b= 0.35 was given by W35f0LP0BA0 at 76 MPa, while w35f30LP0BA0, w35f0LP10BA0 and w35f20LP10BA0 had compressive strengths of 68 MPa, 74 Mpa, and 69 MPa, respectively. For 91-day compressive strength, the highest compressive strength was observed with w35f0LP0BA0 at 88 MPa while w35f30LP0BA0, w35f0LP10BA0 and w35f20LP10 -BA0 showed the values of 84 MPa, 81 MPa and 76 MPa, respectively. The same tendency was also found in the case of w/b = 0.55.

Interesting results are observed when air-cured concretes are analyzed. For 28-day compressive strength, w35f30LP0BA0, w35f0LP10BA0, and w35f20LP10BA0 showed the values of 58 MPa, 65 MPa and 60 MPa, respectively, while w35f0LP0BA0 showed 65 MPa. With no proper curing the compressive strength of concrete with LP was the same as that of the control concrete at early age. For 91-day compressive strength of air-cured concretes, w35f30LP0BA0, w35f0LP10BA0, and w35f20LP10BA0 showed the values of 62 MPa, 67 MPa and 62 MPa, respectively, while w35f0LP0BA0 showed 68 MPa.

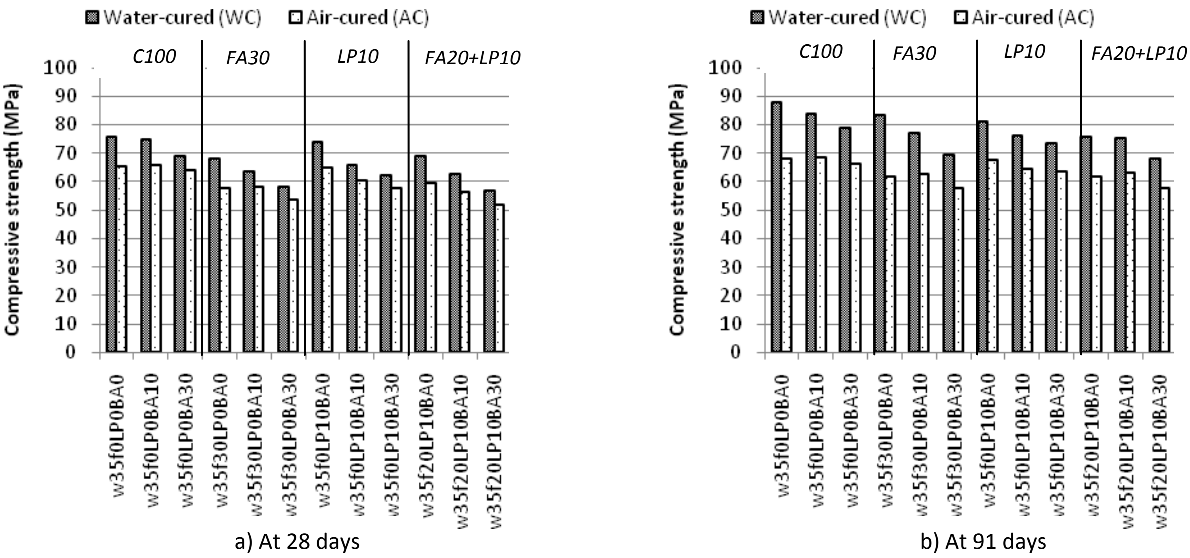

Figure 2 Compressive strength of water-cured and air-cured concrete with w/b=0.35 at 28 days and 91 days

The results of all mixtures show that at both test ages, the values of compressive strength of the specimens cured in water are higher than that of the air-cured specimens especially for the mixes with fly ash.

3.1.2 Effect of bottom ash on compressive strength

In this research, BA was used to partially replace sand at 10% and 30% by volume. The compressive strengths of specimens with w/b=0.35 and w/b=0.55 are shown in Figures 2 and 3, respectively. For water-cured specimens (see Figure 2) with w/b=0.35, it was found that the increase in BA content results in the reduction of compressive strength when compared to the mix without BA for all types of binder combination. This is because BA increases the porosity of the concrete. Similar tendencies were also obtained for the specimens with w/b= 0.55 as shown in Figure 3.

For air-cured concrete with w/b=0.35, cement-only concrete with BA 10%, w35f0LP0BA10, had compressive strength of 66 MPa and 69 MPa at 28 days and 91 days, which is 1.1% and 1.3% higher than the mix without BA w35f0LP0BA0.

For binary and ternary binder mixtures with w/b=0.35, the mixes with BA showed lower compressive strength when compared to the mixes without BA replacement, except for the mix with 30% fly ash with 10% BA and the ternary binder mix with 10% BA.

The mix with 10% BA and fly ash 30% w35f30LP0BA10 showed 0.8% and 1.6% increase in compressive strength for 28 days and 91 days as compared to fly ash mix without BA w35f30LP0BA0. The ternary binder mix with 10% BA w35f20LP10BA10 had 2% increase in compressive strength at 91 days as compared to the mix without BA. Fly ash improves long term strength with good curing condition. However, under poor curing condition, fly ash can still improve long term strength if the mixes contain BA because BA can supply the additional water required for the hydration and pozzolanic reaction with water.

For air-cured concrete specimens with w/b=0.55, the cement-only concrete with 10% BA w55f0LP0BA10 had compressive strength of 35 MPa and 38 Mpa at 28 days and 91 days, respectively,

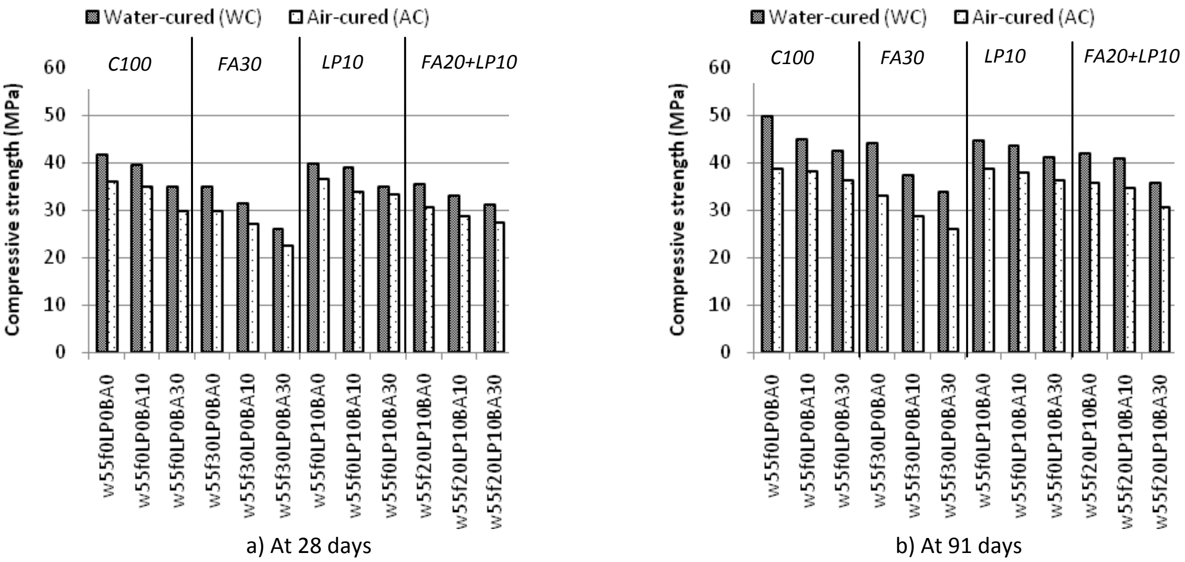

Figure 3 Compressive strength of water-cured and air-cured concrete with w/b 0.55 at 28 days and 91 days

which is only 2.8% and 1.83% below its respective control mix w55f0LP0BA0. So, in air-cured condition, the cement-only concrete with BA had almost the same compressive strength as the mix without BA, (see Figure 3). For binary and ternary binder mixtures, compressive strength continuously dropped with the increase in BA content.

It can be concluded here that BA is more effective in the low w/b concrete. This is because at high w/b, there is more water inside the concrete for hydration. The effect of internal curing is therefore not obvious. In contrast, due to the low w/b, there is not enough water inside the concrete for hydration reaction, so internal curing becomes more effective. At low w/b, concrete is dense and external curing water cannot penetrate into the inner portion of concrete, so external curing is not effective. By adding BA, the additional internal curing is provided. As the relative humidity inside the concrete drops, BA releases water for additional hydration.

The similar behavior was also presented by other researches with other internal curing agents such as light-weight aggregate, super absorbent polymers, porous ceramic waste, etc [7-10].

3.2 Curing sensitivity

The curing sensitivity of concrete on compressive strength was evaluated by using the curing sensitivity index ($CSI_{fc'}$) which is the percentage difference between compressive strength of concrete that is continuously water-cured and that of the continuously air-cured concrete as shown in Eq. (2). The higher curing sensitivity index means concrete is more sensitive to curing.

$$CSI_{fc'} = \left(\frac{f_{c'}(WC) - f_{c'}(AC)}{f_{c'}(WC)} \right) \times 100 \qquad (2)$$

where $CSI_{fc'}$ is curing sensitivity index for compressive strength (%). $f_{c'}(WC)$ and $f_{c'}(AC)$ are compressive strength of water-cured and air-cured specimens, respectively (MPa).

3.2.1 Effect of binder on curing sensitivity

Curing sensitivities of concrete with w/b = 0.35 and 0.55 are shown in Figures 4 and 5. For w/b=0.35, the mixtures

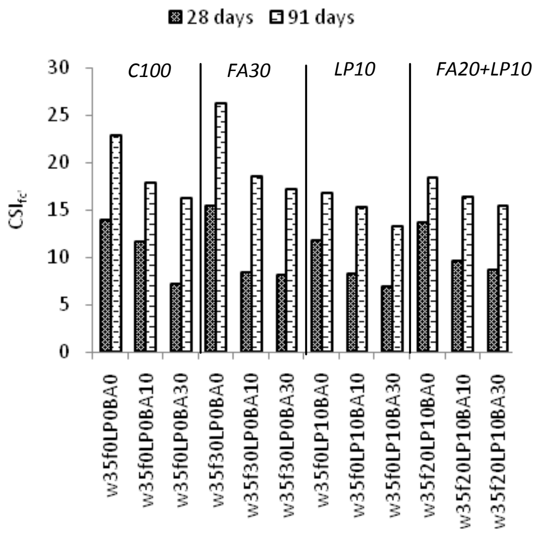

Figure 4 Curing sensitivity index for w/b 0.35

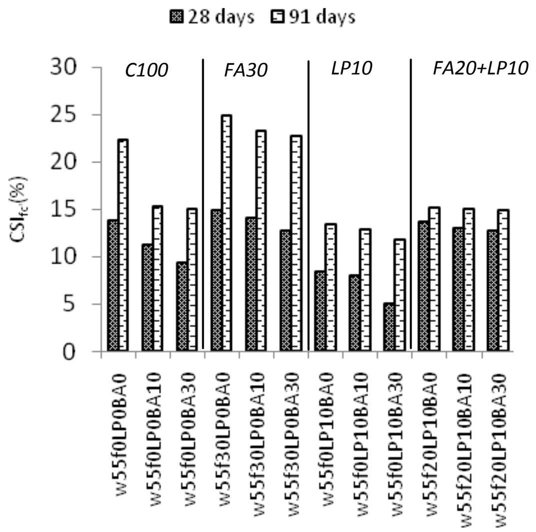

Figure 5 Curing sensitivity index for w/b 0.55

having 30% fly ash replacement (w35f30LP10BA0) had the maximum $CSI_{fc'}$. Concrete with 10% limestone powder replacement (w35f0LP10BA0) had the lowest curing sensitivity. The ternary binder mixtures had lower $CSI_{fc'}$ as compared to the fly ash only concrete. In the case of w/b= 0.55 similar tendencies were also observed (see Figure 5).

LP accelerates the hydration of cement especially at early age [13]; as a result a large portion of cement has reacted at early age and therefore, reduces $CSI_{fc'}$ of concrete. The pozzolanic reaction of fly ash starts at later age, thus it requires a longer curing period. Another reason is that the rate of evaporation of fly ash concrete is higher than cement-only concrete [14], so early water loss by evaporation in air-cured fly ash concrete results in less water inside the concrete for pozzolanic reaction. This makes fly ash concrete more sensitive to curing.

3.2.2 Effect of bottom ash on curing sensitivity

For both w/b= 0.35 and 0.55, it was found that the use of BA reduced the $CSI_{fc'}$ of concrete significantly when compared to the mix without BA (see Figures 4 and 5). For both 28 days and 91 days, the mixes with 10% LP and 30% BA (w35f0LP10BA30, w55f0LP10BA30) were the most effective to reduce $CSI_{fc'}$. Bottom ash reduces $CSI_{fc'}$ by its internal curing ability. In the air-cured condition BA supplies the additional water required for hydration making the concrete less sensitive to curing.

3.3 Autogenous shrinkage strain

The test results of autogenous shrinkage strain of mortar specimens are shown in Figure 6. It was found from the test results that the uses of fly ash and LP reduce autogenous shrinkage significantly. This behavior was also reported in some previous studies [14-16]. The mixes with bottom ash expanded at early age and showed substantial reduction of autogenous shrinkage. The use of bottom ash reduced shrinkage of mortar significantly, and was even more effective than the use of multi-binders. Mortars with higher amount of bottom ash showed lower autogenous shrinkage. This phenomenon is similar to other types of internal curing materials [6-8]. Thus, it proves that BA can be used as an effective internal curing agent to reduce autogenous shrinkage.

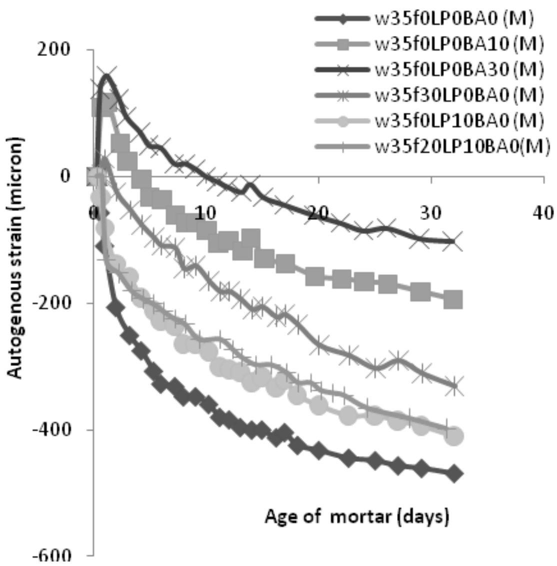

Figure 6. Autgoenous shrinkage of mortars with different binders and BA.

4. Conclusions

Based on the test results, the following conclusions are obtained.

1. For water-cured specimens, compressive strength of the mixes with BA were lower than the mixes without BA. However, for air-cured specimens, BA improved the compressive strength slightly for cement-only concrete and fly ash concrete at w/b= 0.35.
2. The use of 10% limestone powder in the binders reduced the curing sensitivity of the concrete.
3. Bottom ash reduced curing sensitivity of concrete significantly, especially at low w/b.
4. The use of 10% limestone powder in the binder together with 30% bottom ash in the fine aggregate was the most effective in reducing curing sensitivity.
5. The uses of bottom ash reduced autogenous shrinkage of mortars significantly.
6. From results of compressive strength, curing sensitivity and autogenous shrinkage, it was proved that BA could be used as an internal curing material.

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