Effect of Mineral Admixtures on Curing Sensitivity of Concrete

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Abstract

In this study, concretes with binary and ternary blends of Portland cement, fly ash and limestone powder were produced to investigate their curing sensitivity by considering compressive strength and carbonation depth as the indicators. The effect of w/b on the curing sensitivity of concrete was also investigated. Two series of concrete with water to binder ratios by weight (w/b) of 0.35 and 0.55 were produced for compressive strength. For carbonation, the w/b was set at 0.45. For all cases, Portland cement was replaced by: i 30% fly ash; ii 10% limestone powder; and iii 20% fly ash +10% limestone powder. The specimens were subjected to two curing conditions, which are continuously water-cured and continuously air-cured. It was found from the test results that fly ash concrete is more sensitive to curing than the cement only concrete while the use of limestone powder reduced the curing sensitivity. It was also found that the relative humidity (RH) during air-curing of concrete has a vital effect on the curing sensitivity with different w/b ratios.

Keywords: Curing Sensitivity, Multiple Binders, Fly Ash, Limestone Powder, Compressive Strength

1. Introduction

In current practice, the appropriate curing of concrete has become a difficult task, especially in a hot country like Thailand. Due to improper curing, concrete has low strength development and durability problems. Though 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, the curing process has been a tremendous task. There are several ways to cure concrete such as water curing, moist curing, seal curing, steam curing, and autoclave curing, etc. According to EIT 1014 [1], 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. According to ACI 308 [2] the minimum curing periods for Type 1, Type 3, and Type 5 cements should be 7 days, 3 days, and 14 days, respectively. Aitcin et al. [3] found 17–22% reduction in compressive strengths of concretes between moist-cured and air-cured specimens. Wood [4] concluded that the compressive strength of moist-cured specimens increased continuously with age over a 20-year period.

At lower w/b ratio, there is not enough water inside the concrete and the ultimate degree of hydration is not achieved.

With poor curing conditions the problems for mechanical and durability properties of concrete cannot be avoided. In a study conducted by Lo and Lee [5] to determine initial curing effects on carbonation of concrete, they found large differences in carbonation depth between water-cured concrete and air-cured concrete. To respond to the problem of curing, it is useful to develop a concrete which is less sensitive to curing. 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 problems and enhance some performances of the concrete at the same time. These mineral admixtures result in improvement in mechanical properties and durability properties of concrete [6, 7]. However, the results on the curing sensitivity of these materials are limited, especially for the mixtures with limestone powder and ternary binders. As a result, their effects on curing sensitivity are investigated in this study.

The objective of this research is to investigate the effects of fly ash, limestone powder and their combination on curing sensitivity of concrete with different w/b. The final goal (in future study) is to develop concrete with low curing sensitivity.

2. Experimental program

2.1 Materials and mix proportions

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 microns. 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. The ratio of volume of paste to volume of void in combined aggregate (γ) was set at 1.4 for all mixtures.

2.2 Test procedure

2.2.1 Compressive strength

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 specimens were kept in the room with temperature and RH of 28 $\pm 1^{o}$C and 68 ±2%, respectively. To obtain data, three specimens were tested for their average.

2.2.2 Carbonation

Specimens having size 100x100x100 mm were cast and de-moulded at 24 hours after casting. Concrete mix proportions for carbonation test are shown in Table 3. All mixes for testing carbonation were designed at w/b=0.45. All mixes were exposed to two curing conditions, which are water-cured for 28 days (28WC) and air-cured for 28 days (28AC). After curing, all specimens were stored in the carbonation chamber. The CO_2 concentration, temperature and relative humidity in the chamber were controlled at 4% (40,000 ppm), 30±2 ^{o}C and 65±5%, respectively. The specimens were split for measuring the carbonation depth at the age of 56 days. The standard test method for measuring carbonation depth, using phenolphthalein solution, proposed by RILEM Committee CPC-18, was used in this study [8].

Table 1 Physical properties of cement, fly ash and limestone powder

Physical properties	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 limestone powder

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

Table 3. Mix proportions of concrete

Mix	Ingredient (kg/m^3)					
	c	f	LP	w	g	s
Mix design for Compressive strength						
w35f0LP0	441	0	0	155	1059	733
w35f30LP0	308	132	0	154	1059	733
w35f0LP10	422	0	47	164	1059	733
w35f20LP10	313	89	45	156	1059	733
w55f0LP0	340	0	0	187	1059	733
w55f30LP0	241	103	0	189	1059	733
w55f0LP10	325	0	36	199	1059	733
w55f20LP10	244	70	35	192	1059	733
Mix design for Carbonation						
w45f0LP0	412	0	0	184	1059	733
w45f30LP0	276	118	0	176	1059	733
w45f0LP10	368	0	41	183	1059	733
w45f20LP10	278	79	40	178	1059	733

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

3. Experimental Results

3.1 Compressive strength

The test results of compressive strength of concrete with w/b = 0.35 and 0.55 are shown in Figures 1 and 2, respectively. In the case of water-cured specimens, at the age of 28 days, the highest compressive strength for w/b= 0.35 was given by w35f0LP0(28WC) at 76 MPa. For water-cured concretes, w35f30LP0(28WC), w35f0LP10(28WC), w35f20LP10(28WC) had compressive strengths of 68 MPa, 74 MPa, and 69 MPa, which is 10.1%, 2.6%, and 8.8% below w35f0LP0(28WC), repectively. For 91-day compressive strength, the highest compressive strength was observed with w35f0LP0(91WC) at 88 MPa. Water cured concretes w35f30LP0(91WC), w35f0LP10(91WC), w35f20LP10(91WC) had lower percentage differences of 5.0%, 7.8%, and 14.0% with w35f0LP0(91WC), 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, w35f30LP0(28AC), w35f0LP10(28AC), and w35f20LP10 (28AC) showed lower percentage difference with w35f0LP0(28AC) at 11.6%, 0.1%, and 11.3%, respectively. With no proper curing the compressive strength of concrete with LP was the same as the control concrete at an early age. For 91-day compressive strength of air-cured concrete, w35f30LP0(91AC), w35f0LP10(91AC), and w35f20LP10(91AC) showed lower percentage difference with w35f0LP0(91AC) at 9.1%, 0.6%, and 9.0%, respectively. The results for all mixtures show that for all ages, the compressive strength of the specimens cured in water are higher than the air-cured specimen especially for the mixes with fly ash. This is because sufficient water was available for the chemical reactions of those cementitious materials.

3.2 Carbonation

The carbonation depths were measured at the age of 56 days or after the specimens were stored in the carbonation chamber for

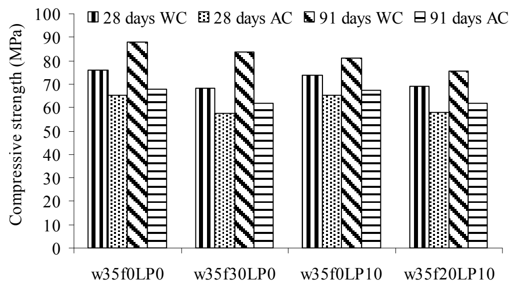

Figure 1 Compressive strength of concrete with w/b 0.35

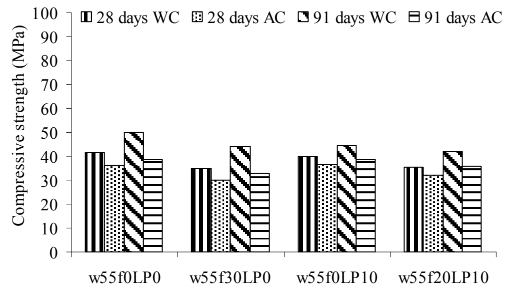

Figure 2 Compressive strength of concrete with w/b 0.55

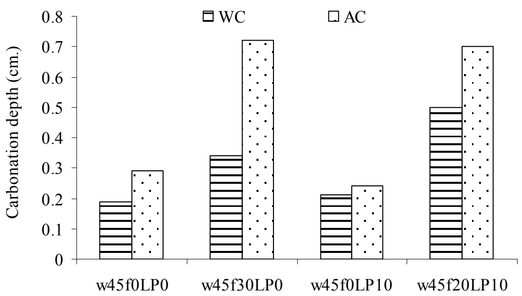

Figure 3 Carbonations depths of concrete at the age of 56 days.

28 days. The test results are shown in Figure 3. The results showed that all air-cured concrete mixes had higher carbonation depths than the water-cured mixes.

For water-cured concrete, the mix with 30% fly ash replacement (w45f30LP0) had the highest carbonation depth. The results were consistent with those obtained by other researchers [9, 10]. The effect of replacement of fly ash was explained by Khunthongkeaw et al. [9]. When a large amount of fly ash is used, the effect of the reduction in $Ca(OH)_2$, by pozzolanic reaction of fly ash and by reduced cement content, dominates over the pore refinement. The mix with 10% LP replacement (w45f0LP10) had a slightly higher value of carbonation depth as compared to the cement concrete mixture. This is because replacement of LP can increase the gas permeability [11], also because the partial replacement of cement with LP dilutes the cement effect. Partial replacement of fly ash with LP as a ternary blended mixture reduced carbonation depth as compared to fly ash mix.

However, for air-cured concrete, water for the chemical reactions of those cementitious materials was not sufficient so the porosity of the concrete increases. As a result, carbon dioxide gas diffuses through the concrete easily. From these reasons, all air-cured concrete mixes had higher carbonation depths than the water-cured mixes.

3.3 Curing sensitivity

3.3.1 Sensitivity on compressive strength

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. (1). A higher curing sensitivity index means concrete is more sensitive to curing.

$$CSI_{fc'} = \left(\frac{f_c'(WC) - f_c'(AC)}{f_c'(WC)} \right) \times 100 \quad (1)$$

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).

The $CSI_{fc'}$ at the ages of 28 and 91 days, for the mixes with w/b = 0.35 and 0.55, are shown in Figure 4. It was found from the results that fly ash concrete is more sensitive to curing than the cement only concrete. This is because the hydration reaction of cement occurs rapidly at an early age when the water content in concrete is high (before water loss due to evaporation in air-cured conditions). In contrast, the pozzolanic reaction of fly ash starts at a later age, thus it requires a longer curing period. Another reason is that the rate of water evaporation of fly ash concrete is higher than cement concrete [12] so early water loss by evaporation in air-cured fly ash concrete results in less water inside the concrete for pozzolanic reaction.

It was also found that the use of LP reduced $CSI_{fc'}$ of concrete. The use of LP reduces the $CSI_{fc'}$ of both cement concrete and cement-fly ash concrete. The results indicate that the binary mixture with LP was the least sensitive to curing while ternary binder mixture had significantly lower $CSI_{fc'}$ as compared to fly ash concrete. This is possibly because LP accelerates the hydration of cement especially at an early age [13]; as a result a large portion of cement has reacted at an early age. Another reason is due to the filling ability of LP, the pore structure was improved [13]. Due to these mechanisms, LP reduces $CSI_{fc'}$ of concrete significantly.

3.3.2 Effect of w/b on CSI for compressive strength

The effect of w/b on the curing sensitivity of concrete is still unclear. However, from the test results, it seems to have a tendency that the mixes with w/b = 0.55 had approximately equal or slightly lower curing sensitivity when compared to w/b = 0.35 mixtures (see Figure 4). It must be mentioned here that after analyzing some test results of 28-day compressive strengths from various research [14, 15, 16, 17, 18], it was found that there is no consistency among the findings. From experimental results of Atis et al. and Samir et al. [14, 17], $CSI_{fc'}$ for cement concrete mix was calculated and it was found that higher w/b was more sensitive. Contradictory results were found in the experiments of Goyal et al and Aitcin et al [15, 16]. It was anticipated by the authors that the conditions of the air-curing environment might be one of the reasons for the inconsistency, especially relative humidity (RH). After analyzing the air-cured conditions in all mentioned studies together with the authors', differences in RH among all studied cases were found. A plot as shown in Figure 5 was made against RH and $CSI_{fc'}$, for the high w/b (w/b >0.45) and the low w/b (w/b ≤0.45). The $CSI_{fc'}$ was calculated from the compressive strength results of Samir et al., Goyal et al, Collins and Sanjayan [17, 15, 18]. It can be seen from Figure 5 that when RH increases, the $CSI_{fc'}$ of concrete decreases. When RH is high, the $CSI_{fc'}$ of both high and low w/b mixtures become nearly the same. It is also clear that at low RH, concrete with high w/b is more sensitive to curing because the water loss due to evaporation is easier when compared to the low w/b mix.

Therefore when RH is high, the effect of w/b on $CSI_{fc'}$ is not significant. In the current study, the RH for air-cured specimens was at 68 ±2%, so the difference between the mixes with w/b= 0.35 and w/b=0.55 was not significant.

3.3.3 Sensitivity on Carbonation

The curing sensitivity of concrete on carbonation (CSI_{CO2}) was calculated by Eq. (2) which is the percentage difference between carbonation depth of concrete that is 28-day water-cured and that of the 28-day air-cured concrete as shown in Eq. (2). The higher curing sensitivity index means concrete is more sensitive to curing.

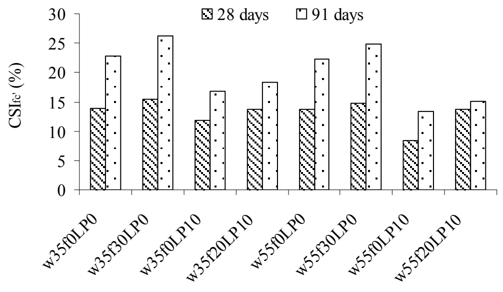

Figure 4 Curing sensitivity index for compressive strength at w/b 0.35 and 0.55

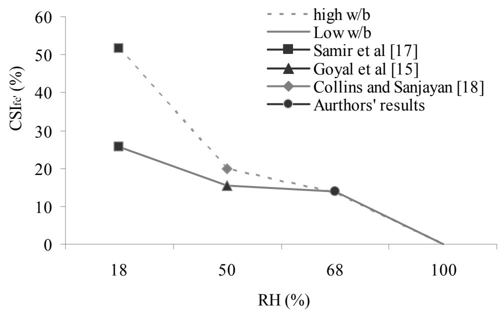

Figure 5 Curing sensitivity index at 28 days of cement concrete [15, 17, 18] cured in different RH conditions.

$$CSI_{CO2} = \left(\frac{C_d(AC) - C_d(WC)}{C_d(WC)} \right) \times 100 \quad (2)$$

where CSI_{CO2} is the curing sensitivity index for carbonation (%). $C_d(AC)$ and $C_d(WC)$ are carbonation depths of 28-day air-cured and 28-day water-cured specimens, respectively (cm).

From Figure 6, it can be seen that CSI_{CO2} for carbonation also has the same tendency as that of the compressive strength (see section 3.2.1). LP reduces the curing sensitivity but fly ash increases the curing sensitivity of the concrete.

With poor curing, fly ash increases the porosity and pore size, thus allowing carbon dioxide to diffuse into the concrete easily. Under drying condition, by the filling ability of LP and the accelerated hydration, the porosity of the paste with LP decreases. The mechanism of LP causing less curing sensitivity of concrete was mentioned earlier in the compressive strength part (see section 3.3.1). LP was effective to produce a minimum curing concrete from this research. This makes it possible to produce a ternary mix which is economical, environment friendly, better in hot weather, and has a possibility to be cured in poor curing conditions.

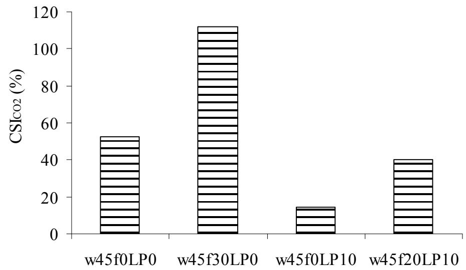

Figure 6 Curing sensitivity index for Carbonation at 56 days.

4. Conclusions

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

1. Fly ash increases the sensitivity of curing due to its slow reaction and it needs water for the pozzolonic reaction process at long term.

2. LP reduces the curing sensitivity of cement concrete and cement-fly ash concrete due to its accelerated hydration and filling abilities.

3. From the test results of compressive strength and carbonation, it was found that LP was an effective mineral admixture to produce a minimum curing concrete.

4. Carbonation depths and CSI_{CO2} for carbonation have a similar tendency as that of the compressive strength.

5. Acknowledgment

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6. References

[1] EIT 1014 Committee, EIT. Standard 1014-46, Standard Specification for Materials and Construction of Concrete Structures, Engineering Institute of Thailand Under H.M. The King's Patronage, 3rd Edition, Global Graphic Printing House, Thailand 2003 (in Thai)

[2] ACI Committee 308, Guide to Curing Concrete, ACI Manual of Concrete Practice, Part 2, American Concrete Institute, Farmington Hills, Mich., 2001

[3] Aitcin, P.C., Neville, A.M and Acker P., Integrated View of Shrinkage Deformation, Concrete International, Vol. 19, No. 9, pp. 35-41, 1997

[4] Wood, S.L., Evaluation of the Long-Term Properties of Concrete, Materials Journal, Vol. 88, No. 6, pp. 630-643, 1992

[5] Lo, Y. and Lee, H.M., Curing effects on carbonation of concrete using a phenolphthalein Indicator and Fourier-transform infrared spectroscopy, Building and Environment, Vol. 37, No. 5, pp. 507 – 514, 2002

[6] Naik, R., Singh, S., and Hossain, M.M., Enhancement in mechanical properties of concrete due to blended ash, Cement and Concrete Research, Vol. 26, No.1, pp. 49-54, 1996

[7] Tazawa, EI., Autogenous shrinkage of concrete, Proceedings of the international workshop by JCI, June 13-14, pp. 9, 1998

[8] RILEM Committee CPC-18. Measurement of hardened concrete carbonation depth. TC14-CPC; 1988.

[9] Khunthongkeaw, J., Tangtermsirikul, S., Leelawat, T., A study on carbonation depth prediction for fly ash concrete, Construction and Building Materials, Vol. 20, No. 9, pp. 744–753, 2006

[10] Khana, M.I., and Lynsdaleb, C.J., Strength, permeability, and carbonation of high-performance concrete, Cement and Concrete Research, Vol. 32, No. 1, pp. 123–131,2002

[11] Tsivilisa, S., Tsantilasa, J., Kakalia, G., Chaniotakisb, E., and Sakellariouc, A., The permeability of Portland limestone cement concrete, Cement and Concrete Research, Vol. 33, No. 9, pp.1465–1471, 2003

[12] Tongaroonsri, S., Prediction of autogenous shrinkage, drying shrinkage and shrinkage cracking in concrete, PhD Thesis, Sirindhorn International Institute of Technology and Faculty of Engineering, Thammasat University, Thailand, 2009

[13] Bonavetti, V., Donza, H., Rahhal V., and Irassar, E., Influence of initial curing on the properties of concrete containing limestone blended cement, Cement and Concrete Research, Vol. 30, No. 5, pp. 703–708, 2000

[14] Atis, C.D., Zcan, F. O., Kılıc, A., Karahan, O., Bilim, C., and Severcan, M.H., Influence of dry and wet curing conditions on compressive strength of silica fume concrete, Building and Environment, Vol. 40, No. 12, pp. 1678–1683, 2005

[15] Goyal, S., Kumar, M., and Bhattacharjee, B., Effect of relative proportion of pozzolana on

compressive strength of concrete under different curing conditions, International Journal of Engineering, Vol. 2, No. 1, 2008

[16] Aitcin, P.C., Miao, B., Cook, W.D., and Mitchell, D., Effect of size and curing on cylinder compressive strength of normal and high-strength concretes, ACI materials journal, Vol. 91, No. 4, pp. 91-M34, 1994

[17] Samir, H**.,** Ani, AL-., Mokdad, A. K., and Zaiwary, AL-., The effect of curing period and curing delay on concrete in hot weather, Materials and Structures, Vol. 21, No. 3, pp. 205-212, 1988

[18] Collins, F., and Sanjayan, J.G., Strength and shrinkage properties of alkali activated slag concrete containing porous coarse aggregate, Cement and Concrete Research, Vol. 29, No. 4, pp. 607–610, 1999