Proceedings of the 6th Asia-Pacific Structural Engineering and Construction Conference (APSEC 2006), 5 – 6 September 2006, Kuala Lumpur, Malaysia

EFFECT OF APPLICATION TIME OF WATER-BASED CURING COMPOUND ON STRENGTH, HARDNESS, SORPTIVITY AND POROSITY OF BLENDING CONCRETES

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ABSTRACT: This paper describes the effectiveness of water-based curing compound (WBCC) applied to concrete surface at different elapsed time from casting on the various properties of OPC, silica fume (SF) and fly ash (FA) concrete. It also signifies the importance of utilizing moist curing prior to applying WBCC .Four series of OPC, OPC/SF and OPC/FA cylindrical concrete specimens made with a constant water-binder ratio of 0.50 were prepared. For the first series, the casting surfaces were sprayed with WBCC after various elapsed periods from casting, 1, 2, 3, 4, 24 hrs, while, for the second series, the casting surfaces were pre-cured with water for 1, 3 and 7 days prior to the application of WBCC. The third and fourth series of samples were exposed to air and water curing regimes, respectively, until the age of testing (28 days). Various test techniques, namely strength, hardness, capillary absorption and porosity, were applied on the four series of samples to assess their mechanical and durability related properties. It was found that the efficiency of WBCC is significantly dependent on the time of its application, used blending material, period of pre-water curing specified prior to its application and considered property of concrete. Increasing the time of application of WBCC from casting can lead to diminishing the possible positive effect of using such regime of curing. The effects of WBCC's application time and period of pre-water curing on durability related properties (sorptivity and porosity) of blending concretes were found to be much greater than their effects on the mechanical (strength and hardness) characteristics.

Keywords: Curing Compounds, Silica Fume, Sorptivity, Fly Ash, Microstructure of Concrete.

1. INTRODUCTION

Concrete curing is defined as the process of maintaining a satisfactory moisture in concrete during hydration and/or pozzolanic reaction, so that the mechanical, microstructure and durability properties of the concrete are developed. Various in situ-curing methods are widely used and mainly divided into two groups, namely, water-adding techniques (e.g. ponding, spraying) and water-retaining techniques (e.g. plastic sheeting, membrane-forming curing compounds). Details of such methods are well documented elsewhere (Senbetta and Scholer, 1982; and Nassif et al, 2005).

Water curing is undoubtedly the much preferred for most concrete construction projects. However, owing to restrictions encountered in situ and for certain concrete applications such as construction of highway pavements, canal lining, shell structures and high-rise buildings circumstances, curing compounds are judged to be more practical and economical (Dhir et al, 1989; Whiting and Synder, 2003). Also, in undeveloped areas, water taps are rarely available and trucking water in is expensive and difficult to supervise.

Various types of curing compounds are used nowadays in concrete industry; mainly include water-based, resin-solvent based, chlorinated rubber, wax-based, etc. Generally, water-based curing compound (WBCC) is considered as one of the most common-used curing compounds worldwide (Senbetta and Scholer, 1982; and Bentz et al 1997). Curing compounds are applied to the exposed surfaces of the fresh or hardened concrete as a liquid by either spraying or brushing or with roller, leaving a thin layer of coating that nearly seals the concrete surface against the evaporation of mixing water. This means that the early application of curing compounds can reduce the amount of moisture evaporated from concrete, and hence reducing the probability of occurrence of plastic shrinkage at concrete surface and in turn diminishing the amount of fine cracks (Whiting and Snyder, 2003).

Previous studies carried by Wang et al (1994) have studied the moisture loss of different OPC concrete mixes sealed with various curing compounds at different time of application. The study concluded that the effectiveness of curing compounds was dependent markedly on their application time and generic type. However, up to the author's knowledge, the effect of time of application of curing compounds, especially WBCC, on the other properties (such as strength, hardness, sorptivity and porosity) of OPC and blending concretes are not cited in literature. Clarification of such aspect will be helpful for Site Engineers, who have not a certain recommendation or rule regarding the determination of the proper time of application of curing compound when it is required for the various concrete types, e.g. OPC, OPC/F and OPC/SF.

Previous studies and manufactures have been recommended the importance of applying the curing compounds as soon as bleeding water evaporates (Fattuhi, 1986; and Dhir et al, 1989). These studies did not however provide the scientific proof for such recommendation, or give a reliable technique for detecting the end of evaporation of bleeding water. Another argument can be also arisen about the validity of such recommendation if cement replacement materials, such as fly ash and silica fume, are incorporated in OPC mixes. Moreover, applying of curing compounds after certain elapsed time from casting may lead to give the chance for fine cracks resulted from plastic shrinkage to develop during the period of bleeding. These arguments signify the importance of specifying the proper time for application of curing compounds.

Another great difficulty was encountered when using compound, its deficiency to achieve the desired properties of concrete when compared to the use of water-added curing regimes (Dhir et al, 1989; and Nassif et al, 2005). So, it can be recommended to utilize pre-water curing for sometime prior to the application of water compounds. Again, the period of pre-water curing is not well defined in literature. So there is a need to understand the effect of pre-water curing period on the efficiency of curing compound and on mechanical and durability related properties of both OPC and OPC/blends concrete.

The assessment of efficiency of curing compounds based on the strength of the concrete does not adequately predict the performance of the concrete in a structure, because the durability of concrete is governed more by its porosity and permeation characteristics than its strength (Fattuhi, 1986; Whiting, and Synder, 2003; and Nassif et al, 2005). Various test techniques, water and gas permeability, initial surface absorption and water absorption, were therefore introduced and used in literature to investigate the efficiency of curing compounds (Fattuhi, 1986; Dhir et al, 1989; Cabrera et al, 1989; and Nassif et al, 2005). However, the reliability of these techniques for measuring the efficiency of curing compounds is still under debate. Therefore, further studies have to be conducted to adopt an accurate, simple and easy test technique to be recommended for concrete-technologist.

To clarify the above-mentioned aspects, an extensive experimental program was therefore conducted to achieve the following objectives;

1) To investigate the effect of application time of water-based curing compound on the durability (sorptivity and porosity) and mechanical (hardness and compressive strength) related characteristics of OPC, FA and SF concrete.

2) To signify the importance of utilizing conventional water curing regime prior to the application of WBCC to the surfaces of OPC, OPC/FA and OPC/SF concrete.

3) To determine the efficiency of water-based curing compound for OPC concrete incorporating either FA or SF fume cured at different time of application.

2. EXPRIMENTAL DETAILS

2.1 Materials, Mix Proportions and Casting

The study was carried out using local materials of an Ordinary Portland Cement (OPC), Silica Fume (SF) and Fly Ash (FA) conforming ESS 373/1991 and ASTM C 618-85, and the details of their physical and chemical characteristics are given in Table 1. Natural sand of a medium fineness and natural gravel with a maximum aggregate size of 20 mm were used. The physical properties of the sand and coarse aggregate are presented in Table 2. Water-based curing compound (WBCC) of emulsified white polymer resistant to water was utilized in this study. The specific gravity and surface tension of the used WBCC were 1.008 and 0.038 N/m, respectively.

Three OPC concrete mixes incorporated with different blending materials, SF and FA, were considered throughout this investigation. A constant free water/binder ratio of 0.55 was used. The mix proportions of these mixes are presented in Table 3.

Table 1 Chemical and physical properties of OPC, SF and FA.

	Material		
	OPC	SF	FA
CaO	64.0	0.31	0.92
SiO_2	20.3	95.1	44.93
Al_2O_3	5.47	1.09	27.79
Fe_2O_3	2.36	0.10	19.06
MgO	2.30	0.73	1.44
SO^-_3	2.80	0.24	0.43
C_3S	68.0	-	-
C_2S	13.5	-	-
C_3A	5.5	-	-
C_4AF	7.01	-	-
Loss-on-ignition	1.2	1.80	2.88
Initial setting time, min	85	-	-
Final setting time, min	140	-	-
Surface Area, m^2/kg	403	20000	-

Table 2 Physical properties of sand and coarse aggregate.

	Water absorption, %	Specific gravity	Fineness modulus	Unit weight, Kg/m^3
Sand	1.71	2.63	2.72	1590
Coarse aggregate	1.69	2.58		1530

Table 3 Mix proportions of concrete specimens.

Concrete type	OPC, kg/m^3	Free water, kg/m^3	Aggregate, kg/m^3		Silica Fume		Fly Ash	
			Fine	Coarse	% wt. of OPC	Content, kg/m^3	% wt. of OPC	Content, kg/m^3
OPC	450	225	783	1068	-	-	-	-
SF	405	225	783	1068	10	45	-	-
FA	315	225	783	1068	-	-	30	135

The mixing procedures of concrete were adopted from BS 5075: Part 2: 1981. Sixty cylindrical concrete specimens with 150 mm diameter and 300 mm height were cast from each concrete mix. The casting was done in three layers. Each layer was compacted on a laboratory vibrating table. After compaction, the top-surface of the specimens was trowel-finished, and the appropriate curing regime was then applied at the designated time, as described below in the next Section.

2.2 Curing Regimes

Four curing regimes were utilized in this study, water-retained curing using WBCC, combined regime of water-retained and water-added curing, water curing and air curing. Therefore, the cast specimens were divided into four series. For the first series, the top-surfaces (as cast-surface) of the specimens were sprayed with WBCC at different elapsed time from trowel-finishing, 1, 2, 3, 4 and 24 hrs. The application rate of WBCC was 0.2 l/m^2 as recommended by manufacture. For the second series, the specimens were demolded, cured with water for different periods (1, 3 and 7 days), sealed with WBCC and then left in the laboratory air till the age of testing (28 days). The third series of samples were left in air for 28 days while the forth series were immersed in water curing tank for 27 days after demolding. Three concrete specimens were allocated for each curing condition to be tested for sorptivity, hardness and compressive strength. Another three specimens were left in each curing condition to be used for measuring the amount of evaporable water in concrete specimens (porosity test).

2.3 Testing

At age of 28 days from casting, the sprayed WBCC layers were removed, if found. Then, all concrete specimens prepared in this study were oven dried (105ºC) till a constant weight for each specimen was achieved. The hardness of casting surfaces of concrete specimens were then determined as a function of rebound number measurements taken by Schmidt hammer (type N), according to ASTM C 805. Four rebound number readings were taken for each allocated specimen.

After assessing the hardness, the as-cast surfaces of concrete specimens were exposed capillary absorption test, as described earlier by McCarter et al (1993). The sorptivity of as-cast surfaces of concrete specimens were then calculated using the data recorded from capillary absorption test, using the same test procedures and mathematical expression used by Hall (1989) and Claisse et al (1997)]. Hall (1989) has defined the sorptivity (S) as the slope of the cumulative volume of water absorbed per unit area (i) against the square root of time (t), using the following Equation.

$$S = \frac{i}{\sqrt{t}} \qquad \text{……………(1)}$$

The 28-days compressive strength of concrete specimens was finally measured using the specimens used for the above tests. The room temperature during the experimental program varied from 20 to 23 °C. Each reported test data point is the mean of the results for three specimens.

To determine the % of evaporated water (%EW) of the cover concrete cured with different curing regimes, a disc sample of 25 mm thickness, including as cast-surface, was cut-off from each specimen specified for this test, stored in water tanks till a constant weight (W_1) for each specimen was achieved, followed by calculating the difference in weight of sample at saturated surface dry and oven dry at 105ºC (W_2) conditions. EW can be then determined by dividing such difference by the weight of sample at 105ºC, using the following Equation.

$$EW = \frac{W_1 - W_2}{W_2} \times 100 \qquad \text{……..(2)}$$

The %EW were adopted in this study to provide an indicative measure for the amount of interconnected pores (porosity) in concrete and hence its durability. This method was suggested by Parrott (1992). Each reported test data point is the mean of the results for three samples.

3. CURING EFFICIENCY

The two cases which will give the extreme values of any concrete property are: (1) curing in water until age of testing, and (2) no curing under the same environmental conditions (air curing). Based on these values it is possible to define a curing efficiency (E) for a particular method of curing (WBCC), by the following equation (Cabrera et al, 1989).

$$E \approx \frac{k_1 - k_2}{k_1 - k_3} x100 \qquad \text{………….(3)}$$

Where, k_1 = studied property of a non-cured specimen, k_2 = studied property of a specimen cured by the method being evaluated, and k_3 = studied property of water-cured specimen till age of testing. If the curing method is equally good as water-curing ($k_2 = k_3$) then the value of E = 100%, while for poor curing method ($k_2 > k_3$) the value of E tends to 0%. This definition gives a convenient scale with which to assess the efficiency of chemical curing compounds or traditional methods (Cabrera et al, 1989). This concept of analysis was adopted in this study to investigate the various factors that could affect the efficiency of WBCC applied at OPC concrete cast-surface, e.g. time of application of WBCC and presence of blending materials in OPC mixes.

4. RESULTS AND DISCUSSION

4.1 Effect of Application Time of Curing Compound

This part of study aims to clarify the role of application time of WBCC on the various properties of concrete, mainly mechanical and durability, and then determine the most appropriate time for applying such type of curing compound on different concrete types made with different local ingredients. The most appropriate time (proper application time) was defined as the time at which best value of concrete property can be achieved. The durability related properties of concrete was investigated in terms of its sorptivity and porosity (represented by %EW), of which can provide a good image to the alteration that might happen to the fluid transport and pore structure of the surface zone of concrete cured with such type of curing. On the other hand, the mechanical properties are described in this study using a non-destructive technique (Schmidt hammer tool for measuring the hardness of cover concrete) and a destructive approach (compressive strength).

Figures 1 illustrates the sorptivity and %EW of OPC, SF and FA concretes cured with WBCC applied at different periods from casting (1, 2, 3, 4 and 24 hour), respectively. It can be seen from the results shown in this figure that the sorptivity and %EW of all considered types of concretes increase with delaying the application of WBCC to the concrete surface. The lowest values of sorptivity and %EW for OPC and SF concrete were noted when WBCC applied after one hour from casting processes, while the corresponding values for FA concrete was achieved when WBCC applied after two hours from casting processes. This means the proper application times of WBCC for OPC, SF and FA concrete are 1, 1 and 2 hours after mixing, respectively.

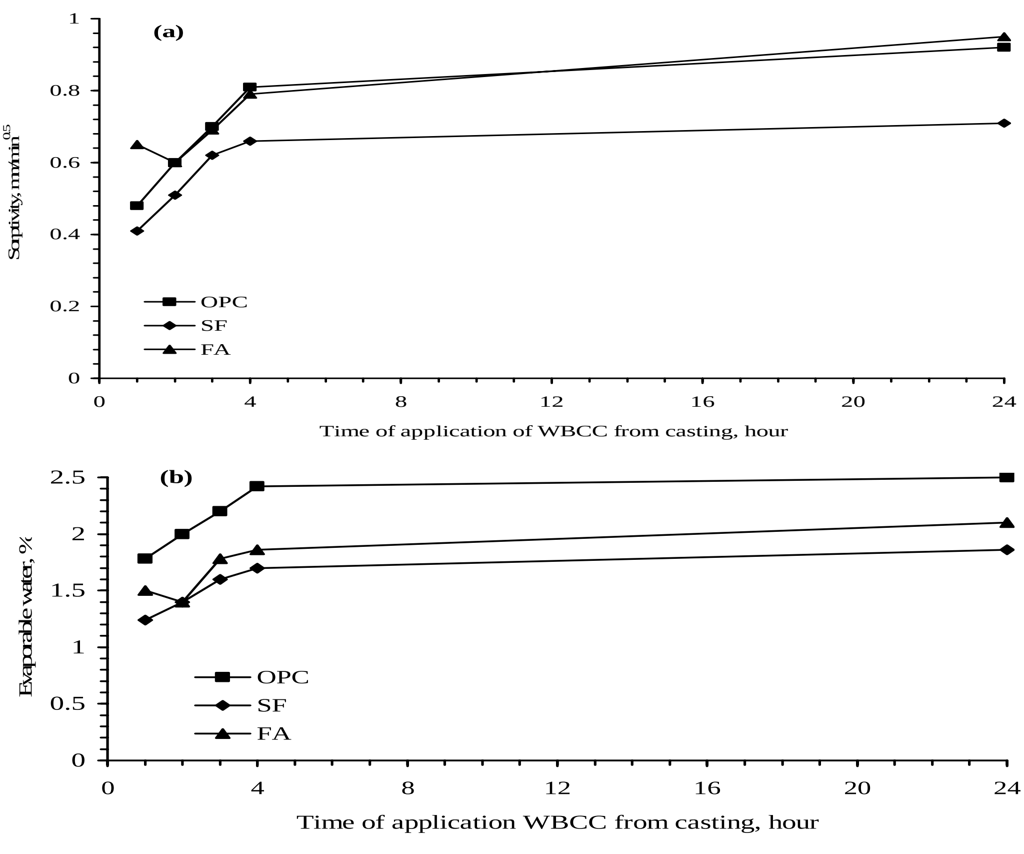

Figure 1 Effect of time of application of WBCC on a) sorptivity and b) %EW of OPC, OPC/SF and OPC/FA concrete.

The amount of increase in sorptivity of OPC, SF and SF concrete, due to delaying the application of WVCC for 24 hours from mixing, reaches about 90, 75 and 45%, respectively. Similarly, the amount of increase in porosity in terms of %EW has attained 40, 50 and 40%, for OPC, SF and FA concrete, respectively.

It is also clear from the results depicted in Figure 1 that the sorptivity and %EW values of SF concrete are always lower than the corresponding of OPC and FA concrete. Additionally, the fly ash concrete has shown better performance than OPC, especially when %EW results are regarded, where the %EW values of OPC/FA concrete are slightly lower than that of OPC concrete. However, the sorptivity of OPC and OPC/FA concrete seems to be close. This means that concrete containing cement replacement materials are sensitive to the considered application time of curing compounds.

Similarly, the effect of application time of WBCC on the mechanical properties of OPC and OPC/blends was studied and the results are shown in Figure 2, where the hardness (expressed by Schmidt hammer rebound number) and compressive strength of OPC, OPC/SF and OPCFA concrete sprayed with WBCC at different periods from casting (1, 2, 3, 4 and 24 hour) are plotted. It is apparent that the proper time of application (at which highest value of rebound number and compressive strength can be achieved) are 2, 3 and 2 hours for OPC, OPC/SF and OPC/FA concrete, respectively, when rebound number measurements are considered, and 2, 1 and 2 hours or OPC, OPC/SF and OPC/FA concrete, respectively, when compressive strength results are regarded. However, these estimated are not similar to that estimated from the results reported in Figure 1.

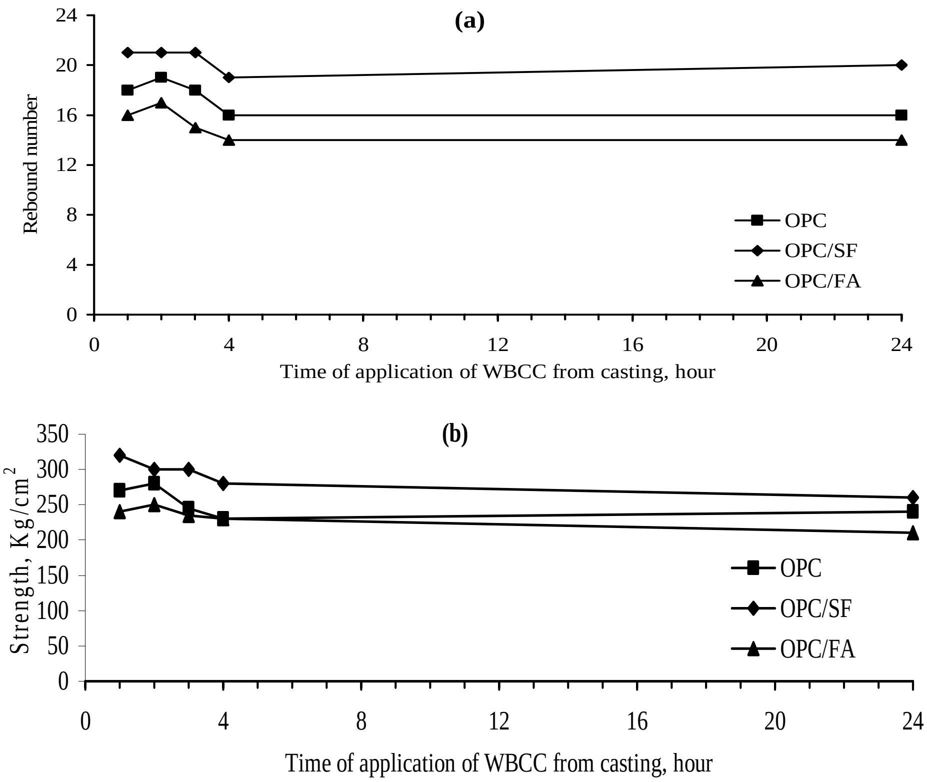

Figure 2 Effect of application time of WBCC on a) hardness and b) compressive strength of OPC, OPC/SF and OPC/FA concrete.

It can be also seen from Figure 2 that the variations occurred to rebound number due to alteration the application time of WBCC are not notable when compared with that noted from sorptivity and %EW. Delaying the application of WBCC for 24 hours from casting has led to reducing the hardness of concrete (in terms of rebound number measurements) by a range of 5 to 12% for all considered concrete types. This means that this approach (Schmidt hammer) is not sensitive for the variations occurred to the surface of concrete sealed with curing compounds.

On the other hand, the compressive strength of OPC, OPC/SF and OPC/FA is slightly affected by application time of WBCC. Late application of WBCC can led to increase the amount of reductions in compressive strength by about 15, 20 and 13% for OPC, SF and FA concrete. However, these amounts of reductions in mechanical properties due to altering the time of application of WBCC are not coincident with the amount of degradations in durability related characteristics (sorptivity, %EW). Theses finding support earlier claims that compressive test on cubes or cylinders is not a suitable test for assessing curing (Fattuhi, 1986; and Whiting Snyder, 2003). Generally, adopting techniques used for assessing the mechanical characteristics such as Schmidt hammer and compression test is not a unique approach for characterizing the effectiveness of curing.

Generally, it seems that the earlier application of curing compounds, the better achieved performance of concrete is, through reducing the amount of fluid that can penetrate into the surface zone of concrete and enhancing pore structure system in cover concrete. This may be attributed to the fact that the early application of WBCC can lead to decreasing the rate of moisture loss in surface zone of concrete and also reducing the possible shrinkage cracks at casting surface (Wang et al, 1994), of which affect the sorptivity and %EW results, as discussed above.

The positive effects of blending materials (SF and FA) on sorptivity of OPC concrete can be attributed to the pozzolanic reaction of these blending materials with calcium hydroxide resulted from hydration process forming calcium-silicate hydrate gel, thus improving the microstructure of concrete and make it denser. On other words, the pozzolanic reaction may lead to reducing the amount of connected pores (porosity) and hence blocking the pathway of fluid movement into cover concrete, i.e. reducing the sorptivity of concrete. Such explanation was confirmed by establishing the correlation between sorptivity and %EW of different concrete types, see Figure 3. Where, it is clear from the plotted correlation shown in Figure 3 that there is direct proportional relationship between sorptivity and %EW of OPC, OPC/SF and OPC/FA concrete cured with WBCC.

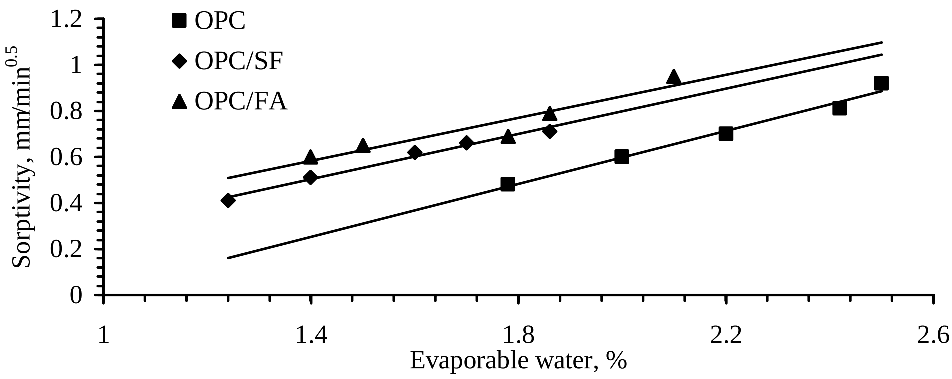

Figure3 Relationship between %EW and sorptivity of different concrete types cured with WBCC.

4.2. Effect of Utilization Pre-water Curing Prior to Application WBCC

As an attempt for improving the mechanical and durability related properties of concrete sealed with WBCC, the concrete specimens were pre-cured with for 1, 3 and 7 days immediately subsequent to demolding (24 hours) and prior to application of WBCC. The sorptivity, %EW and compressive strength of these specimens were assessed at age of 28 days, and the results are demonstrated in Figure 4. It is clear that introducing pre-water curing (water-added curing) for one day prior to the application of WBCC (water-retained curing) resulted in remarkable enhancements for all investigated properties of OPC and OPC/blends concrete. Where, the sorptivity and %EW of OPC, SF and FA concretes have been reduced by amount of 105, 90 and 90%, and 50, 55 and 55%, respectively. Meanwhile, the compressive strength of OPC, OPC/SF and OPC/FA concrete has been increased by 25, 30 and 35%, respectively. It seems that the amount of improvements in durability related characteristics due to utilization of water curing for one day prior to application of WBCC are higher than the corresponding in mechanical properties (represented by compressive strength).

Moreover, it is apparent from the data shown in Figure 4 that prolonging the period of pre-water curing from 1 to 7 days resulted in reducing the sorptivity and %EW and increasing the compressive strength of OPC, OPC/SF and OPC/FA concrete. The amount of reduction in sorptivity and %EW reach 17, 13 and 18%, and 12, 14 and 17%, approximately, for OPC, OPC/SF and OPC/FA concrete, respectively. On the other hand, the compressive strength of OPC, SF and FA concrete increased by about 4, 16 and 16%, respectively.

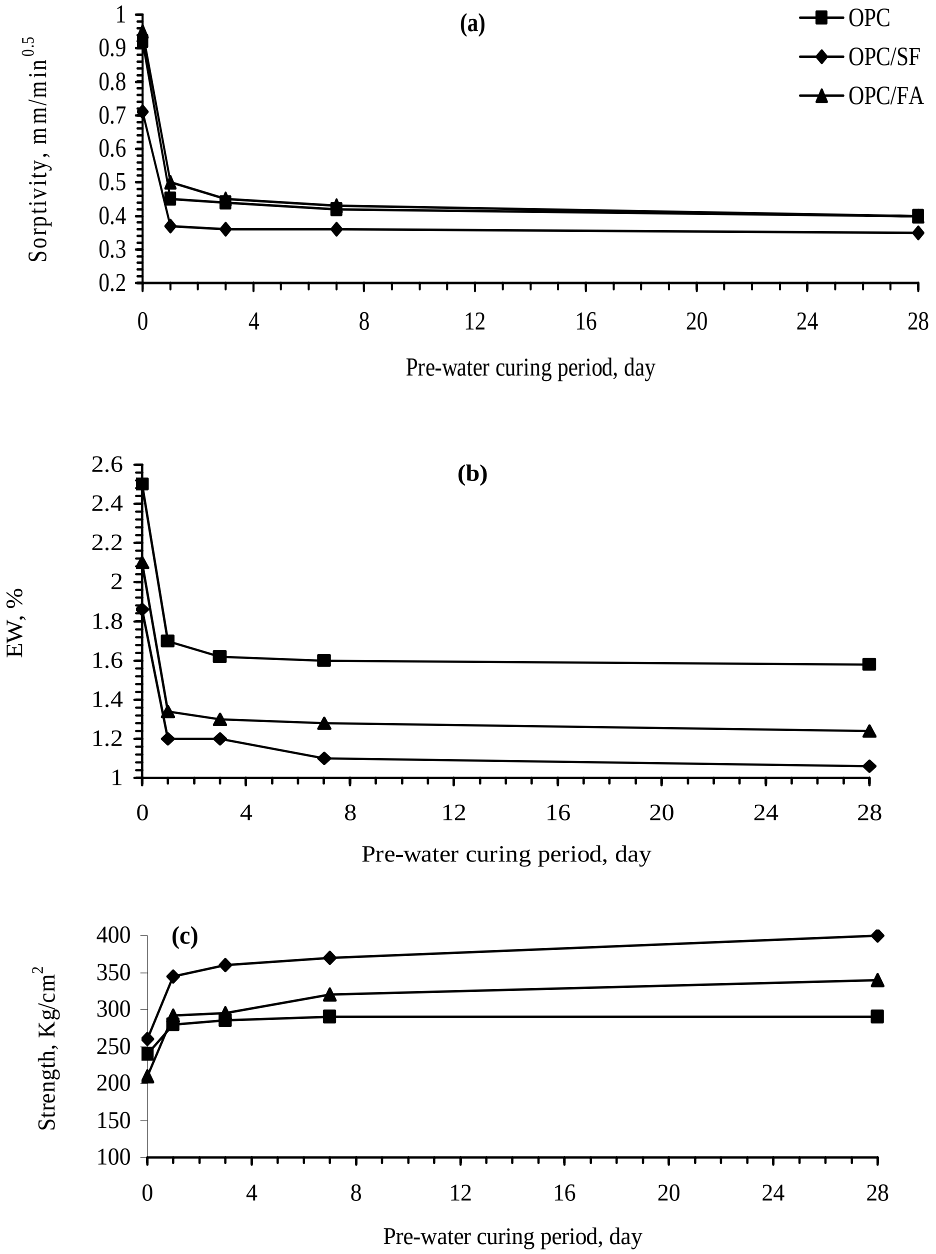

Figure 4 Effect of Pre-water curing period on a) sorptivity, b) %EW and c) compressive strength of OPC, SF and FA concrete.

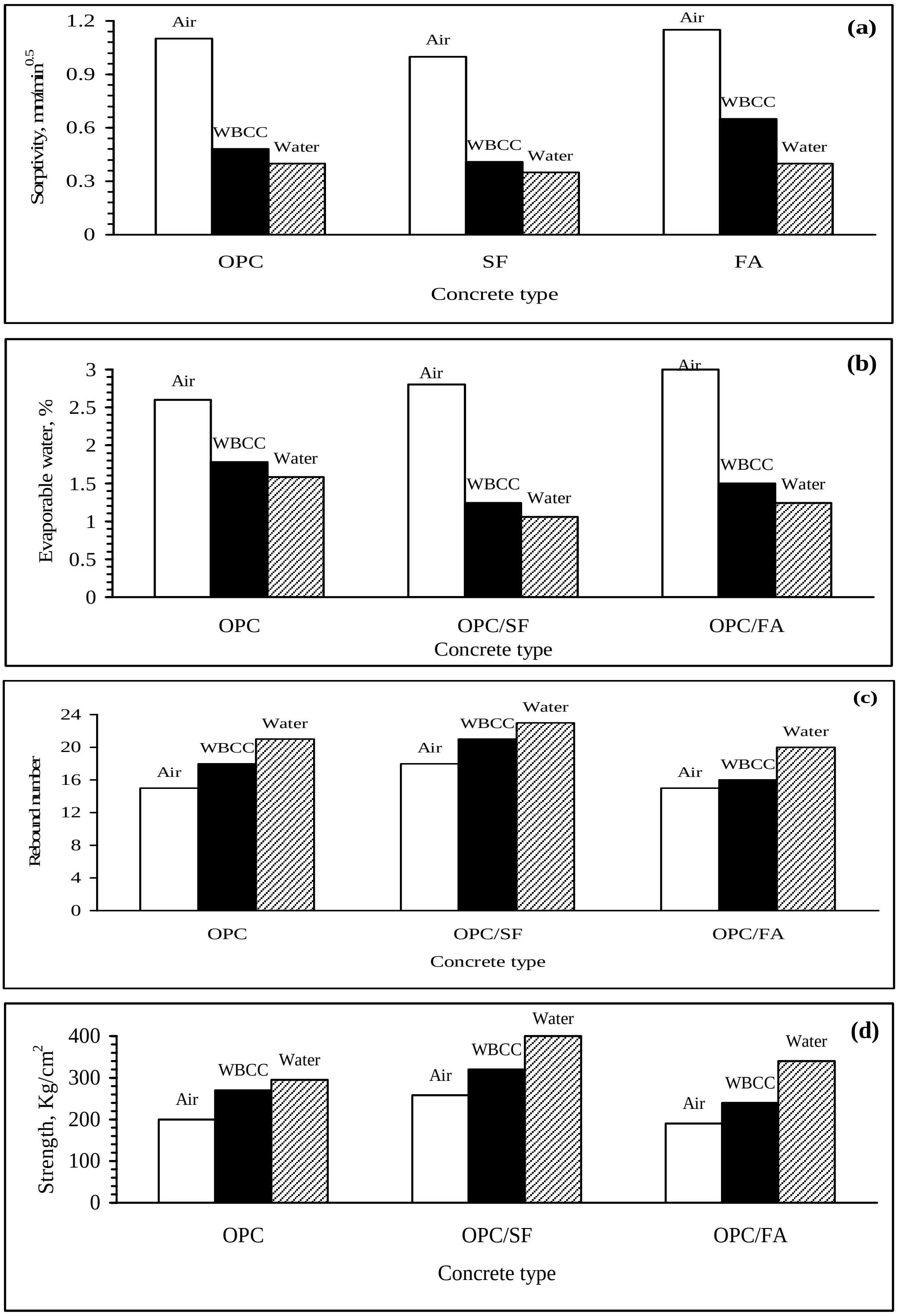

Figure 5 Sorptivity, %EW, rebound number and compressive strength of OPC, OPC/SF and OPC/FA concrete cured with different regimes, WBCC was applied after an hour from casting.

The noted improvements in the durability related properties of OPC and OPC/blends concrete pre-cured with water may be attributed to the fact that curing in water provides the wet environment (100% RH) which is enough for proceeding the hydration process and pozzolanic reaction. Therefore, the more period of pre-water curing, the better enhancements in the pore structure and hence mass transport properties of concrete are.

4.3. Efficiency of WBCC

To investigate the efficiency of WBCC, the effect of WBCC on the various properties of concrete has to be compared with the effects of air curing and water curing. So, a comparison between the effects of different curing regimes (air, WBCC and water) on the sorptivity, %EW, hardness and compressive strength of OPC, SF and FA concretes is firstly carried out, as shown in Figure 5.

Based on the data shown in Figure 5, the efficiency (%) of WBCC applied at different time of applications was deduced for all investigated types of concretes using the mathematical expression in Section 3 (Equation 3). The calculated values of efficiency of WBCC with regards to durability related (sorptivity and porosity) and mechanical properties (hardness and strength) are listed in Table 4 and 5, respectively.

Table 4 Efficiency of WBCC applied to OPC, OPC/SF and OPC/FA concretes at different times of application from casting, based on sorptivity and %EW results.

Time of application	Sorptivity			%EW		
	OPC	SF	FA	OPC	SF	FA
1 hour	89	90	67	80	89	85
2 hour	71	75	73	58	80	90
3 hours	57	58	61	39	68	69
4hours	41	52	48	17	63	64
24 hours	26	44	17	10	54	51

Table 5 Efficiency of WBCC applied to OPC, OPC/SF and OPC/FA concretes at different times of application from casting, based on rebound number and compressive strength results.

Time of application	Rebound number			Compressive strength		
	OPC	SF	FA	OPC	SF	FA
1 hour	50	60	20	73	62	33
2 hour	66	60	40	84	30	40
3 hours	50	60	0	47	30	30
4 hours	16	20	0	32	16	27
24 hours	16	40	0	42	1	13

As seen from Figure 5, the sorptivity and %EW of all concretes cured with WBCC are higher than the corresponding of specimens cured with air, and meanwhile lower than the corresponding of specimens cured in water for 28 days. So, it can be stated that WBCC is not completely efficient like long water curing (28 days), but definitely is better than air curing. The data shown in Table 4 indicated that the calculated values of efficiency (%) of WBCC are significantly reduced with increasing time of application, i.e. with delaying the application of WBCC. However the amounts of reductions in the efficiency of WBCC are inconsistent for all considered concrete types and tested properties.

Similarly, the hardness (in terms of rebound number) and compressive strength of OPC, SF and FA concrete cured with WBCC are higher than the corresponding of specimens cured in air, and always lower than the corresponding of specimens cured in water for 28 days. However, these effects are in less extent when compared to the effects of WBCC on sorptivity and porosity of concrete. This observation are confirmed by the results shown in Table 5, where, the maximum achieved efficiency of WBCC varies from 33 to 65% when the mechanical properties are considered, while the maximum achieved efficiency of WBCC varies from 85 to 90% when the durability related properties are regarded.

The results tabulated in Table 5 also point out that the efficiency of WBCC is decreased with increasing its time of application and amount of decrease in the efficiency of WBCC is not similar for rebound number and compressive strength results. Again the efficiency of WBCC is inconsistent and relies on the considered technique of testing, where the values of efficiency of WBCC are not similar at the same time of application for all concrete types. However, the results emphasize the doubt about the reliability of using Schmidt hammer in assessing the effectiveness of WBCC, where this tool has failed in monitoring the effect of application time of WBCC in many occasions, see the results shown in Figure 2-a and Table 5.

The highest improvement in the properties of OPC and OPC/blends concrete was obtained when water curing regime was considered, at which wet environment (100% RH) is enough for proceeding the hydration process and pozzolanic reaction. The adverse effect of air curing on all properties of concrete, especially durability related properties, may be attributed to the extensive shrinkage cracking which develops in dry environment (Toutanji and Bayast, 1999). Moreover, air curing is not suitable environment to satisfy the conditions required for both the hydration process of cement and pozzolanic reactions of blending materials to continue and hence improving their microstructure.

5. CONLUSIONS

From the study carried out herein, the following conclusions have been drawn:

1. Significant role for the application time of water-based curing compound (WBCC) on the various mechanical (strength and hardness) and durability related properties (sorptivity and porosity) of OPC, silica fume and fly ash concrete was noted. Increasing the time of application of WBCC from casting can lead to diminishing the possible positive effect of using such regime of curing. As a result, an early application of WBCC (within the first two hours from casting) is preferable, to achieve the best possible properties of concrete.
2. Utilization of pre-water curing regime prior to the application of WBCC has remarkable optimistic effects on all considered properties of concrete. The sorptivity and porosity of OPC and OPC/blends are significantly reduced with increasing the period of pre-water curing; meanwhile, the hardness and compressive strength of these concretes can be improved with prolonging the period of pre-water curing.
3. The effects of WBCC's application time and period of pre-water curing on durability related properties (sorptivity and porosity) of blending concretes were found to be much greater than their effects on the mechanical (strength and hardness) characteristics.
4. The efficiency of WBCC is significantly dependent on time of application, introducing pre-water curing regime prior to application of WBCC, inducing cement replacement materials into OPC mixes and considered tested property of concrete.
5. Reasonable correlation between the various durability related properties of surface zone of OPC and OPC/blends concrete cured with WBCC was established.
6. Both compressive strength and Schmidt hammer tool are not suitable approaches for assessing the efficiency of curing regimes.

6. ACKNOWLEDGMENTS

The author would like to thank Prof. Assem Abdelalim for his helpful discussion. The author would like to acknowledge all staff members working in the laboratory of Quality Control Lab., Civil Engineering Department, Faculty of Engineering in Shoubra, Banha University, for their technical support.

7. REFERENCES

Bentz, D. P., Synder, K. A. and Stutzman, P. E., 1997, "Hydration of Cement: The Effects of Curing Conditions", *Proceedings of the 10th International Congress on the Chemistry of Cement*, Gothenburg, Sweden, June 2-6, 1997, Vol.2.

Cabrera, J.G., Gowripalan, N. and Wainwright, P.J., 1989, "An Assessment of Concrete Curing Efficiency Using Gas Permeability", *Magazine of Concrete Research*, 1989, Vol. 41, No. 149, pp. 193-198.

Claisse, P. A., Elsayad, H. I. and Shabaan, I. G., 1997, "Absorption and Sorptivity of Cover Concrete", Journal of Materials in Civil Engineering, 1997, pp. 105-110.

Dhir, R. K., Levitt, M. and Wang, J., 1989, "Membrane Curing of Concrete: Water Vapour Permeability of Curing Membranes", *Magazine of Concrete*, 1989, Vol. 41, No. 149, pp. 221-228.

Fattuhi, N. I., 1986, "Curing Compounds for Fresh or Hardened Concrete", *Building and environment*, 1986, Vol. 21, No. 2, pp. 119-125.

HALL, C., 1989, "Water Sorptivity of Mortars and Concretes: A review", *Magazine of Concrete research*, 1989, Vol. 47, No. 147, pp. 51-61.

McCarter, W. J., 1993, "Influence of Surface Finish on Sorptivity on Concrete", *Journal of Materials in Civil Engineering*, 1993, Vol. 5, No 1, pp. 130-136.

Nassif, H. H., Najm, H. and Suksawang, N., 2005, "Effect of Pozzolanic Materials and Curing Methods on the Elastic Modulus of HPC", *Cement and Concrete Composites*, July 2005, Vol. 27, pp. 661-670.

PARROTT, L.J., 1992, "Variations of Water Absorption Rate and Porosity with Depth from an Exposed Concrete Surface: Effects of Exposure Conditions and Cement Type", *Cement and Concrete Research*, 1992, Vol. 22, pp. 1077-1088.

Senbetta, E. and Scholer, C.F., 1984, "A New Approach for Testing Concrete Curing Efficiency" *ACI Journal*, 1984, Vol. 81, No. 1, pp. 82-86.

Toutanji, H. A. and Bayasi, Z., 1999, "Effect of Curing Procedures on Properties of Silica Fume Concrete", *Cement and concrete Research*, 1999, Vol. 29, pp. 497-501.

Wang, J., Dhir, R. K. and Levitt, M., 1994, "Membrane Curing of Concrete: Moisture Loss", *Cement and Concrete Research*, 1994, Vol. 24, No. 8, pp. 1463-1474.

Whiting, N. M. and Synder, M.B., 2003, "A Study of the Effectiveness of Portland Cement Concrete Curing Compounds", *Transportation Research Board*, 22 pp., 2003.