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Effect of curing methods on strength and durability of concrete under hot weather conditions

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ABSTRACT

This paper reports the results of a research study conducted to evaluate the effect of curing methods on the mechanical properties of ordinary Portland cement (OPC) and Silica Fume Cement (SFC) concretes. Slab and beam specimens were prepared and cured by covering them with wet burlap or applying a curing compound under field conditions. Four types of curing compounds, namely water-, acrylic-, and bitumen-based and coal tar epoxy, were applied on the concrete specimens. The curing compounds were applied immediately after casting or after an initial period of burlap curing. The effect of the selected curing regime on the properties of OPC and SFC concrete specimens was evaluated by measuring compressive strength, water-absorption and chloride permeability. The strength and durability characteristics of both OPC and SFC concrete specimens cured by applying the selected curing compounds were similar or better than that of concrete specimens cured by covering with wet burlap. Though no significant change in strength could be noted due to the curing methodology; however, its effect was noticeable on the durability. The best performance was shown by concrete specimens cured by applying the bitumen-based curing compound followed by those cured by applying coal tar epoxy, acrylic-based or water-based curing compound. The initial period of water curing, prior to the application of the curing compound, was also noted to be beneficial in increasing the durability of concrete.

1. Introduction

The hot weather conditions in many parts of the world create several problems for both the fresh and hardened concrete. Reduced durability is one of the major problems in concrete prepared under hot weather conditions. Under hot weather conditions, concrete has to be cured for an extended period of time compared to normal weather conditions in order to achieve acceptable strength and durability. Rasheeduzzafar et al. [1] indicated that the protection provided by concrete against corrosion of steel by migration of chlorides into the concrete is greatly dependent upon the duration of curing. With increasing use of supplementary cementing materials, proper curing of concrete becomes all the more important. Many problems of cracking of silica fume cement concrete have been reported from the field due to inadequate curing. Curing is also essential for the pozzolanic cement concretes as water is required for the pozzolanic reaction to take place in the later stages of hydration of cement [2]. Concrete is cured either by water ponding, covering with wet hessian, or by the application of a curing compound. The first two methods have been preferred over the third one. However, due to shortage of water there is an increasing tendency to cure concrete by applying a curing compound. This is particularly true in regions with severe water shortage.

Some studies have been conducted on the efficiency of curing compounds. Wang et al. [3] evaluated the performance of a membrane curing compound and the experimental results showed that the effectiveness of membrane curing was dependent markedly on the time of its application. Among the curing compounds studied, chlorinated rubber was reported to be the most effective one, followed by the solvent-based curing compound, and the least effective was the water-based type. However, concretes moist cured for only 2 days exhibited significant improvement in strength and other characteristics, compared with concrete without any curing [4].

Austin and Robins [5] indicated that wet burlap curing was the most effective and air curing was the least effective between 7 and 28 days in the hot climatic conditions. Moist cured blast furnace slag cement concrete exhibited a greater increase in the pulse velocity than similarly cured OPC concrete. Wang and Black [6] reported that the curing efficiency index (CEI) correlated well with the capability of the curing membranes in retaining moisture within concrete.

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Experiments conducted by Grafe and Grube [7] on the influence of curing on the gas permeability of concrete prepared with different types of cement indicated that GGBFS and PFA cement concrete had greater permeability than OPC concrete, when specimens were cured only for 1 day. However, they concluded that with prolonged sealed curing, mixes prepared with blended cements performed better than OPC with the same water–cement ratio and cement content.

According to Khan and Ayers [8], the minimum period of curing should be optimized in terms of several properties, such as strength, permeability and the movement of aggressive gases and/or liquids from the environment. Their results show that the minimum period of curing required for OPC, FA and the SFC concrete mixtures were 3, 3.75, and 6.5 days, respectively. In general, it has been shown that concretes prepared with mineral admixtures are more sensitive to water curing than OPC concretes.

The effect of curing period and curing delay on the properties of concrete in hot weather was studied by Al-Ani et al. [9]. They reported that wet burlap curing method was an effective technique for maintaining the moisture in concrete for curing. However, they recommended a minimum of 3 days of wet burlap curing for rich mixes whereas 7 days for lean mixes.

The effect of curing on the strength development in both OPC and fly ash cement concretes was investigated by Haque [10]. The 90-day compressive strength of OPC and fly ash cement concrete was reported to be 67% and 50% of continuously fog cured concrete specimens. However, 7 days prior curing improved these values to 95% and 82% of the fully cured concrete.

Soroka et al. [11] studied the effect of stream curing on the later age strength of concrete with cement content raging from 150 to 400 kg/m^3. The delay in pouring the concrete was 30–60 min, the curing period varied from 2 to 5 h and the curing temperature ranged from 60 to 80 °C. The results showed that stream curing adversely affected the later age strength of concrete. However, under short curing periods and moderate temperatures this adverse effect was primarily due to lack of supplementary wet curing and due to physical factors, such as increased porosity, internal cracking and the heterogeneity of the paste.

Not much information could be found in the literature on the performance of curing compounds under hot weather conditions. Few studies that have been conducted on this aspect have indicated a beneficial effect of curing compounds in general. Whitting and Snyder [12] conducted a laboratory study to examine the effectiveness of different types of curing compounds in retaining water for hydration. The results indicated that application of curing compounds improved concrete strength and reduced permeability, relative to classic curing techniques, such as plastic sheeting and ponding and relative to the use of no curing treatment. Comparisons of moisture loss, compressive strength, permeability, and capillary porosity were made for specimens representing three high-VOC curing compounds, three low-VOC curing compounds, water curing, and plastic-sheet curing, and for specimens with no curing treatment after 3 days and 28 days of curing. The performance of the six curing compounds tested varied greatly, but none of the curing compounds performed as well as the specimens cured with water or plastic sheeting. However, it was reported that all the curing compounds performed better than specimens with no curing treatment.

Hani et al. [13] investigated the effect of curing on the elastic modulus of ternary cement concretes. Three methods of curing, namely air-dry curing, curing compound and wet curing with burlap were evaluated. The results showed that adding silica fume resulted in an increase in strength and modulus at early ages; however, there was no change in the modulus at 28 and 56 days. In addition, adding 20% fly ash with various percentage of silica fume had an adverse effect on both strength and modulus values at all ages. It was also shown that dry curing and curing compound reduced the modulus of elasticity compared to wet curing with burlap.

Recently, Al-Gahtani [14] studied the effect of curing methods on the properties of plain and blended cement concretes. The concrete specimens were prepared with Type I, silica fume, and fly ash cement concretes. They were cured either by covering with wet burlap or by applying two types of curing compounds, namely water-based and acrylic-based under a laboratory environment. The effect of curing methods was assessed by measuring plastic and drying shrinkage, compressive strength, and pulse velocity. It was reported that the strength development in the concrete specimens cured by covering with wet burlap was more than that in the specimens cured by applying water- or acrylic-based curing compounds [14]. It was reported that concrete specimens cured by applying curing compounds exhibited higher efficiency in decreasing the plastic and drying shrinkage strain than specimens cured by covering with wet burlap only. Among the two curing compounds investigated, acrylic-based curing compound was reported to perform better than the water-based curing compound.

Bushlaibi and Alshamsi [15] evaluated the efficiency of curing methods based on the strength property of the concrete. The compressive strength results of the water cured specimens were compared with the strength of concrete specimens cured under different regimes, such as indoor and outdoor environments with and without sprinkling water twice a day for 7 days. It was reported that the effect of curing regimes on strength is highly influenced by the exposure environment. Noticeable difference in the influences of the curing methods was observed for indoor specimens only. It was also reported that the strength of concrete specimens stored in the outdoor environment was less than the strength of results than those stored indoors for all curing regimes.

Austin et al. [16] reported a study conducted to compare the development of strength and permeability of ordinary OPC and GGBFS concretes that were cured in a simulated arid climate. The arid environment of Algerian Sahara was simulated inside an environment chamber to create different field conditions. It was concluded that under good curing conditions strength of the GGBFS concretes was higher than that of the OPC control concrete at all test ages. However it was reported that the GGBFS concrete was more sensitive to poor curing than OPC concrete.

With growing scarcity of water, it becomes essential to cure concrete by the application of a curing compound. Also, in certain regions curing by water ponding or by covering with wet hessian is costly as desalinated water utilized for this purpose is expensive. Further, under certain situations the wet burlap curing cannot be prolonged due to construction constraints. Under such circumstances, curing by the application of a curing compound may be preferred after initial wet burlap curing for few days. Further, there is a need to study the effect of optimum duration of wet curing prior to the application of curing compounds on the properties of concrete.

In the reported study the performance of the curing methods was evaluated under field conditions in a hot and arid environment.

2. Methodology of research

2.1. Materials and specimens

Concrete slab specimens, measuring $1 \times 1 \times 0.15$ m, and beam specimens, measuring $0.2 \times 0.2 \times 1$ m, were prepared. Table 1 shows the mix constituents used to prepare OPC and silica fume cement concrete specimens. The OPC and silica fume cement concrete specimens were prepared with ASTM C150 Type I cement.

Table 1
Mix constituents used to prepare ordinary and silica fume cement concrete specimens.

Concrete mix	Cement content (kg/m^3)	Silica fume (kg/m^3)	w/cm ratio	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)
OPC	370	0	0.4	1177	721
SFC	344	26	0.4	1170	717

Four generic curing compounds, namely acrylic-based, water-based, bitumen-based and coal tar epoxy, were selected for inclusion in the reported study.

The concrete specimens were cured under the following conditions:

i. Applying curing compound (acrylic-based, water-based and bitumen-based) on fresh concrete.
ii. Covered with plastic sheeting for 1 day.
iii. Cured under wet burlap for 1 day followed by the application of one of the selected curing compounds (acrylic-based, water-based, bitumen-based and coal tar epoxy).
iv. Under wet burlap for 2 days.
v. Cured under wet burlap for 2 days followed by the application of one of the selected curing compounds (acrylic-based, water-based and bitumen-based).
vi. Under wet burlap for 3 days.
vii. Cured under wet burlap for 3 days by the application of one of the selected curing compounds (acrylic-based, water-based and bitumen-based).
viii. Under wet burlap for 7 days.
ix. Cured under wet burlap for 7 days by the application of one of the selected curing compounds (acrylic-based, water-based, and bitumen-based).

The concrete specimens intended for water curing were cured by covering them with wet burlap over laid by a plastic sheet. The burlap was wetted by spraying water from time to time. The curing compounds were applied by either a brush or with a spray. The coverage rate of the curing compound corresponded to that recommended by the manufacturers, as shown in Table 2.

The concrete specimens were prepared in summer times (July; mean temperature 40 °C and RH: 70–80%). The specimens were prepared in the early hours of the morning in order to meet the hot weather recommendations of ACI 305 [17].

2.2. Tests

The effect of curing conditions on the properties of hardened cement concrete was assessed by the following procedures:

(i) Compressive strength: Core specimens, 75 mm diameter and 150 mm long, were retrieved from slab specimens to determine compressive strength, according to ASTM C39 [18], after 14, 28, and 60 days of completion of curing or application of the curing compound.

Table 2
Coverage rates of selected curing compounds.

Generic designation of the curing compound	Coverage rate
Acrylic-based	6.1–8.6 m^2/l
Water-based	3.5–5.0 m^2/l
Bitumen-based	5–6 m^2/l
Coal tar epoxy	10.7 m^2 per gallon

(ii) Water absorption: Core specimens, 75 mm diameter and 150 mm long, were retrieved from the beam concrete specimens to determine water absorption according to ASTM C 642 [19], after 14, 28, and 60 days of completion of curing or application of the curing compound.
(iii) Chloride permeability: Core specimens, 75 mm in diameter and 150 mm long, were retrieved from beam specimens to determine chloride permeability, according to ASTM C 1202 [20], after 14, 28, and 60 days of completion of curing or application of the curing compound.

3. Results and discussion

3.1. Compressive strength

The compressive strength development in the OPC concrete specimens cured by the application of the curing compound on fresh concrete is summarized in Table 3. As expected the compressive strength increased with age. Maximum compressive strength was noted in the concrete specimens cured by applying the water-based curing compound and the minimum strength was noted in the concrete specimens cured by applying acrylic-based curing compound.

Table 4 depicts the compressive strength of OPC concrete specimens cured by applying selected curing compounds after 1, 2, 3 and 7 days of initial curing by covering them with wet burlap. The compressive strength of concrete specimens cured by covering with wet burlap for 1, 2, 3, and 7 days is also included in this table. Maximum compressive strength was measured in the concrete specimens cured by applying the bitumen-based curing compound while it was the least in the concrete specimens cured by covering

Table 3
Compressive strength of OPC concrete specimens with curing compound applied on fresh concrete.

Age (days)	Compressive strength (MPa)			
	Coal-tar epoxy	Acrylic-based	Bitumen-based	Water-based
14	25.4	23.7	24.4	27.8
28	27.3	24.5	26.1	28.3
60	28.2	26.5	28.8	30.4

Table 4
Compressive strength of OPC concrete specimens cured by covering with wet burlap or applying the selected curing compounds.

Curing method	Initial wet burlap curing (days)	Compressive strength, MPa, after		
		14 days	28 days	60 days
Wet burlap	1	27.2	29.7	30.1
	2	30.3	32.0	34.4
	3	31.0	33.0	35.0
	7	31.1	33.2	35.1
Acrylic curing compound	1	27.4	27.8	30.4
	2	31.9	33.0	34.5
	3	32.4	34.0	35.5
	7	33.0	34.5	36.2
Bitumen-based curing compound	1	30.6	32.2	34.9
	2	33.3	34.5	36.0
	3	34.0	35.5	36.5
	7	34.5	36.0	37.1
Water-based curing compound	1	28.8	31.3	32.4
	2	29.0	31.1	33.1
	3	29.9	30.2	34.0
	7	32.7	33.5	35.0

with burlap, in the batch specimens cured initially for 1 day by covering with wet burlap.

Also, in the batch of concrete specimens cured under wet burlap for 2 days prior to the application of curing compounds, the maximum strength was measured in the concrete specimens cured by the application of bitumen-based curing compound while it was the least in the specimens cured by applying the water-based curing compound. The 60-day strength values were 33.1, 34.5, 36.0, and 34.4 MPa in the concrete specimens on which water-based, acrylic-based, or bitumen-based curing compounds were applied or they were cured by covering with wet burlap respectively.

Further, in both the batches of concrete specimens cured under wet burlap for 3 and 7 days prior to the application of curing compounds, the compressive strength of specimens cured by applying the bitumen-based curing compound was more than that of other specimens. Minimum compressive strength was noted in the specimens cured by applying the water-based curing compound. However, the effect of type of curing compound or curing by covering the specimens with wet burlap was not that significant.

Table 5 summarizes the compressive strength development in the SFC concrete specimens cured by applying the selected curing compounds on fresh concrete. Maximum compressive strength was noted in the concrete specimens cured by applying coal-tar epoxy while it was the minimum in the specimens cured by applying the acrylic-based curing compound.

Table 6 summarizes the compressive strength of SFC concrete specimens cured by applying selected curing compounds after 1, 2, 3 and 7 days of wet burlap curing. The compressive strength development in the SFC concrete specimens cured by covering with wet burlap is also included in this table. In the batch of concrete specimens cured under wet burlap for 1 day prior to the application of curing compounds, the compressive strength was the maximum in the specimens cured by the application of the bitumen-based curing compound while the minimum compressive strength was noted in the concrete specimens cured by applying acrylic-based curing compound.

In the SFC concrete specimens cured by applying the selected curing compounds, after 2, 3, and 7 days of initial water curing, maximum compressive strength was noted in the concrete specimens coated with the acrylic-based curing compound while the minimum strength was noted in the concrete specimens cured by covering with wet burlap. However, the strength variation between the four batches of concrete specimens was not that significant.

It should be noted that the compressive strength data presented in Tables 3–6 are average values of three replicate specimens. The variation in the compressive strength was in an acceptable range as indicated by the standard deviation varying from 0.6 to 0.8 MPa.

3.2. Water absorption

The water absorption in the OPC concrete specimens cured by the application of curing compounds on the fresh concrete is summarized in Table 7. The water absorption in the OPC concrete specimens cured by applying the selected curing compounds after 1, 2, 3, or 7 days of initial curing by covering with wet burlap is summarized in Table 8. As the curing period increased, there was a reduction in the water absorption in all concrete specimens. Lower absorption values were noted in the concrete specimens cured by applying the bitumen-based curing compound. However, the variation in the absorption values was not that significant.

Table 9 summarizes the water absorption in the SFC concrete specimens cured by applying the selected curing compounds on

Table 5
Compressive strength of silica fume cement concrete specimens with curing compound applied on fresh concrete.

Age (days)	Compressive strength (MPa)			
	Coal-tar epoxy	Acrylic-based	Bitumen-based	Water-based
14	28.99	26	27.6	27.3
28	30.26	27	28.1	28
60	32.5	28	29.4	29.1

Table 6
Compressive strength of silica fume cement concrete specimens cured by covering with wet burlap or applying the selected curing compounds.

Curing method	Initial wet burlap curing (days)	Compressive strength, MPa, after		
		14 days	28 days	60 days
Wet burlap	1	26.5	28.1	29.1
	2	28.9	29.1	30.2
	3	30.1	31.1	32.0
	7	30.5	31.5	33.0
Acrylic curing compound	1	27.6	28.3	28.4
	2	27.8	29.0	32.3
	3	30.4	28.5	33.6
	7	33.5	34.0	38.7
Bitumen-based curing compound	1	28.0	28.5	30.5
	2	29.2	30.0	31.2
	3	30.0	31.2	33.0
	7	31.5	32.0	33.1
Water-based curing compound	1	28.0	28.9	30.0
	2	28.5	30.2	31.5
	3	31.1	32.2	33.1
	7	31.5	33.0	33.5

Table 7
Water absorption in OPC concrete specimens with curing compound applied on fresh concrete.

Age (days)	Water absorption (%)			
	Coal-tar epoxy	Acrylic-based	Bitumen-based	Water-based
14	6.45	7.01	6.4	6.9
28	6.28	6.54	6.09	6.48
60	5.95	6.4	5.9	6.35

Table 8
Water absorption in OPC concrete specimens cured by covering with wet burlap or applying the selected curing compounds.

Curing method	Initial wet burlap curing (days)	Water absorption, % after		
		14 days	28 days	60 days
Wet burlap	1	6.6	6.45	6.37
	2	6.50	6.40	6.30
	3	6.40	6.25	6.15
	7	6.30	6.25	6.00
Acrylic curing compound	1	6.65	6.50	6.38
	2	6.40	6.30	5.94
	3	6.23	6.15	5.85
	7	6.15	6.05	5.75
Bitumen-based curing compound	1	6.20	6.10	5.85
	2	6.00	5.90	5.75
	3	5.90	5.75	5.65
	7	5.80	5.65	5.50
Water-based curing compound	1	6.75	6.40	6.25
	2	6.50	6.35	6.15
	3	6.45	6.30	6.00
	7	6.40	6.20	5.85

Table 9
Water absorption in silica fume cement concrete specimens with curing compound applied on fresh concrete.

Age (days)	Water absorption (%)			
	Coal-tar epoxy	Acrylic-based	Bitumen-based	Water-based
14	5.75	5.68	5.5	5.88
28	5.6	5.5	5.4	5.6
60	5.56	5.35	5.25	5.45

fresh concrete. The water absorption values in the SFC concrete specimens cured by applying the selected curing compounds after 1, 2, 3, and 7 days of initial curing by covering with wet burlap are shown in Table 10. The water absorption in SFC concrete specimens was less than that of OPC concrete specimens in all the curing regimes. Bitumen-based curing compound performed better compared to all other curing compounds investigated.

It should be noted that the data on water absorption strength presented in Tables 7–10 are average values of three replicate specimens. The variation in the water absorption was in an acceptable range as indicated by the standard deviation varying from 0.2% to 0.4%.

3.3. Chloride permeability

The chloride permeability in the OPC concrete specimens, cured by the application of curing compounds, on the fresh concrete is summarized in Table 11. The chloride permeability in the OPC concrete specimens cured by applying the selected curing compounds after 1, 2, 3, or 7 days of initial curing by covering with wet burlap is depicted in Table 12. Minimum chloride permeability was noted in the concrete specimens coated with the bitumen-based curing compound while maximum chloride permeability was noted in the concrete specimens coated with the acrylic-based curing compound. Also, the chloride permeability of concrete specimens cured by covering with wet burlap was more than that of concrete specimens cured by applying the selected curing compounds, particularly after initial water curing.

Table 10
Water absorption in the silica fume cement concrete specimens cured by covering with wet burlap or applying the selected curing compounds.

Curing method	Initial wet burlap curing (days)	Water absorption, % after		
		14 days	28 days	60 days
Wet burlap	1	6.20	5.99	5.77
	2	6.10	5.85	5.67
	3	5.90	5.76	5.50
	7	5.65	5.45	5.30
Acrylic curing compound	1	5.55	5.36	5.30
	2	5.30	5.20	5.10
	3	5.15	5.05	4.95
	7	5.10	4.95	4.80
Bitumen-based curing compound	1	5.35	5.30	5.15
	2	5.10	5.00	4.95
	3	4.95	4.85	4.75
	7	4.85	4.76	4.65
Water-based curing compound	1	5.71	5.50	5.35
	2	5.48	5.30	5.15
	3	5.33	5.15	5.00
	7	5.20	5.00	4.85

Table 11
Chloride permeability in the OPC concrete specimens with curing compound applied on fresh concrete.

Age (days)	Total charge passed (Coulombs)			
	Coal-tar epoxy	Acrylic-based	Bitumen-based	Water-based
14	2877	3662	3424	3558
28	2803	3560	3174	3330
60	2753	3462	3115	3088

Table 12
Chloride permeability in the OPC concrete specimens cured by covering with wet burlap or applying the selected curing compounds.

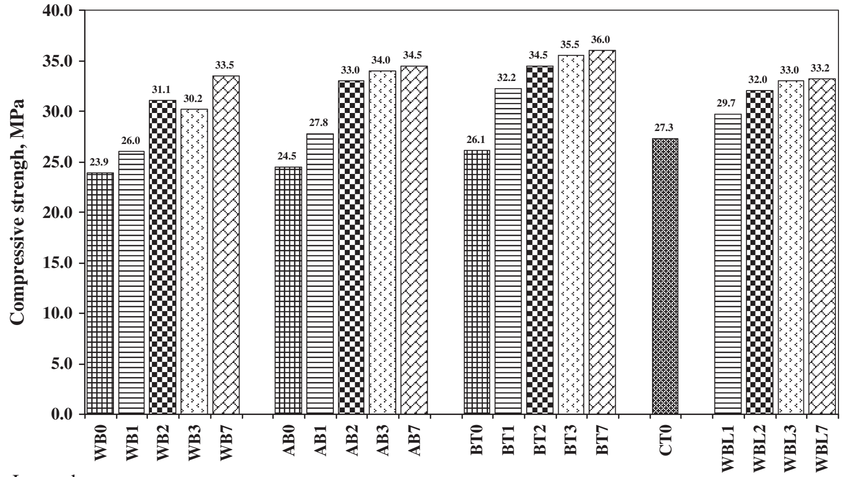
Curing method	Initial wet burlap curing (days)	Chloride permeability, Coulombs, after		
		14 days	28 days	60 days
Wet burlap	1	3491	3303	3298
	2	3377	3256	3227
	3	3223	3155	3088
	7	2956	2887	2853
Acrylic curing compound	1	3369	3223	2977
	2	3223	3021	2820
	3	2908	2887	2753
	7	2820	2753	2618
Bitumen-based curing compound	1	3357	3088	2685
	2	3290	2786	2585
	3	2891	2685	2518
	7	2590	2551	2450
Water-based curing compound	1	3491	3119	2878
	2	3315	2904	2887
	3	3256	2820	2685
	7	3189	2662	2551

Table 13
Chloride permeability in silica fume cement concrete specimens with curing compound applied on fresh concrete.

Age (days)	Chloride permeability (Coulombs)			
	Coal-tar epoxy	Acrylic-based	Bitumen-based	Water-based
14	2471	3239	2701	2916
28	2448	3122	2450	2887
60	2383	3055	2350	2731

Table 14
Chloride permeability in the silica fume cement concrete specimens cured by covering with wet burlap or applying the selected curing compounds.

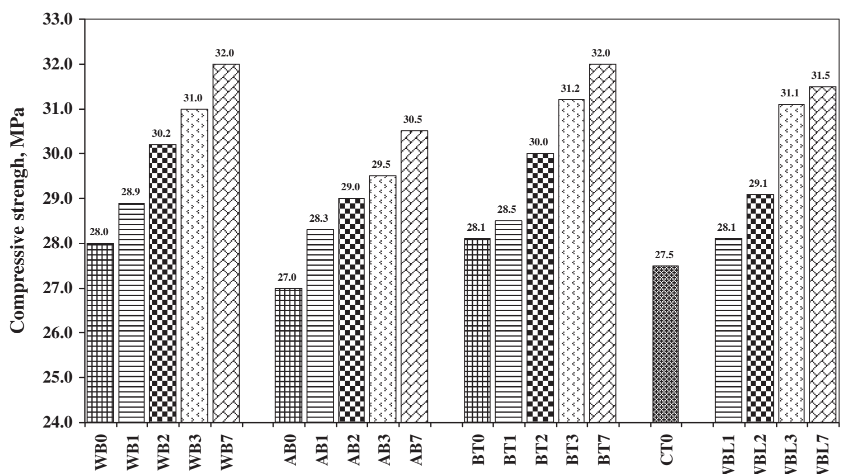
Curing method	Initial wet burlap curing (days)	Chloride permeability, Coulombs, after		
		14 days	28 days	60 days
Wet burlap	1	2713	2582	2553
	2	2618	2565	2450
	3	2551	2484	2328
	7	2435	2363	2283
Acrylic curing compound	1	3185	2881	2728
	2	2839	2685	2618
	3	2570	2417	2350
	7	2441	2330	2283
Bitumen-based curing compound	1	2652	2390	2289
	2	2615	2350	2226
	3	2590	2316	2215
	7	2468	2289	2136
Water-based curing compound	1	2794	2753	2685
	2	2618	2432	2399
	3	2594	2383	2316
	7	2296	2215	2139



Legend:

WB0 Water based applied on fresh concrete
WB1 Water based applied on 1 day cured concrete
WB2 Water based applied on 2 day cured concrete
WB3 Water based applied on 3 day cured concrete
WB7 Water based applied on 7 day cured concrete
BT0 Water based applied on fresh concrete
BT1 Water based applied on 1 day cured concrete
BT2 Water based applied on 2 day cured concrete
BT3 Water based applied on 3 day cured concrete
BT7 Water based applied on 7 day cured concrete
AB0 Water based applied on fresh concrete
AB1 Water based applied on 1 day cured concrete
AB2 Water based applied on 2 day cured concrete
AB3 Water based applied on 3 day cured concrete
AB7 Water based applied on 7 day cured concrete
CT0 Coal tar epoxy applied on fresh concrete
WBL1 Water based applied on 1 day cured concrete
WBL2 Water based applied on 2 day cured concrete
WBL3 Water based applied on 3 day cured concrete
WBL7 Water based applied on 7 day cured concrete

Fig. 1. Compressive strength of OPC concrete specimens after 28 days.



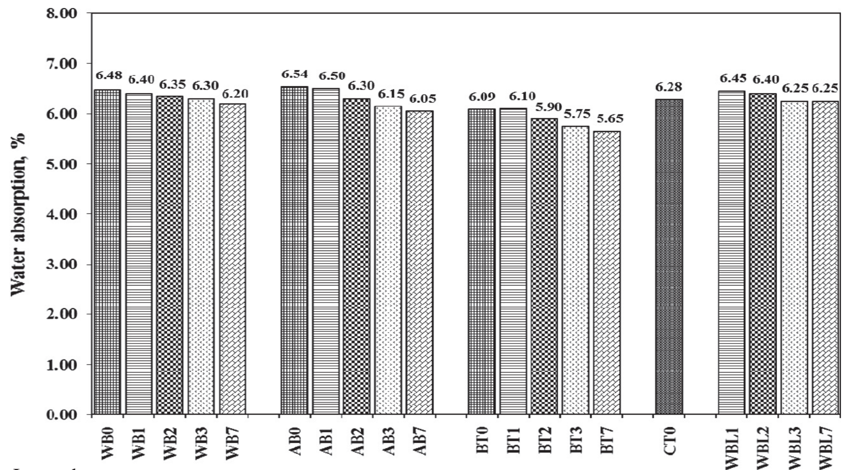
Legend:

WB0 Water based applied on fresh concrete
WB1 Water based applied on 1 day cured concrete
WB2 Water based applied on 2 day cured concrete
WB3 Water based applied on 3 day cured concrete
WB7 Water based applied on 7 day cured concrete
BT0 Water based applied on fresh concrete
BT1 Water based applied on 1 day cured concrete
BT2 Water based applied on 2 day cured concrete
BT3 Water based applied on 3 day cured concrete
BT7 Water based applied on 7 day cured concrete
AB0 Water based applied on fresh concrete
AB1 Water based applied on 1 day cured concrete
AB2 Water based applied on 2 day cured concrete
AB3 Water based applied on 3 day cured concrete
AB7 Water based applied on 7 day cured concrete
CT0 Coal tar epoxy applied on fresh concrete
WBL1 Water based applied on 1 day cured concrete
WBL2 Water based applied on 2 day cured concrete
WBL3 Water based applied on 3 day cured concrete
WBL7 Water based applied on 7 day cured concrete

Fig. 2. Compressive strength of silica fume cement concrete specimens after 28 days.

Table 13 summarizes the chloride permeability in the SFC concrete specimens cured by applying the selected curing compounds on fresh concrete. Table 14 summarizes the chloride permeability in the SFC concrete specimens cured by applying the selected curing compounds after 1, 2, 3, and 7 days of initial curing by covering with wet burlap. This table also shows the chloride permeability values for concrete specimens cured by covering with wet burlap. Minimum chloride permeability was noted in the concrete specimens coated with the bitumen-based curing compound while maximum chloride permeability was measured in the concrete specimens coated with the water-based curing compound. The chloride permeability of concrete specimens cured by covering with wet burlap was generally less than that of concrete specimens cured by the application of acrylic-based curing compound.

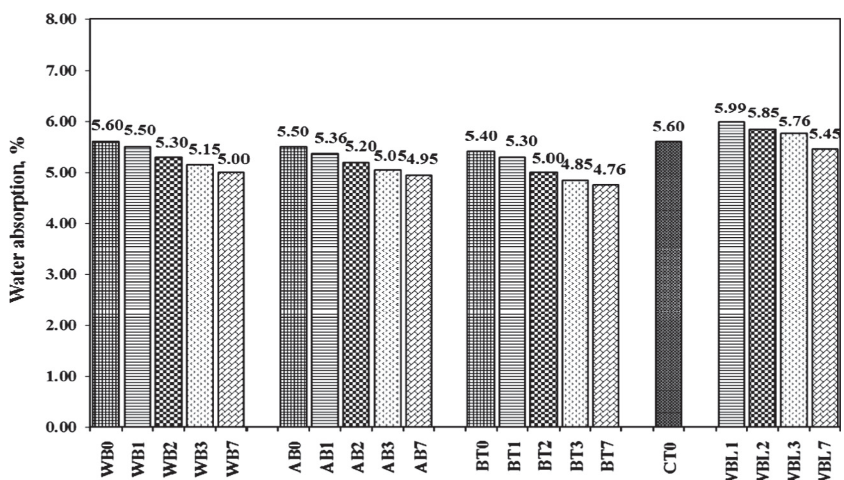
It should be noted that the chloride permeability data presented in Tables 11–14 are average values of three replicate specimens.



Legend:

WB0 Water based applied on fresh concrete
WB1 Water based applied on 1 day cured concrete
WB2 Water based applied on 2 day cured concrete
WB3 Water based applied on 3 day cured concrete
WB7 Water based applied on 7 day cured concrete
BT0 Water based applied on fresh concrete
BT1 Water based applied on 1 day cured concrete
BT2 Water based applied on 2 day cured concrete
BT3 Water based applied on 3 day cured concrete
BT7 Water based applied on 7 day cured concrete
AB0 Water based applied on fresh concrete
AB1 Water based applied on 1 day cured concrete
AB2 Water based applied on 2 day cured concrete
AB3 Water based applied on 3 day cured concrete
AB7 Water based applied on 7 day cured concrete
CT0 Coal tar epoxy applied on fresh concrete
WBL1 Water based applied on 1 day cured concrete
WBL2 Water based applied on 2 day cured concrete
WBL3 Water based applied on 3 day cured concrete
WBL7 Water based applied on 7 day cured concrete

Fig. 3. Water absorption in the OPC concrete specimens after 28 days.



Legend:

WB0 Water based applied on fresh concrete
WB1 Water based applied on 1 day cured concrete
WB2 Water based applied on 2 day cured concrete
WB3 Water based applied on 3 day cured concrete
WB7 Water based applied on 7 day cured concrete
BT0 Water based applied on fresh concrete
BT1 Water based applied on 1 day cured concrete
BT2 Water based applied on 2 day cured concrete
BT3 Water based applied on 3 day cured concrete
BT7 Water based applied on 7 day cured concrete
AB0 Water based applied on fresh concrete
AB1 Water based applied on 1 day cured concrete
AB2 Water based applied on 2 day cured concrete
AB3 Water based applied on 3 day cured concrete
AB7 Water based applied on 7 day cured concrete
CT0 Coal tar epoxy applied on fresh concrete
WBL1 Water based applied on 1 day cured concrete
WBL2 Water based applied on 2 day cured concrete
WBL3 Water based applied on 3 day cured concrete
WBL7 Water based applied on 7 day cured concrete

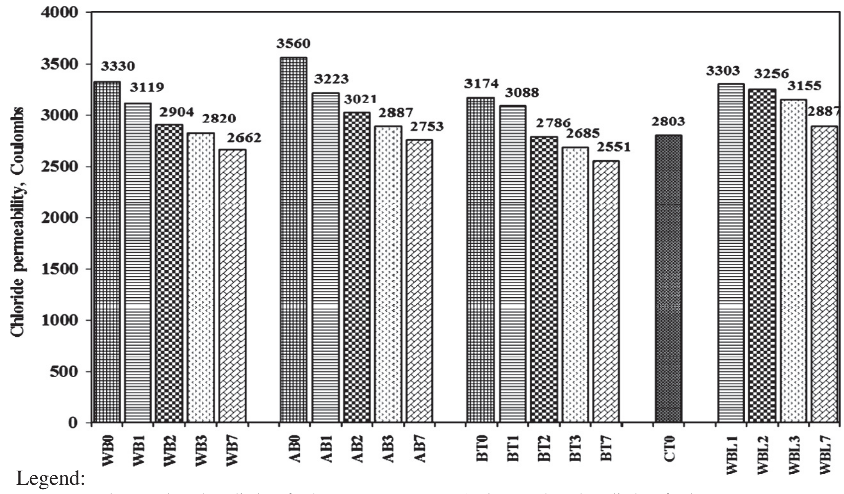
Fig. 4. Water absorption in the silica fume cement concrete specimens after 28 days.

The variation in the chloride permeability was in an acceptable range as indicated by the standard deviation varying from 50 to 100 Coulombs.

4. Discussion

The 28-day compressive strength of OPC concrete specimens cured by covering with wet burlap or applying the selected curing compounds is depicted in Fig. 1. Maximum compressive strength was generally noted in the concrete specimens cured by applying the bitumen-based curing compound. The compressive strength generally increased with the period of initial wet burlap curing prior to the application of the curing compound. However, there was no significant difference in the compressive strength of specimens cured for 2, 3 or 7 days. This indicates that at least 2 days of initial curing by covering with wet burlap is recommended prior to the application of the curing compound.

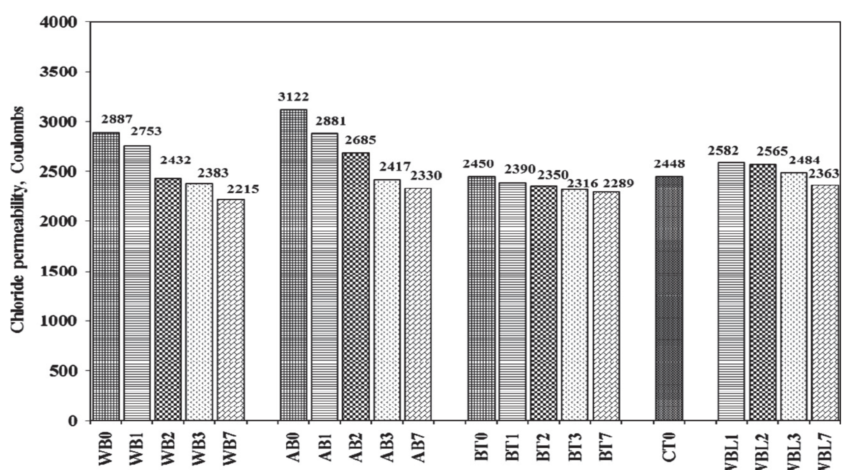
The 28-day compressive strength of SFC concrete specimens cured by covering with wet burlap or applying the selected curing



Legend:

WB0 Water based applied on fresh concrete	AB0 Water based applied on fresh concrete
WB1 Water based applied on 1 day cured concrete	AB1 Water based applied on 1 day cured concrete
WB2 Water based applied on 2 day cured concrete	AB2 Water based applied on 2 day cured concrete
WB3 Water based applied on 3 day cured concrete	AB3 Water based applied on 3 day cured concrete
WB7 Water based applied on 7 day cured concrete	AB7 Water based applied on 7 day cured concrete
BT0 Water based applied on fresh concrete	CT0 Coal tar epoxy applied on fresh concrete
BT1 Water based applied on 1 day cured concrete	WBL1 Water based applied on 1 day cured concrete
BT2 Water based applied on 2 day cured concrete	WBL2 Water based applied on 2 day cured concrete
BT3 Water based applied on 3 day cured concrete	WBL3 Water based applied on 3 day cured concrete
BT7 Water based applied on 7 day cured concrete	WBL7 Water based applied on 7 day cured concrete

Fig. 5. Chloride permeability in the OPC concrete specimens.



Legend:

WB0 Water based applied on fresh concrete	AB0 Water based applied on fresh concrete
WB1 Water based applied on 1 day cured concrete	AB1 Water based applied on 1 day cured concrete
WB2 Water based applied on 2 day cured concrete	AB2 Water based applied on 2 day cured concrete
WB3 Water based applied on 3 day cured concrete	AB3 Water based applied on 3 day cured concrete
WB7 Water based applied on 7 day cured concrete	AB7 Water based applied on 7 day cured concrete
BT0 Water based applied on fresh concrete	CT0 Coal tar epoxy applied on fresh concrete
BT1 Water based applied on 1 day cured concrete	WBL1 Water based applied on 1 day cured concrete
BT2 Water based applied on 2 day cured concrete	WBL2 Water based applied on 2 day cured concrete
BT3 Water based applied on 3 day cured concrete	WBL3 Water based applied on 3 day cured concrete
BT7 Water based applied on 7 day cured concrete	WBL7 Water based applied on 7 day cured concrete

Fig. 6. Chloride permeability in the silica fume cement concrete specimens.

compound is depicted in Fig. 2. The maximum compressive strength was noted in the concrete specimens cured by applying the bitumen-based curing compound. However, the difference in the strength between the specimens cured by applying the selected curing compounds or by covering them with wet burlap was not that significant. Further, the compressive strength increased with the initial period of curing by covering with the wet burlap. Comparison of data in Figs. 1 and 2 indicate a marginal decrease in the compressive strength of silica fume cement concrete compared to OPC concrete. This may be attributed to the material characteristics of the silica fume used. It is not necessary that silica fume increases the compressive strength of OPC. However, the durability characteristics of silica fume cement concrete were noted to be better than that of OPC, as will be discussed later.

The 28-day water absorption in the OPC concrete specimens cured by covering with wet burlap or applying the selected curing compounds is depicted in Fig. 3. The water absorption was the least in the concrete specimens coated with the bitumen-based

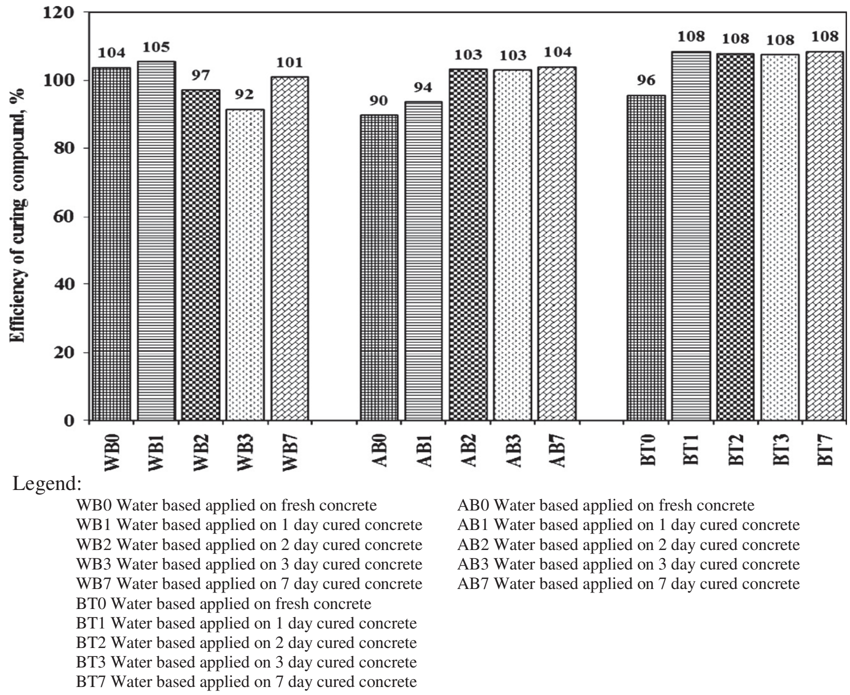


Fig. 7. Efficiency of curing compounds in terms of compressive strength as compared to wet burlap curing at 28 days age for the OPC concrete specimens.

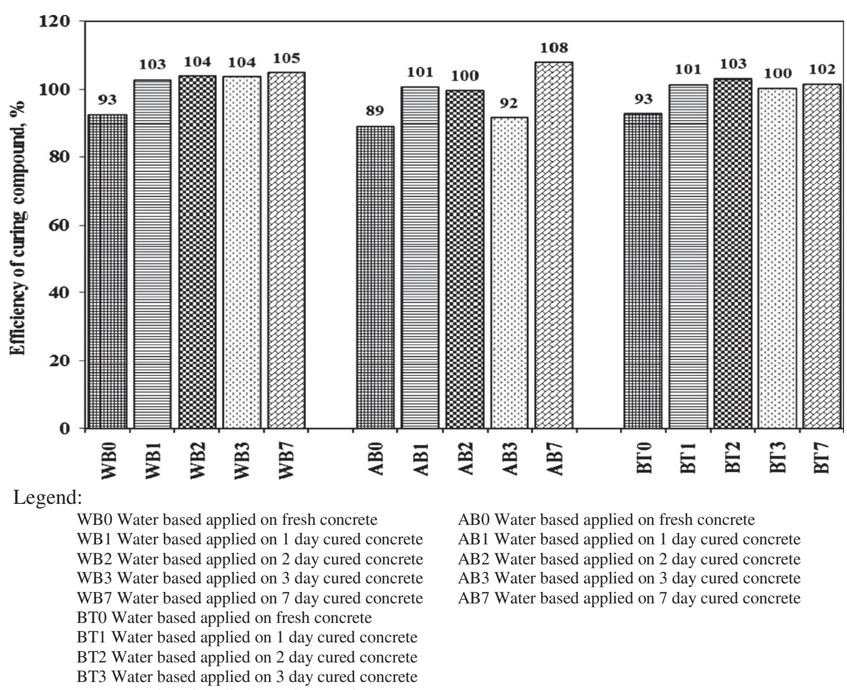


Fig. 8. Efficiency of curing compounds in terms of compressive strength as compared to wet burlap curing at 28 days age for the silica fume cement concrete specimens.

curing compound while it was the maximum in the concrete specimens cured by covering with wet burlap. However, the difference in the absorption values was not that significant. The water absorption decreased with the initial period of water curing prior to the application of the curing compound.

The 28-day water absorption in the SFC concrete specimens is depicted in Fig. 4. The water absorption was the least in the specimens cured by applying the bitumen-based curing compound while it was the maximum in the concrete specimens cured by covering with wet burlap.

The chloride permeability in the OPC concrete specimens is shown in Fig. 5. Minimum chloride permeability was noted in the concrete specimens coated with the bitumen-based curing compound after 7 days of initial water curing while the maximum chloride permeability was noted in the concrete specimens cured by covering with wet burlap.

The chloride permeability in the SFC concrete specimens is depicted in Fig. 6. Maximum chloride permeability was noted in the concrete specimens coated with the water-based curing compound after initial 7 days of water curing while the minimum chloride permeability was noted in the concrete specimens cured by covering with the wet burlap. However, the difference in the chloride permeability of the concrete specimens cured by applying the selected curing compounds or covering with wet burlap was not that significant.

Figs. 7 and 8 show the efficiency of curing compounds in terms of compressive strength in OPC and silica fume cement concrete specimens, respectively. The efficiency of curing compounds selected in this study was more or less 100% in all the concrete specimens, except for those on which the curing compound was applied on fresh concrete, both in OPC and silica fume cement concretes.

The data developed in this study have indicated the usefulness of the selected curing compounds, particularly the bitumen- and acrylic-based curing compounds in improving the strength and durability of both OPC and SFC concretes. The compressive strength and durability of both OPC and SFC cured by applying either acrylic- or bitumen-based curing compound was better than that of concrete specimens cured by covering with wet burlap. This is a positive indication for regions where there is a severe scarcity of curing water. Among the curing compounds selected, bitumen-based curing compounds performed better than acrylic-based, coal tar epoxy and water-based curing compounds, generally in the decreasing order.

Another finding of this study is that initial 2 days of wet burlap curing was found to be beneficial prior to the application of the curing compound. This probably supplies the initial loss of water when the concrete is fresh. With growing time period and sealing of the surface by the curing compound the need for more water decreases.

5. Conclusions

Maximum compressive strength was measured in the concrete specimens cured by applying the bitumen-based curing compound, indicating the usefulness of curing compounds even under hot weather conditions.

The water absorption was the least in the concrete specimens coated with the bitumen-based curing compound while it was the maximum in the concrete specimens cured by covering with wet burlap.

Minimum chloride permeability was noted in the concrete specimens coated with the bitumen-based curing compound after 7 days of initial water curing while the maximum chloride permeability was measured in the concrete specimens cured by covering with wet burlap.

The data developed in this study have shown that the strength and durability characteristics of both plain and silica fume cement concrete specimens cured by applying the selected curing compounds were superior or equal to those of the concrete specimens cured by covering with wet burlap. Generally, 2 days curing by covering with wet burlap prior to applying the curing compound was necessary from strength perspective while 7 days prior curing is required from durability requirement, especially in the silica fume cement concrete. The strength and durability of concrete cured by applying a curing compound, when the concrete was fresh, was generally not similar to specimens cured by covering with wet burlap, except in the specimens cured by applying the bitumen-based curing compound.

Among the selected curing compounds, the performance of bitumen-based curing compound was generally better than that of other curing compounds, followed by coal tar epoxy, and acrylic- and water-based curing compound in the decreasing order.

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