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# Efficiency of curing on partially exposed high-strength concrete in hot climate

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**Abstract**

This investigation aims at studying and evaluating the efficiency of existing concrete curing practices in hot climates. It deals with the effect of curing methods on compressive strength development of high-strength concrete (HSC). The efficiency of curing methods was evaluated in terms of concrete compressive strength of samples tested at 1, 3, 7, 14, 28, and 270 days. The strength of samples cured under four different curing regimes was compared with the strength results of water-cured samples, which is designated as the control regime. In order to simulate actual site conditions, only the top-as-cast face of the samples was left exposed to the climatic conditions. It was found 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 samples only. Moreover, strength of samples stored in the outdoor environment (OD) exhibited lower results than those stored indoors (ID) for all curing regimes. The finding of this investigation indicates a deficiency in the curing practices in the region. Actual curing practices had no significant effects on strength specially those samples cured in a hot dry OD. More care and more efficient curing methods and techniques should be considered when dealing with hot dry climate. 

*Keywords:* Curing methods; High-strength concrete (HSC); Hot climates

## 1. Introduction

Loss of water from fresh and young concrete caused by inadequate curing can result in detrimental effects on the properties of concrete in the short and long run. These undesirable effects include appearance of plastic shrinkage cracks, reduction in strength, increase in permeability, and increase in porosity resulting in a shorter service life of the structure [1–6].

In the interior part of the United Arab Emirates where Al-Ain City is located, low humidity, high ambient temperature, persistent high wind speeds, and the solar radiation are the predominant weather factors. In such a weather where the loss of water from fresh and young concrete is greatly accelerated by the environment, the need for proper early moist curing is essential. Effective curing reduces the loss of water and increases the hydration of the cement, and hence reduces the total porosity and increases the probability of the pores being either blocked or narrowed down by continued formation of hydration products. Permeability of concrete, on the other hand, is extremely important for the long-term durability of concrete. The lower the permeability, the lower the ingress of harmful deleterious substances in concrete. Moreover, curing has significant effect not only on fresh concrete but also on hardened concrete. It has been shown that proper curing reduced concrete permeability and absorption characteristic [6–8].

## 2. Background

ACI 318-81 [2] indicates that in hot weather where drying rates are high, concrete should be adequately cured by maintaining moist continuous curing specially for the first few days. Haque [3] demonstrated that barring of any of the moist curing parameters such as humidity or temperature adversely affects the compressive strength of the Portland cement (PC) concrete.

Although curing is an important aspect in the production of good concrete, the timing and duration of curing is more

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important [4,5]. It is demonstrated that in case of curing interruption, significant concrete strength could be regained by recuring of concrete. Nevertheless, the detrimental effects resulting from lack of proper early curing are irreversible [6], and the strength gained by recuring is lower. Carrier [7] suggested that a short period of drying early in concrete life can reduce strength gain potential.

Longer curing duration allows increased hydration. Curing duration affects the porosity and pore size distribution of cement mixes [8]. Lower porosity and smaller pore sizes result from longer periods of curing [8]. The curing method is important as well. Arafah et al. [9] have presented results of the effect of curing in Riyadh area of Saudi Arabia. They showed that concrete strength was significantly influenced by the method of curing.

It is well known that hydration of cement can take place only when vapor pressure in the capillaries is sufficiently high [10]. Proper curing not only reduces the rate of water evaporation, but it provides a continuous source of moisture for the hydration that reduces the porosity, and provides a finer pore size distribution in the concrete [8]. This in turns allows concrete to develop its strength and durability.

Among the various curing methods practiced in the Gulf States, one approach is widely practiced. This is the conventional system in which continuous or frequent application of water is maintained through spraying, plastic cover, or wet burlap. Other systems include the chemical membrane approach in which excessive loss of water is prevented by application of a membrane-forming curing compound to the freshly placed concrete.

Most curing-related research has focused on normal-strength concrete (NSC) [8,11]. Information about effects of curing on strength development of high-strength concrete (HSC) is relatively less documented. This paper attempts to investigate the influence of the different conventional curing methods on the strength development of HSC. Methods of curing investigated here are generally similar to those used in every day practice in the region.

## 3. Experimental

### 3.1. Material

The composition of the concrete used in the five curing regimes is shown in Table 1. Potable water, ordinary PC (OPC-Type I), dune sand, and fine sand as fine aggregate and crushed gravel as coarse aggregate were used. A modified lignosulfonate and polyoxycarboxylic acids-based superplasticizer conforming to ASTM C494-80 types A, B, C (chloride-free) was used to maintain a target slump of 120–150 mm.

Table 1
Mix proportions of concrete (by weight)

| | Fine aggregate | | Coarse aggregate | | | |
|---|---|---|---|---|---|---|
| OPC | Dune sand | Fine sand | Gravel 14-10 | Gravel 10-5 | w/c | Superplasticizer (ml/kg) |
| 1 | 0.358 | 1.54 | 0.61 | 1.41 | 0.33 | 4.61 |

Table 2
Curing regimes

| Codes | Environment | Method of curing |
|---|---|---|
| ID NC | indoor | indoor, uncured |
| OD NC | outdoor | outdoor, uncured |
| ID SC | indoor | indoor, sprinkling two times a day without cover for 7 days |
| OD SC | outdoor | outdoor, sprinkling two times a day without cover for 7 days |
| ID PC | indoor | indoor, sprinkling two times a day with plastic cover for 7 days |
| OD PC | outdoor | outdoor, sprinkling two times a day with plastic cover for 7 days |
| ID BC | indoor | indoor, sprinkling two times a day with burlap cover for 7 days |
| OD BC | outdoor | outdoor, sprinkling two times a day with burlap cover for 7 days |
| WC | not applicable | water-cured, fully submerged for 28 days, considered as control case |

### 3.2. Mixing, casting, and curing

The concrete, in batch of 50 kg, was mixed in a laboratory Pan-type mixer for a period of 3 min. In the preparation of the specimens, 100-mm$^3$ molds were used. A water–cement ratio (w/c) of 33% was chosen to obtain a desired concrete mix of an average 28 days compressive strength of 60 MPa and above.

All specimens were cast in two layers and were compacted on a vibrating table. After casting, the molded specimens were transferred to their correspondent environment [indoor (ID) or outdoor (OD)] and left for 24 h to set. They were then demolded. All sides were covered with plastic sheet except the top-as-cast face that was cured according to their designated curing method. The cubical specimens were tested for compressive strength at 1, 3, 7, 14, 28, and 270 days from the termination period of the curing method.

In addition to water-tank curing, four curing methods were examined, which were carried both ID and OD. The first

Table 3
Compressive strength results (MPa)

| Age (days) | Curing method | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | NC | | SC | | PC | | BC | |
| | WC | ID | OD | ID | OD | ID | OD | ID | OD |
| 1 | 23.0 | 25.0 | 27.0 | 27.0 | 27.0 | 19.0 | 22.0 | 20.0 | 12.0 |
| 3 | 48.0 | 48.0 | 50.0 | 49.5 | 47.0 | 44.5 | 42.5 | 50.5 | 44.0 |
| 7 | 60.5 | 56.0 | 50.0 | 60.0 | 49.0 | 56.0 | 49.0 | 62.5 | 54.0 |
| 14 | 62.0 | 62.0 | 48.5 | 65.5 | 51.0 | 68.0 | 56.0 | 71.0 | 55.0 |
| 28 | 61.0 | 60.5 | 53.5 | 69.5 | 51.0 | 75.0 | 53.0 | 77.0 | 54.0 |
| 270 | 72.0 | 62.0 | 57.0 | 66.0 | 60.5 | 71.0 | 57.5 | 64.5 | 61 |

Table 4
Compressive strength results in percentage form relative to 28-day strength of water-cured samples

| Age days | Curing method | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | NC | | SC | | PC | | BC | |
| | WC | ID | OD | ID | OD | ID | OD | ID | OD |
| 1 | 23.0 | 41 | 44 | 44 | 44 | 31 | 36 | 33 | 20 |
| 3 | 48.0 | 79 | 82 | 81 | 77 | 73 | 70 | 83 | 72 |
| 7 | 60.5 | 108 | 82 | 98 | 80 | 92 | 80 | 102 | 89 |
| 14 | 62.5 | 102 | 80 | 107 | 84 | 111 | 92 | 116 | 90 |
| 28 | 61.0 | 99 | 88 | 114 | 84 | 123 | 87 | 126 | 89 |
| 270 | 72.0 | 102 | 93 | 108 | 99 | 116 | 94 | 106 | 100 |

method was water sprinkling twice a day for 7 days, which is designated as SC; the second was water sprinkling twice a day for 7 days with a plastic cover, which is designated as PC; the third was water sprinkling twice a day for 7 days with a burlap cover, which is designated as BC; and the forth method was no curing, designated as NC (see Table 2).

## 4. Results and discussions

The compressive strength results are shown in Table 3. Table 4 presents the results in relative form (%) of control; i.e., 28-day water-cured samples.

### 4.1. Effect of environment

The effect of environment on strength is shown in Figs. 1–4. The OD environment as expected was seen to lower the strength of concrete for all curing methods. The reduction in strength is seen to increase with age. The reduction in concrete strength was mostly negligible for ages up to 3 days. At ages beyond 7 days, reduction in strength of up to 25% of control was recorded. Hot climates are known to lower the strength of concrete in two ways:

1. Reduction in strength due to the high curing temperature. ACI 305 [6] and many other researchers [8,12,13] have indicated that high curing temperatures result in weak and badly dispersed hydration products. The results of the current work are in agreement with these findings.

2. Lower strength due to the higher evaporation rate of water needed for hydration [6]. The results of the current work confirm such finding. In addition to this, the difference between the two environments increases with age. This shows that while water is being lost from samples kept in laboratory environment, the rate of water loss is higher for samples stored in OD environment.

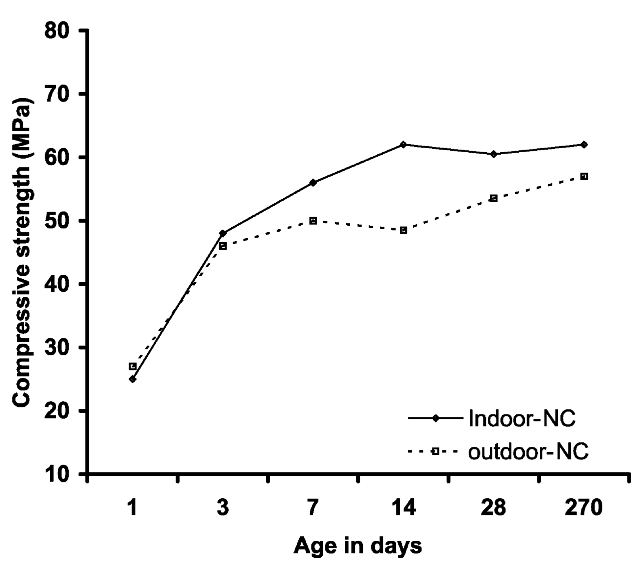


Fig. 1. Compressive strength development of uncured samples.

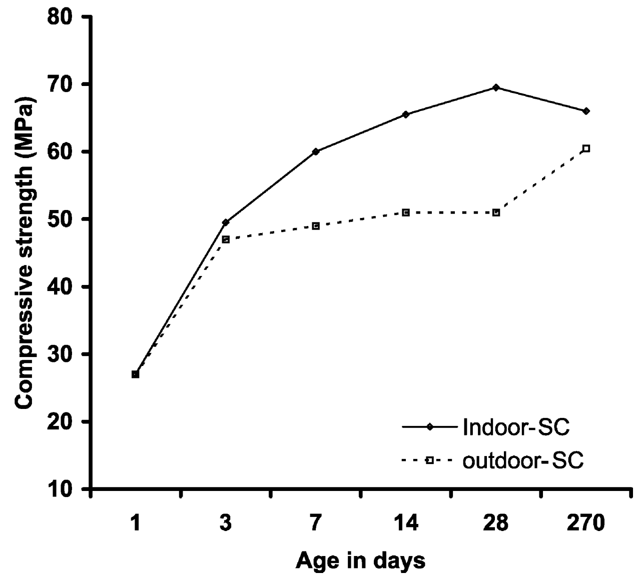


Fig. 2. Compressive strength development of sprinkle-cured samples.

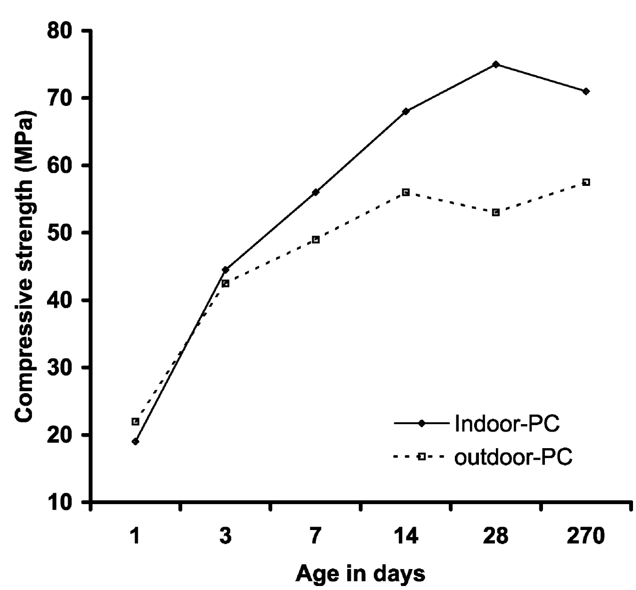


Fig. 3. Compressive strength development of plastic-cured samples.

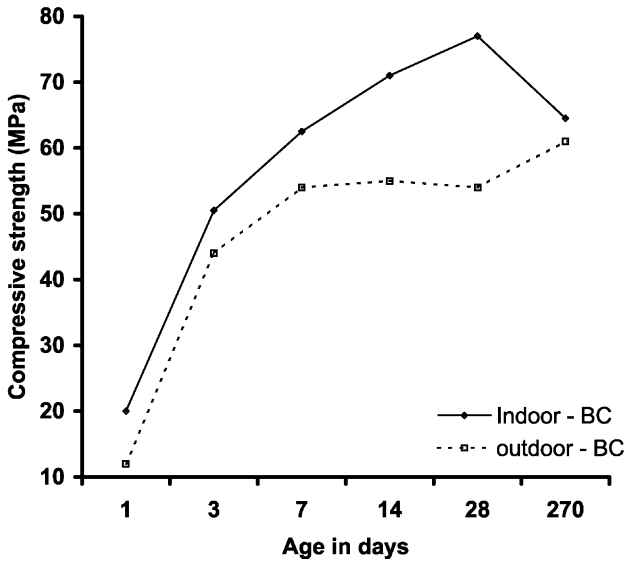


Fig. 4. Compressive strength development of burlap-cured samples.

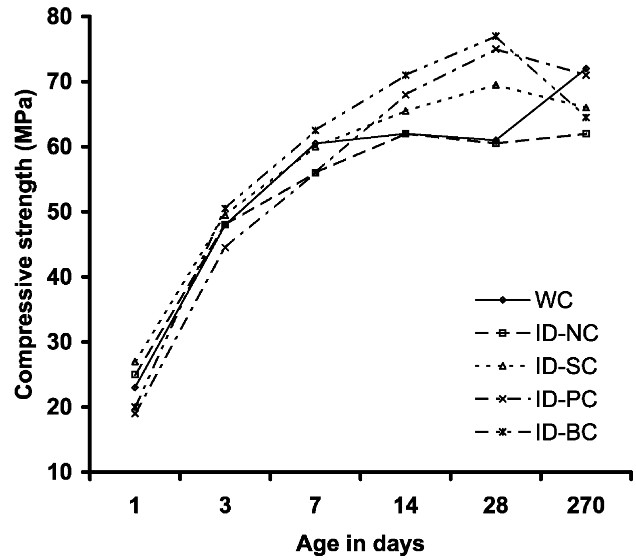


Fig. 6. Influence of curing methods on concrete strength, ID.

The results of water-cured concrete (WC) are interesting. It was expected that such curing regime would provide the strongest concrete. The results here are somewhat different. Water-cured samples (in many cases) are weaker than other samples. Such a trend has been explained earlier by Popovics [11]. It was suggested that saturated concrete tend to show lower strength than dry concrete due to the internal hydrostatic pressure within the pores.

Moreover, the results show that the OD environment of Al-Ain City (where the ambient temperature is high and the relative humidity is low during the summer months) significantly reduces strength for the different curing regimes compared to the strength values found for the control method WC (see Fig. 5).

The main factor behind the decrease in the strength of the different curing regimes in case of OD environment compared to the control method WC is the excessive evaporation due to the arid nature of Al-Ain hot climate. In such climatic conditions, all these curing regimes will give similar results unless carried under more controlled conditions (more frequent water application than twice per day). Fig. 5 shows that the differences in strength of samples cured under different regimes (except uncured case) are small.

Another explanation to the decrease in compressive strength observed for OD environment can be attributed to the fact that in the current study, only one face of the sample is exposed to the environment. The other faces are insulated by plastic cover. In other words, only one-sixteenth of the sample surface area was exposed to the environment. Such

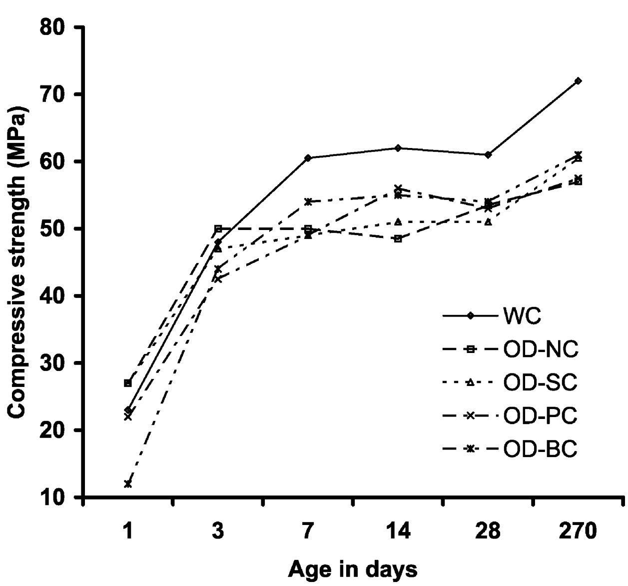


Fig. 5. Influence of curing methods on concrete strength, OD.

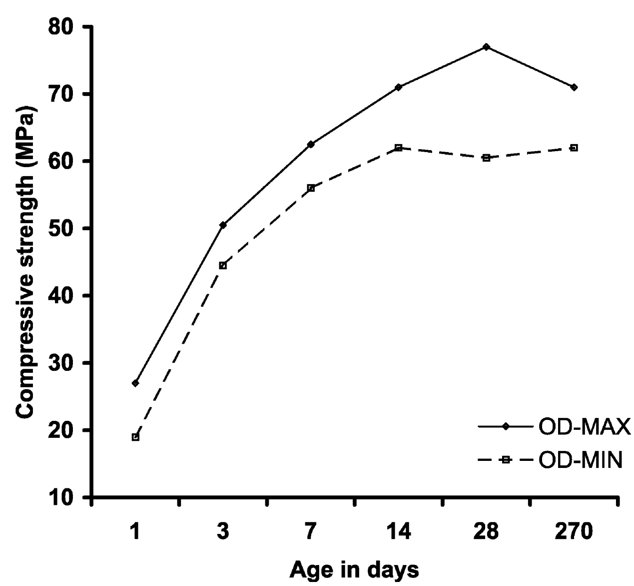


Fig. 7. Strength envelope for outdoor-cured samples.

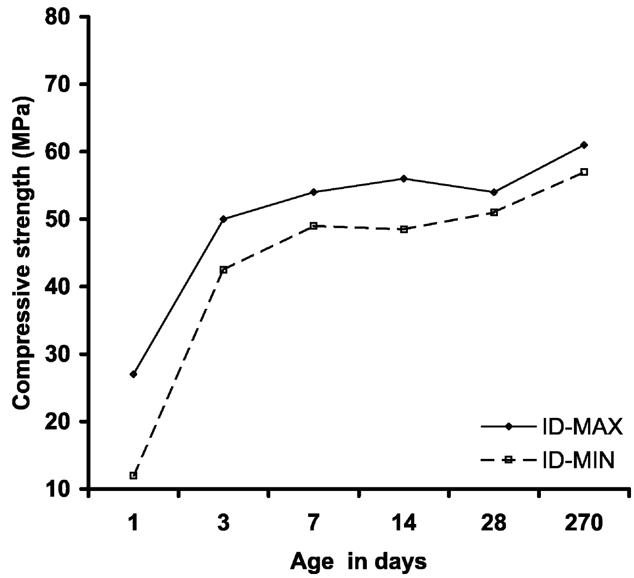


Fig. 8. Strength envelope for indoor-cured samples.

exposure condition delayed water retention inside the samples and minimized water loss influencing the results in the case of OD environment curing regimes.

### 4.2. Effect of different curing method

Fig. 5 shows that OD environment had an obvious effect on lowering the strength of all samples compared to water curing. However, the differences in the strength between the various curing regimes in this OD environment are insignificant. This can be attributed to the aridity of the OD environment where evaporation is so high that the moisture induced by the different curing method does not last long enough to influence the strength results. It is also evident from Fig. 5 that the strength at all curing regimes was similar at each testing age. Other works [9,13] showed that curing significantly effected the strength. In relation to the current work where moisture was allowed to escape from one side only, all faces of samples in other works referred to here were exposed to external environment.

The results show that there is only marginal increase in concrete strength for ages beyond 7 days in the OD environment. In the ID environment, however, continuation of strength gain was seen up to 28 days (Fig. 6). This suggests the following:

1. The high ambient temperature of the OD at Al-Ain accelerated hydration to the point where no further increase in strength was possible.

2. Despite the fact that the samples were cured, water loss is taking place and such curing regimes are inefficient. Evaporation of concrete moisture due to the combined effect of low relative humidity, high temperature, and solar radiation surpasses that of curing.

It is very interesting however to see that ID samples were more sensitive to curing than those cured outdoors. This observation is contrary to what one might expect. Figs. 7 and 8 show the envelope of results in each case. The width of the envelope for ages of 3 days onwards ranged from 2.5 to 16.5 MPa in indoor and from 3 to 7.5 MPa in outdoor exposures.

## 5. Conclusion

The following conclusions can be drawn from the results and discussion presented in this paper:

1. Curing methods had significant effect on strength of samples cured in laboratory from 14 days and onwards.
2. Curing regimes practiced in the Gulf States region (where the environment is arid and hot) had no significant effect on strength.
3. HSC is adversely affected by hot dry environments in a similar manner to NSC due to excessive moisture evaporation and badly dispersed hydration products resulting from high curing temperatures.

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