

## **EFFICIENCY OF CONCRETE CURING IN RIYADH AREA**

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### **Abstract**

This paper presents the efficiency of two concrete curing methods commonly employed in Riyadh as a case study for evaluation of curing efficiency under severe hot and dry weather conditions. The efficiency of curing methods was measured in terms of concrete compressive strength at 28 days. The methods were water sprinkling two times a day for seven days, which is designated as SWC; and water sprinkling two times a day for seven days with a burlap cover, which is designated as SBC. The specimens were tested at 28 days and compared with standard cured specimens, which were designated as STD. A total of 56 cube specimens were collected from construction sites in Riyadh during the sampling period and cured under STD-, SWC-, and SBC- conditions. The ratios of SWC and SBC to STD strengths were plotted on normal probability forms. The mean values of these ratios were 0.84 and 0.93, respectively. The probability of these ratios being less than the ACI-318 general requirement for concrete curing of 0.85 was 54 and 20 percent, respectively. These high probabilities indicate a deficiency in the curing methods, specially for SWC curing. Recommendations for improving the curing methods in Riyadh or, for that matter, in any other region of similar weather conditions are made. Keywords: Concrete curing, hot weather concreting, concrete durability.

## 1 Introduction

The temperature of the concrete is affected by the surrounding air, absorption of solar heat, heat of hydration of cement and initial temperature of materials. An undesirable reduction in moisture content of the cement paste at this stage tends to reduce hydration and results in drying shrinkage and development of cracks in the paste. In the parlance of concrete technology, hot weather is defined as any combination of high air temperature, low relative humidity, and wind velocity [1]. The effects of hot weather are most critical during periods of rising temperature or falling relative humidity, or both. Undesirable hot weather effects on concrete in the plastic state may include: (a) increased water demand, (b) increased rate of slump loss, (c) increased rate of setting and (d) increased tendency for plastic cracking [1]. Thus, a continuous curing, particularly during the first few hours, is acutely needed.

ACI 318 [2] and ACI 308 [3] recommend that concrete be maintained in a moist condition for at least the first 7 days after placement. Alternate cycles of wetting and drying promote the development of pattern cracking and should be avoided. ACI 318 [2] specifies that the procedure for curing concrete shall be improved when the strength ratio of field cured specimens to the companion laboratory cured specimens is less than 0.85 unless the field-cured strength exceeds the specified strength by more than 3.5 MPa.

Spears [4] indicated that proper curing maintains relative humidity above 80 percent and, thereby, advances hydration to the maximum attainable limit. Proper curing decreases concrete permeability, surface dusting, thermal-shock effects, scaling tendency and cracking. It increases strength development, abrasion resistance, durability, pozzolanic activity and weatherability. Haque [5] investigated the strength development of concrete under the conditions of fog, temperate dry, warm-wet and warm-dry weather conditions. He found that the lack of any moist curing adversely affects the compressive strength of plain concrete at all ages.

Martin [6] demonstrated that rising placing temperatures do not, as a rule, lead to lower strengths. With favorable combinations of cementitious materials and admixtures, the strength performance of concrete can remain unaffected by higher placing temperatures, or it can even improve over that at lower temperatures. Malvin and Odd [7] conducted a large-scale field investigation of high-strength light-weight concrete and concluded that maximum curing temperatures of up to 85 °C (153F) did

not adversely affect the mechanical properties of the concrete. On the contrary, they observed a slight increase in compressive strength.

Khan [8] quantified the effect of interrupted curing. He found that the losses in strength of concrete due to an interruption in moist curing can be regained significantly by recuring the concrete.

Carrier [9] indicated that a short period of drying early in the curing life of concrete specimens prevents water molecules from reaching unhydrated cement particles and prevents concrete from gaining full strength. He also indicated that much of the concrete deterioration that takes place each year should be blamed on inadequate curing. Early and rapid drying can lead to failure such as shrinkage cracks, crazing, wear, dusting, scaling, and spalling. Once a surface has cracked, dusted, scaled or spalled, the entire member is more susceptible to other types of deterioration.

## **2 Research significance**

Twice a day sprinkling of water with or without burlap cover for seven days are the curing practices used on the majority of construction jobs in Saudi Arabia [10]. The average annual maximum temperature of 46 °C and the average annual minimum humidity of 4.0 % in summer in the central region (arid zone of the Kingdom) and the prevalent methods of curing which are below the required standard practice call for studying their effects on the strength of concrete.

## **3 Objective and scope**

This paper presents results of an experimental program designed to investigate the influence of the prevalent curing practice on the strength of concrete cast during ten month period in an arid area.

## **4 Experimental program**

The experimental program was designed to evaluate the influence of the prevalent curing practices on the compressive strength of the concrete. The Three curing methods which were employed are described and designated as in Table 1.

Concrete samples were collected from randomly selected construction sites in Riyadh (in the central province) of Saudi Arabia. The sampling was done during ten

Table 1. Curing methods used and their designation

Designation	Curing method
SWC	Twice a day <u>s</u> prinkling <u>w</u> ithout <u>c</u> over for seven days
SBC	Twice a day <u>s</u> prinkling with <u>b</u> urlap <u>c</u> over for seven days
STD	Twenty eight day immersion in water, considered <u>s</u> tandard <u>c</u> uring

months (September to June). The annual minimum relative humidity and maximum temperature data of the central region for 25 years between 1965 and 1989 as recorded by MEPA [11] are presented in Figs. 1 and 2, respectively.

A total of 56 concrete samples were collected at construction sites in Riyadh during the sampling period and cast into standard cubes of 150x150x150 mm. Each sample consisted of three pairs of cubes and each cube in a pair was collected from a separate truck. The cubes were left at the site for about 24 hours and then transferred to the laboratory. A pair in a sample was cured by SWC, the second by SBC and the third by STD method. The cubes were tested for strength at age of 28 days.

## 5 Results, analysis and discussion

The ratios  $R_1$  and  $R_2$  of the compressive strength of the SWC and SBC cured cubes, respectively, to the STD cured cubes were subjected to analysis by order statistics. The results are presented in Table 2 and plotted on a normal probability paper along with the best fit by linear regression in Fig. 3. The mean values of  $R_1$  and  $R_2$  are 0.84 and 0.93, respectively. This clearly indicates the beneficial effect of curing with burlap cover in dry-hot weather. The maximum values of the two ratios are 1.09 and 1.14, respectively, and their minima are 0.63 and 0.75.

Table 2. Basic statistics of the strength ratios  $R_1$  and  $R_2$  in the Riyadh Area.

$R_i$	Min.	5 Percentile	Mean	Max	COV %	$P(R < 0.85)$
$R_1$	0.63	0.67	0.84	1.09	12.60	0.54
$R_2$	0.75	0.78	0.93	1.14	9.80	0.20

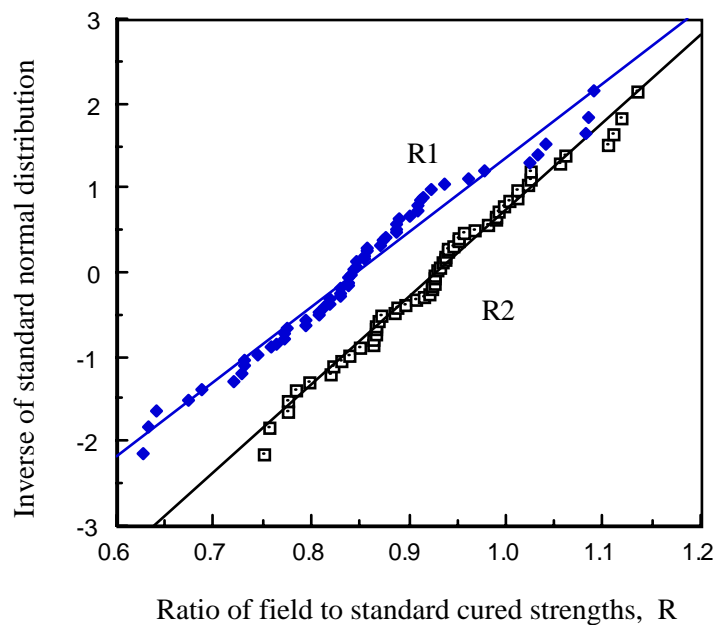


Fig. 3 Influence of curing methods on concrete strength in the central province

It is interesting to note that the variability in compressive strength and curing process can cause these ratios to be higher than unity. The five percentiles (the values with probability of 5 percent of being not exceeded) of the two ratios are 0.67 and 0.78, respectively.

ACI 318 [2] specifies that “procedures for protecting and curing concrete shall be improved when strength of field cured cylinders at test age designated for determination of  $f'_c$  is less than 85 percent of that of companion laboratory-cured cylinders.” In the presence of strength variability, there is a possibility of having this ratio less than 0.85 which is very small with good curing practices, however, this probability will increase when poor practices are employed.

Results indicate that the mean values of  $R_1$  are less than those for  $R_2$  while the coefficients of variation of  $R_1$  are higher than that of  $R_2$ . As a result, the probability of being  $R_1$  less than 0.85 is 54%, which is very high. This indicates that the SWC curing method does not meet the ACI-318 requirement in arid areas. The probability of having  $R_2$  less than 0.85 in Riyadh area is about 20%, which is also relatively high.

The authors suggest that the efficiency of curing methods should be based on the 5 percentile of the distribution function of the ratio  $R$  which is affected by both its mean and COV. The results indicate that the 5 percentiles for  $R_1$  and  $R_2$  are 0.67 and 0.78, respectively. The curing methods should be improved to bring these values to 0.85.

The ACI-308 recommends that concrete be maintained in a moist condition for at least the first 7 days after placement. In arid areas, it is impossible to meet this recommendation using SWC where the available water for concrete curing is very limited. The SBC curing method is more efficient; however, the frequency of water sprinkling per day should be increased so that the 5 percentile of the distribution of  $R_2$  is at least equal to 0.85. The efficiency of water sprinkling three times a day with a burlap cover is under investigation.

## **6 Conclusions**

The effect of curing practice was evaluated by statistical analysis of strength ratio,  $R$ , of field cured to standard cured cubes. The field curing methods used were sprinkling without cover and with burlap cover. The results in the Riyadh area showed that the mean values of  $R_1$  and  $R_2$  are 0.84 and 0.93, respectively. The higher value of  $R_2$  indicates the effectiveness of burlap cover in improving the curing process. The probability of having  $R_1$  less than 0.85, specified by ACI-318, is 54 percent, indicating that curing by water sprinkling without cover twice a day for 7 days will not satisfy the ACI-318 requirement. The SBC curing method is more efficient; however, the frequency of water sprinkling per day should be increased so that the 5 percentile of the distribution of  $R_2$  is at least equal to 0.85. The efficiency of water sprinkling three times a day with a burlap cover is under investigation.

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## 8 References

1. ACI Committee 305. (1989) *Hot Weather Concreting*. ACI-305, American Concrete Institute, Detroit.
2. ACI Committee 318. (1989) *Building Code Requirements for Reinforced Concrete*. ACI-318, American Concrete Institute, Detroit.
3. ACI Committee 308. (1989) *Recommended practice for curing concrete*. ACI-308, American Concrete Institute, Detroit.
4. Spears, R. E. (1983) *The 80 Percent Solution to Inadequate Curing Problems*. Concrete International. pp.15-18.
5. Haque, M.N. (1990) *Some Concretes Need 7 Days Initial Curing*. Concrete International. Vol. 12, No. 2, pp. 42-46.
6. Mittelaehar, M. (1992) *Compressive Strength and the Rising Temperature of Field Concrete*. Concrete International. pp. 29-33.
7. Sandvik, M. and Gjørsv, O. E. (1992) *High Curing Temperatures in Light Weight High-Strength Concrete*. Concrete International. pp. 40-42.
8. Khan, M., S. and Ayers, M., E., (1993) *Interrupted Concrete Curing*. Concrete International. pp. 25-28.
9. Carrier, R. E. (1983) *Concrete Curing Tests*. Concrete International. pp. 23-27.
10. Arafah, A. M., et al.(1990) *Development of a Solid Foundation for a Local Reinforced Concrete Building Code*. Final Report on KACST Project No. AR-9-34, Riyadh.
11. Meteorology and Environmental Protection Administration. (1990) *Records from 1965 to 1990*, Riyadh, Saudi Arabia.