EFFECT OF CURING METHODS ON THE STRENGTH OF BRICK AGGREGATE CONCRETE

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ABSTRACT
This paper describes the influence of mainly the curing method on the strength of brick aggregate concrete. Six types of curing method (CM-1: water submersion curing; CM-2: wet earth curing; CM-3: polythene sheet curing; CM-4: gunny sack curing; CM-5: water spraying curing; and CM-6: air curing) which are followed in various practical cases in Bangladesh have been considered. Other parameters considered are the concrete mix ratio (1:2:4 and 1:1.5:3 by volume) and the age of concrete (7, 14, 28 and 90 days). The Ordinary Portland Cement was used in making concrete and the water-cement ratio considered was 0.50 by weight. A total of 144 nos. of standard concrete cylinders were cast and tested for crushing strength of concrete. It has been found that curing method CM-1 gives the highest concrete strength and the curing method CM-6 gives the lowest strength to concretes irrespective of the concrete mix ratio. The rich concrete mix (1:1.5:3) gives higher strength than that of lean concrete mix (1:2:4) except the curing method of CM-4. For lean concretes, at the age of 28 days, the curing methods CM-3, CM-4 and CM-5 yielded 13%, 33% and 8% higher strengths than that of the CM-6 method. The increase of concrete strength at the age of 90 days over that at 28 days has been found to vary from 1% to 48% with a mean of 18%.

Keywords: Age of concrete, brick aggregate, compressive strength, curing method, mix proportion

INTRODUCTION
Concrete is the most widely used man-made construction material. It is a stone like material obtained by permitting a carefully proportioned mixture of cement, sand, gravel or other suitable coarse aggregate, and water to harden in forms of the shape and dimensions of the desired structure. The compressive strength of concrete is commonly considered its most valuable property, although, in many practical cases, other characteristics such as durability and permeability may in fact be more important. Nevertheless, compressive strength usually gives an overall picture of the quality of the concrete. Moreover, the strength of concrete is almost invariably a vital element of structural design and is specified for compliance purpose (Nilson et al., 2010).

Curing of concrete is the process of controlling the rate and extent of moisture loss from concrete during cement hydration. It may be needed after concrete has been placed in position thereby providing time for the hydration of the cement to occur. Since the hydration of cement does take time – days, and even weeks rather than hours – curing must be undertaken for a reasonable period of time if the concrete is to achieve its potential strength and durability. Curing may also encompass the control of temperature since this affects the rate at which cement hydrates. The curing period may depend on the properties required of the concrete, the purpose for which it is to be used, and the ambient conditions, i.e. the temperature and relative humidity of the surrounding atmosphere. Curing is designed primarily to keep the concrete moist, by preventing the loss of moisture from the concrete during the period in which it is gaining strength. Curing may be applied in a number of ways and the most appropriate means of curing may be dictated by the site or the construction method (James et al., 2011).

The physical properties of concrete depend to a large extent on the extent of hydration of cement and the resultant microstructure of the hydrated cement. Upon coming in contact with water, the hydration of cement proceeds both inward in the sense that the hydration products get deposited on the outer periphery of the cement grain, and the nucleus of un-hydrated cement inside gets gradually diminished in volume. At any stage of hydration the cement paste consist of the product of hydration, the remnant of un-reacted cement, calcium hydro-oxide and water. The product of hydration forms a random three dimensional network gradually filling the space originally occupied by the water. Accordingly, the hardened cement paste has a porous structure, the pore size varying from very small (4×10^{-10} m) to very large and are called gel pores. As the hydration proceeds, the deposit of hydration products on the original cement grain makes the diffusion of water to the un-hydrated nucleus more and more difficult and so the rate of hydration decreases with time. Therefore, the development of the strength of concrete, where starts immediately after setting is completed, continue for an indefinite period, though at a rate gradually diminishing with time. Eighty to eighty five percent of the eventual strength is attained in the first 28 days and this strength is considered to be the criterion for the structural design and is called the characteristic strength (Sing, 2001).

In Bangladesh, depending upon the suitability and availability, different methods are followed for curing of concrete in different structures. Pounding method (blocking water on the surface of cast concrete) is normally used for curing the top surface of flat or near-flat surfaces such as floor slab, pavements, roof slab etc. Structural elements such as footings, pile cap, column below grade etc. are usually covered by soil after few hours/days of their casting. This is done with the view that the curing of these concrete will continue by the damp environment created by the surrounding soil. Sometimes concrete structures such as column, floor slab etc. are wrapped or covered with polythene sheets in order to keep the concrete moist by preventing evaporation of water from it. In some cases, after removing the formwork, concrete structures are wrapped or covered with gunny-sacks and then water is sprayed several times in a day for curing the concrete. This method of concrete curing is usually followed for column, pier, retaining wall and some other vertical structures. On the other hand, exposed side surfaces of floor beams are generally cured by spraying water on the concrete surfaces several times in a day. In some exceptional cases concrete elements are just left exposed in the open air which may be due to the non-availability of curing facilities or some other reasons. However, in all of the above mentioned cases, the representative concrete specimens (cylinder and/or cube) of various concrete elements are normally cured by full submersion of specimens into water. This difference between the curing conditions of real structural element and the representative concrete specimens may yield concretes of different qualities. As a result the strength of the representative specimens may differ from that of the concretes of actual structures.

In Bangladesh, both crushed stone and broken bricks are widely used as coarse aggregates in making concrete. However, due to non-availability and price considerations of stones, the use of broken bricks as coarse aggregate is getting popularity especially in the private sectors. Effect of the moist curing on the strength of brick aggregate concrete was investigated experimentally by Rahman et al. (2009). It was reported that moist-cured brick aggregate concrete show significant higher compressive strength in comparison with that of the air-cured concrete. An average value of the ratios of the compressive strengths of air-cured concrete to those of moist-cured concrete was found to be 0.74. Also the initial moist curing of 3, 7, 14 and 21 days yielded 67%, 68%, 81% and 89% respectively of the 28 days moist-cured compressive strength (all were tested at 28 days).

Experimental investigation on the effect of curing on the strength of brick aggregate concretes was also done by Ahmad and Amin (1998). They reported that the curing of concrete at any stage is beneficial to overcome the losses due to discontinuity in curing. The delayed curing was found to be helpful even in attaining the desired strength provided that the early age (1st one week) curing is not hampered. However, in such cases curing for a longer duration was reported to be required.

So far, no study on the influences of different curing methods on the real structural concrete elements (those are practically followed in Bangladesh) has been reported. This paper has, therefore, been aimed at to study the above mentioned issue considering the brick aggregate concretes.

EXPERIMENTAL PROGRAM

In the experimental program a total of 144 standard cylindrical concrete specimens (150×300 mm) have been cast and then tested to get the concrete crushing strengths. Three parameters considered were curing method, age of concrete and concrete mix ratio. Six type of curing methods of concrete which are commonly followed in Bangladesh have been considered as the main parameter. The curing methods considered are:

(i) Full submersion of concrete specimens into water (CM-1).
(ii) Covering the concrete specimens with wet earth (CM-2).
(iii) Wrapping the concrete specimens with polythene sheets (CM-3).
(iv) Covering the concrete specimens with gunny sacks and then spraying water on this several times in a day (CM-4).
(v) Spraying water on the exposed specimens at several times in a day (CM-5).
(vi) Concrete specimens left in the open air outside the lab (i.e. air cured) (CM-6).

Two types of concrete mix ratio (1:2:4 and 1:1.5:3 by volume) along with the age of concrete (7, 14, 28 and 90 days) have also been considered in this study. Therefore, a total of 6×2×4 or, 48 nos. of mixes of concrete and hence a total of 48×3 or 144 nos. of cylindrical specimens were cast and then tested for compressive strength at the age of specified days. Ordinary Portland Cement (Type-I) was used in this experiment. Properties of the cement used are shown in Table 1.

Table 1: Properties of the cement (OPC) used in the experiment

Property of cement	Test value
Normal consistency	28.6%
Initial setting time	3 hr. 0 min.
Final setting time	6 hr. 0 min.
Compressive strength (3 days)	25.5 MPa
Compressive strength (7days)	34.3 MPa

The coarse aggregates used were 25 mm down well graded brick aggregates. The properties of fine and coarse aggregates used in the experiment are presented in Table 2. Potable water was used in making concretes with a water-cement ratio of 0.5 by weight.

Table 2: Properties of fine and coarse aggregates used

Property of materials used	Test values of	
	Fine aggregate (sand)	Coarse aggregate (brick aggregate)
Fineness modulus	2.4	7.4
Water absorption (%)	2.0	6.0
Unit weight (kg/m^3)	1492	1102

Required numbers of steel moulds each of 150×300 mm size were cleaned using wire brush and then their joints were tightened by nut-bolts. These cleaned moulds were placed on firm and level floor on concrete laboratory. Lubricating oil (Mobil) was used to smear the bottom and inside of the mould for its easy removal after hardening of concrete. Fresh concrete was prepared as per designed mix in a mixture machine. Immediately after unloading from mixture machine, the fresh concrete was placed in the mould in three layers and was compacted each layer of concrete by using nozzle type vibrator machine. The fresh concrete in the specimen molds were kept in the laboratory without any disturbance for about 24 hours. Then the concrete specimens were demoulded and were placed under the specified curing method. The maximum curing period considered was 28 days except for the curing method of CM-2 in which the maximum curing period was 90 days.

The test cylinders were collected from their specified curing conditions before 24 hours of their testing and kept in air dry condition in the laboratory. Both the ends of cylinders were ground by grinding machine in order to make the end surfaces smooth and level. Then the measurements for diameter of each specimen were taken using slide callipers. Average of three measurements those at top, middle and bottom were considered in determining the diameter and then the cross sectional area of each specimen. Concrete cylinders were tested in the lab using the 2000 KN capacity Universal Testing Machine following the ASTM C39 specifications. At first the test cylinder was placed on the machine's base platen keeping it vertical and centered on the plate. Then load was applied on the top surface of the specimen. This load was increased gradually until the specimen failed. The crushing load was then recorded. The crushing load of each of the test specimens was divided by the average cross sectional area of respective cylindrical specimen and was recorded as the compressive strength of that concrete. The compressive strengths of all concretes along with different parameters are presented in Table 3.

Table 3: Compressive strength of test concretes

Age of concrete (day)	Compressive strength (MPa) of concrete under the curing condition of -					
	CM-1	CM-2	CM-3	CM-4	CM-5	CM-6
Mix ratio = 1:2:4 (by volume)						
7	23.7	24.4	25.8	27.6	25.4	17.6
14	27.5	25.4	32.9	32.3	27.5	22.4
28	32.2	28.7	32.6	38.5	31.3	28.9
90	39.4	42.4	43.3	41.9	38.4	34.8
Mix ratio = 1:1.5:3 (by volume)						
7	24.7	24.7	27.3	35.5	31.6	26.7
14	35.2	32.9	31.3	36.1	35.1	27.1
28	42.9	37.9	36.8	36.6	37.1	38.1
90	46.5	41.2	44.1	39.9	40.8	38.5

ANALYSIS AND DISCUSSION OF TEST RESULTS

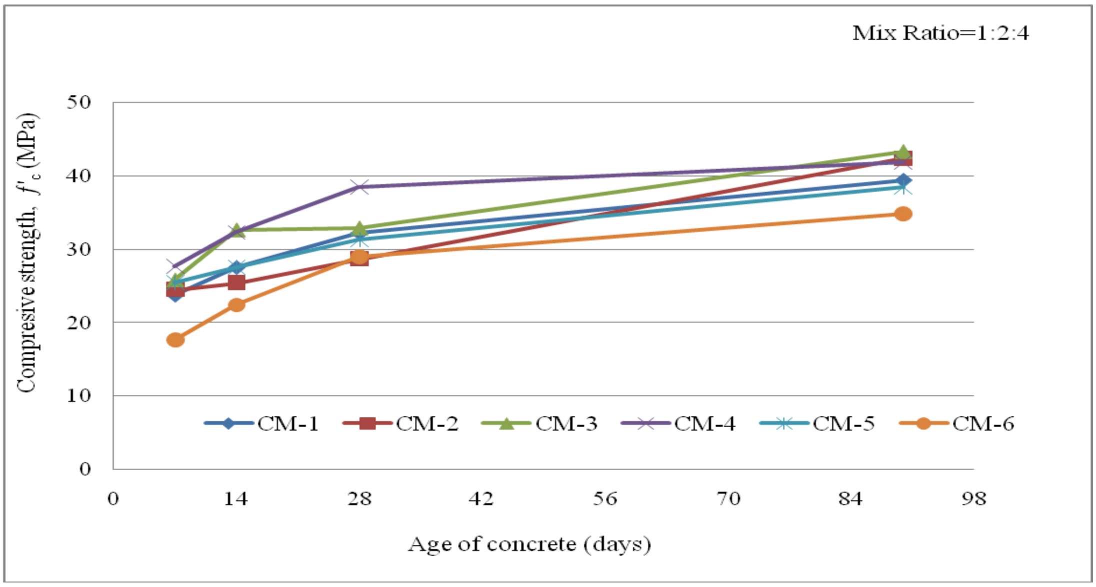
Test data have been analyzed with a view to study the influence of curing methods along with other variables considered in this study and are discussed in the followings.

Influence of the Curing Methods on the Concrete Strength

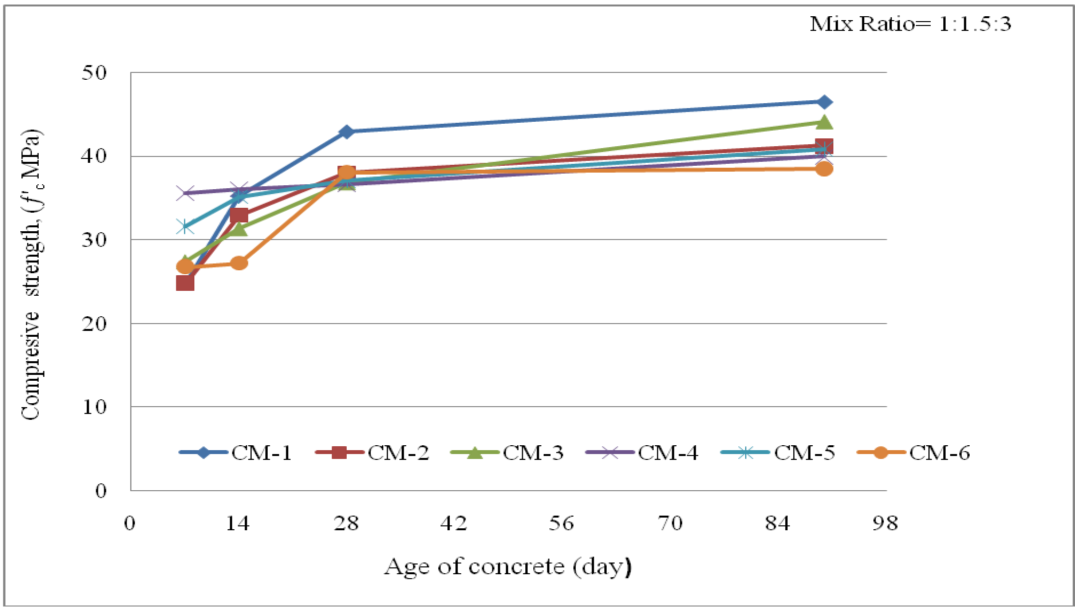
Fig. 1 shows the relative influences of curing methods considered in this study on the concrete crushing strength for a wide range of the age of concretes made with brick aggregate. It is seen that the curing method CM-1 (full submersion of concrete specimens into water) gives higher concrete strength than any other curing method irrespective of the concrete mix ratios except that of mix ratio of 1:2:4. The exceptional case may be due to a comparatively lean concrete mix along with the much higher absorption capacity of brick aggregates. On the other hand, the air curing method CM-6 (concrete specimens left in open air in the lab) gives the minimum strengths to concretes considered.

The curing methods CM-3 (wrapping the concrete specimens with polythene sheet) and CM-4 (covering the concrete specimen with gunny sack and then spraying water on this several times in a day) are seen to be the much influential in giving strengths to concrete. These may be due to the available moisture around the concrete specimens provided by the almost air-tight polythene sheet system and long time existence of sprayed water on concrete surface because of the coarse gunny sack. The curing method CM-5 (spraying water on the exposed specimens several times in a day) also gives higher strengths, but to a lesser amount, than those of the air-cured concretes.

A comparative study of the 28-days crushing strengths of concrete cured following the different methods is given in Table 4. Ratios of strength of concrete cured following either of CM-1, CM-2, CM-3, CM-4, and CM-5 to that of the concrete cured by CM-6 (air curing method) are presented in this table. From Table 4 it is seen that for rich concretes (mix ratio=1:1.5:3) curing methods CM-2, CM-3, CM-4 and CM-5 do not have any influence in increasing the concrete strength over that by CM-6 curing



(a)



(b)

Fig. 1: Influence of different curing methods on the strength of concrete

method. Whereas the CM-1 method gives a significant increase (an average of 12%) in concrete strengths for both the rich and the lean (mix ratio=1:2:4) concretes. On the other hand, the CM-2 method of curing has no influence in increasing concrete strength over those of CM-6 method for either rich or lean concretes. However, for lean concrete, CM-3, CM-4 and CM-5 show 13%, 33% and 8% increase, respectively, in concrete strength.

Table 4: Ratios of compressive strengths (28-days) obtained following different curing methods.

Coarse aggregate	Mix Ratio (by volume)	Ratio of concrete strengths at 28 days for curing methods				
		CM-1/CM-6	CM-2/CM-6	CM-3/CM-6	CM-4/CM-6	CM-5/CM-6
Broken bricks	1:2:4	1.11	0.99	1.13	1.33	1.08
	1:1.5:3	1.13	0.99	0.97	0.96	0.97
Mean		1.12	0.99	1.05	1.15	1.03
Standard Deviation (SD)		0.008	0.001	0.115	0.263	0.077

Influence of the Concrete Mix Ratio on the Concrete Strength

The relative influences of the concrete mix ratios on the crushing strength of concretes made with brick aggregates are presented in Fig. 2. It is seen from this figure that the rich concrete mix (1:1.5:3) gives higher strengths than those of lean concrete mix (1:2:4) except the concrete cured with CM-4 method.

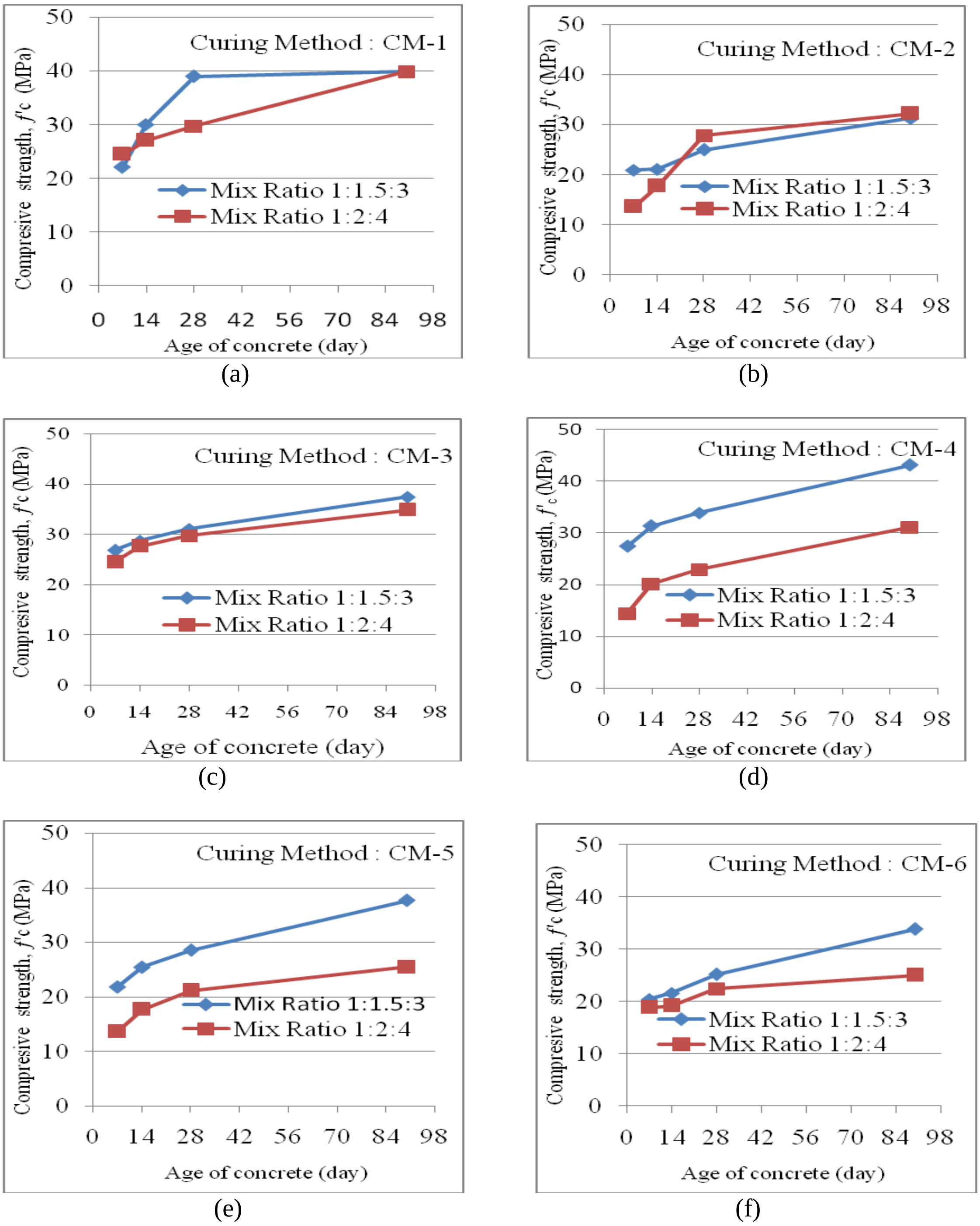


Fig. 2: Effects of mix ratio on the strength of concrete

Concrete Strengths at 7 and 14 Days

The ratios of concrete strengths at 7 days to those of 28 days and the strengths at 14 days to those of 28 days are presented in Table 5. From the table, it is seen that the concrete continue to increase its strength with its age. The mean strength of concretes at the age of 7 days is 75% of that at 28 days. While the concrete reaches 87% of its 28-days strength at the age of 14 days.

Table 5: Comparison among compressive strengths (28-days) of concrete

Concrete mix ratio (by vol.)	Curing method	$f'_{c,7}$ (MPa)	$f'_{c,14}$ (MPa)	$f'_{c,28}$ (MPa)	$\frac{f'_{c,7}}{f'_{c,28}}$	$\frac{f'_{c,14}}{f'_{c,28}}$
1:2:4	CM-1	23.7	27.5	32.2	0.74	0.85
	CM-2	24.4	25.4	28.7	0.85	0.89
	CM-3	25.8	32.9	32.6	0.79	1.01
	CM-4	27.6	32.3	38.5	0.72	0.84
	CM-5	25.4	27.5	31.3	0.81	0.88
	CM-6	17.6	22.4	28.9	0.61	0.78
1:1.5:3	CM-1	24.7	35.2	42.9	0.58	0.82
	CM-2	24.7	32.9	37.9	0.65	0.87
	CM-3	27.3	31.3	36.8	0.74	0.85
	CM-4	35.5	36.1	36.6	0.97	0.99
	CM-5	31.6	35.1	37.1	0.85	0.95
	CM-6	26.7	27.1	38.1	0.70	0.71
				Mean	0.75	0.87
				SD	0.1120	0.083

Increase in Concrete Strength after 28 Days

The ratios of concrete strengths at 90 days to those of 28 days are presented in Table 6. It is to be mentioned here that after 28 days no curing was applied to any concrete specimen except those for the curing method of CM-2 in which the maximum curing period was 90 days. From Table 6 it is seen that the gain in concrete strength at the age of 90 days over that at 28 days ranges from an insignificant value (1%) to a quite high value (48%) and the mean increase is 18%.

Table 6: Ratio of concrete strength at 90 days to that of 28 days

Concrete mix ratio (by vol.)	Curing method	$f'_{c,28}$ (MPa)	$f'_{c,90}$ (MPa)	$\frac{f'_{c,90}}{f'_{c,28}}$
1:2:4	CM-1	32.2	39.4	1.22
	CM-2	28.7	42.4	1.48
	CM-3	32.6	43.3	1.33
	CM-4	38.5	41.9	1.09
	CM-5	31.3	38.4	1.23
	CM-6	28.9	34.8	1.20
1:1.5:3	CM-1	42.9	46.5	1.08
	CM-2	37.9	41.2	1.09
	CM-3	36.8	44.1	1.20
	CM-4	36.6	39.9	1.09
	CM-5	37.1	40.8	1.10
	CM-6	38.1	38.5	1.01
			Mean	1.18
			SD	0.129

CONCLUSIONS

Following conclusions can be drawn based on the findings of this study-

(i) Curing method CM-1 (full submersion of concrete specimens into water) gives higher concrete strength than any other curing method irrespective of the concrete mix ratios. On the other hand, curing method CM-6 (air curing) gives minimum strengths to concretes considered.

(ii) The rich concrete mix (1:1.5:3) gives higher strength than that of lean concrete mix (1:2:4) except the curing method of CM-4.

(iii) For lean concretes, the curing methods CM-3, CM-4 and CM-5 yielded 13%, 33% and 8% higher strengths (28 days) than that of the CM-6 method (air curing).

(iv) The increase in concrete strength at the age of 90 days over that at 28 days (maximum curing period except the CM-2 method of curing) varies from an insignificant value (1%) to a quite high value (48%) and the mean increase is 18%.

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