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EFFECT OF CURING CONDITIONS ON COMPRESSIVE STRENGTH OF BRICK AGGREGATE CONCRETE

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ABSTRACT : Compressive strengths of brick aggregate concrete subjected to different curing conditions have been studied. For this purpose two concrete mixes were designed for a particular strength using crushed brick as coarse aggregate. Cylindrical specimens prepared from two batches of concrete were subjected to different sequences of interrupted curing and were tested for compressive strengths. Results have been compared with those of stone aggregate concrete. The lesser sensitivity to interrupted moist curing in the gain of strength of brick aggregate concrete over the stone aggregate concrete has been distinctly observed and interpreted. The rate of strength gain of the continuously cured specimen beyond 28-day was also found to be significant. Based on these findings, an outline for the practice of curing of brick aggregate concrete has also been suggested.

KEY WORDS : Brick aggregate concrete, compressive strength, porosity, absorption capacity, interrupted curing.

INTRODUCTION

Concrete is generally designed specifically for a particular strength using locally available ingredients. The quality and durability of concrete depend not only on the quality and properties of the ingredients but also on the method of preparation, placing, curing and environmental conditions to which it is exposed over its service life.

Proper curing of concrete is indispensable in developing its optimum properties. Adequate supply of moisture is necessary to ensure sufficient hydration for reducing the porosity to such a level that the desired strength and durability can be attained. So the most desirable objective is to provide a continuous moist curing condition until the concrete has attained its specified designed strength. In contrast, it becomes impossible sometimes to ensure continuous curing in the construction sites. Concrete in many buildings is not cured properly because of ignorance or negligence of the workmen/supervisors. Due to interruption in curing, it becomes impossible to resaturate fully the pores of concrete. The amount of resaturation depends on the porosity and other

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environmental factors. Thus the extent of additional hydration becomes unpredictable. The intermittent moist curing also subjects the concrete to wetting and drying cycles at a time when the concrete is weak enough to be susceptible to tensile stresses that may develop during drying. In summer months, the interrupted moist curing may subject the concrete to thermal length changes, which can also cause cracking. Once again, matured exterior concrete is normally exposed to wetting and drying repeatedly during its life time and there are the opportunities for continued hydration.

Because of wide use of natural stone aggregates all over the world, earlier works on the effect of limited moist curing for the development of compressive strength were concentrated on stone aggregate concrete. It was observed (Price 1951) that the cessation of moist curing slows down the strength gain as water is lost from the concrete. A 3-day moist curing allowed concrete to reach only 75 to 80% of the potential strength which can be achieved with 28-day continuous moist curing and none of the additional 25 to 30% strength gain that can be gathered beyond 28 days will be realised. The findings also suggested that a 7-day moist curing will ensure the eventual achievement of 28-day moist cured strength. Another study (Portland Cement Association 1952) showed the state of gain of strength when the uncured specimens were subjected to curing from the 28th day, 3rd month and 1 year respectively. Studies (Tan and Gjorv 1996) on the effect of curing conditions on the strength and permeability of concrete concluded that after 3 and 7 days of moist curing only the concretes with w/c ratios equal to or less than 0.4 can be accepted, while after 28 days of moist curing, however, even the concrete with w/c of 0.6 could be accepted. But these studies did not cover the features of strength gain when the curing is started after cessation for a short duration. And this is the phenomenon which is met in common cases.

Again aggregates occupy about 70 to 80% volume of the concrete and their impact on the whole concrete is certainly considerable. The strength, porosity, absorption capacity, shrinkage, angularity and modulus of elasticity of the aggregates have a significant effect on the ultimate strength of concrete. Due to lack of sources of natural aggregate, the crushed brick aggregates are widely being used in Bangladesh. But all the leading design methods are based on stone aggregate concrete. So a thorough and systematic study on the effect of use of this indigenous material on the behaviour of concrete is essential. Earlier investigations on the brick aggregate concrete were focused on its physical and mechanical properties (Akhtaruzzaman and Hasnat 1983, 1986). The modulus of elasticity of brick aggregate concrete was found 30% lower and tensile strength was about 11% higher for the same grade of concrete. Brick aggregate concrete was characteristically found to be of lower unit weight. The higher shear strength of brick aggregate concrete beams than those of stone aggregate ones was also visible. As these values are in between those of normal weight and light weight concrete, brick aggregate concrete was classified by them as medium aggregate concrete. But no work has been reported until now on the effects of discontinuous curing on strength of this concrete. With this background in view, an extensive investigation on the strength of brick aggregate concrete in different sequences of curing conditions was carried out in the Civil Engineering Department of BUET. This paper presents the results of investigation of two separately designed brick aggregate concrete mixes and interprets the findings.

EXPERIMENTAL DETAILS

Materials and Mix Design

Brick aggregates produced by crushing of well burnt clay bricks were used as coarse aggregate. Coarse Sylhet sand and local sand in equal proportions were used in the first mix whereas, in the second mix, coarse Sylhet sand was solely used as fine aggregate. Ordinary Portland Cement (Type 1) was used as binder in the investigation.

The required material properties, such as specific gravity (ASTM C127-84 1988 and ASTM C128-84 1988), unit weight (ASTM C29-87 1988), fineness modulus of coarse and fine aggregate (ASTM C136-84a 1988) were determined to design the concrete mixes. Table 1 presents these

Table 1. Relevant Properties of the Aggregates

Properties	Coarse Aggregate		Fine Aggregate	
	Batch 1	Batch 2	Batch 1	Batch2
Unit weight (SSD), pcf	70.75	71.50	98.00	95.00
Specific gravity (SSD)	2.00	2.08	2.48	2.68
Specific gravity (OD)	1.81	1.83	2.45	2.66
Absorption capacity, %	10.50	13.66	1.22	0.75
Fineness modulus	7.35	6.88	1.86	2.74

engineering properties of the coarse and fine aggregates. The grading characteristics of coarse, fine and combined aggregates are shown in Fig. 1 and Fig. 2.

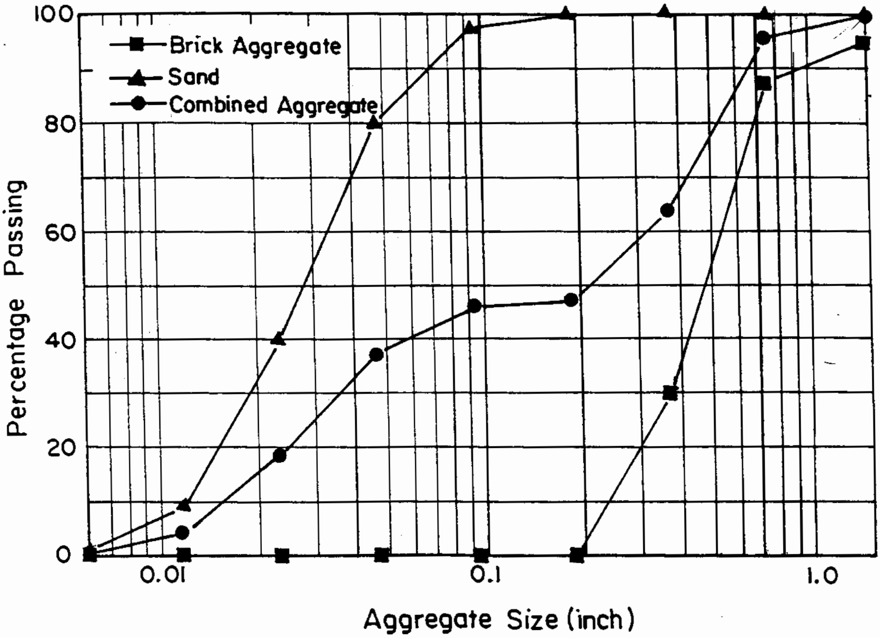

Fig 1. Grading Characteristics of the Aggregates (Batch-1)

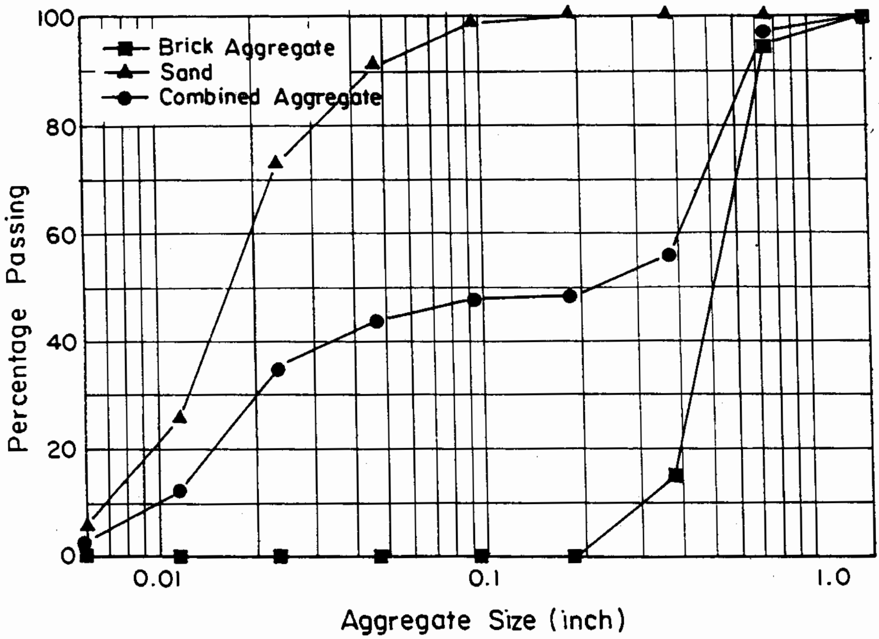

Fig 2. Grading Characteristics of the Aggregates (Batch-2)

After getting data about material properties, the mixes were designed for 4000 psi strength with 1 inch slump following ACI method (ACI 211.1-77 1984). The proportions of the mix ingredients as obtained from mix design are summarised in Table 2.

Table 2. Proportion of Ingredients in the Mix

Ingredients	Quantity lb./yd3	
	Batch 1	Batch 2
Cement	525.00	525.00
Fine Aggregate	1356.28	1251.95
Coarse Aggregate	1275.47	1483.30
Water	299.00	299.00

Preparation of Cylinder Specimens

Based on mix design, the required quantities of the materials were calculated and measured on SSD weight basis. The coarse aggregate, fine aggregate and cement were then spread evenly on the mixing pan of the mixing machine, mixed thoroughly and continuously and water was gradually added. Thorough mixing was continued until uniform concrete mix was prepared. Proper and uniform quality of concrete were maintained. Then the slump of the mix was checked according to standard method (ASTM C143-78).

After mixing, the concrete was placed in reusable cylindrical moulds that conformed to standard requirements (ASTM C470-87 1988) in two layers. The concrete after placement in the cylindrical moulds was compacted by using vibrator (ASTM C31-88 1988).

Curing

After casting of concrete, the cylinders were stored in moulds for 24 hours in moist condition at room temperature and then the moulds were carefully removed. The curing of the cast cylinders of the two batches of concrete was carried out in the following sets of sequences.

Batch1

Set 1

a. Concrete was cured continuously in water for six months.

b. Concrete was cured in water up to 7 days and then kept in air up to the age of six months.

Set 2

a. Concrete was not subjected to any curing for six months.

b. A set of uncured specimens was subjected to curing from the 28th day and continued up to the age of six months.

Batch 2

Set 1

a. Concrete was cured continuously in water for four months.

b. After 28 days of curing a set of specimens was kept in air up to age of three months.

Set 2

a. Concrete was cured in water up to 7 days and then kept in air up to the age of three months.

b. Concrete that was cured under water up to 7 days was kept in air up to 28th day and then again curing was continued up to the age of three months.

Set 3

a. Concrete was not subjected to any curing up to third month.

b. A set of uncured specimens was subjected to curing from the 28th day and continued up to the age of three months.

The cylinders were stored in lime water at room temperature to provide necessary supply of moisture during curing (ASTM C31-88 1988). Throughout the discontinued period of curing, the specimens were kept in air in a shaded room. All these operations were carried out during May to October.

Testing of the Cylinder Specimens

All the cylinders were tested in wet condition. To ensure wet condition, the dry cylinders were kept under water for 24 hours before testing. The top surfaces of the cylinders were capped with sulphur mortar in accordance with standard specification (ASTM C617-87 1988) before testing.

Diameters of cylinder specimens were recorded before crushing. The cylinders were crushed for their compressive strength in a Universal Testing Machine (ASTM C39-86 1988).

FINDINGS FROM THE INVESTIGATION

The compressive strengths of concrete at different ages under different curing conditions are presented in Fig. 3 and Fig. 4.

From the two sets of curves of Fig. 3 it appears that the rate of gain of strength of concrete beyond the 28th day is higher for the cylinders which have been continuously cured. But the rate drastically slows down in the other set which have not received any early age curing.

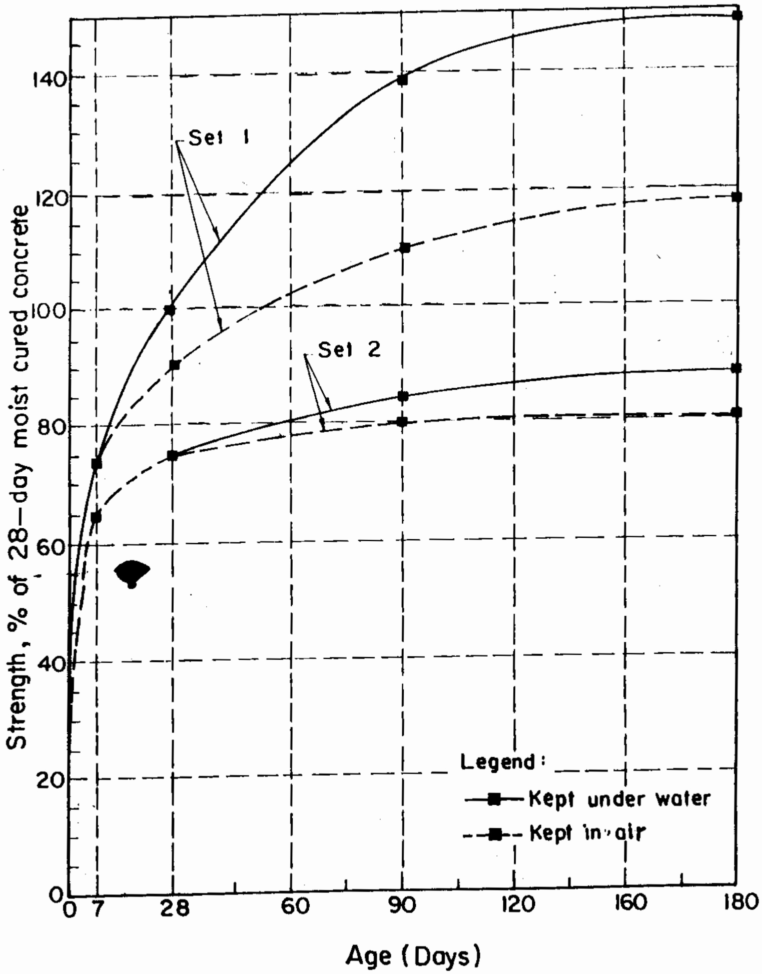

Fig 3. Compressive Strength of Concrete at Different Ages Under Different Curing Conditions as Obtained from Cylinder Tests. (Batch-1)

From the three sets of curves of Fig. 4, it is apparent that interrupted curing always results in considerable reduction in concrete strength. But interruption in curing at early ages were again found to be the most damaging to concrete from the point of view of long term strength attainment.

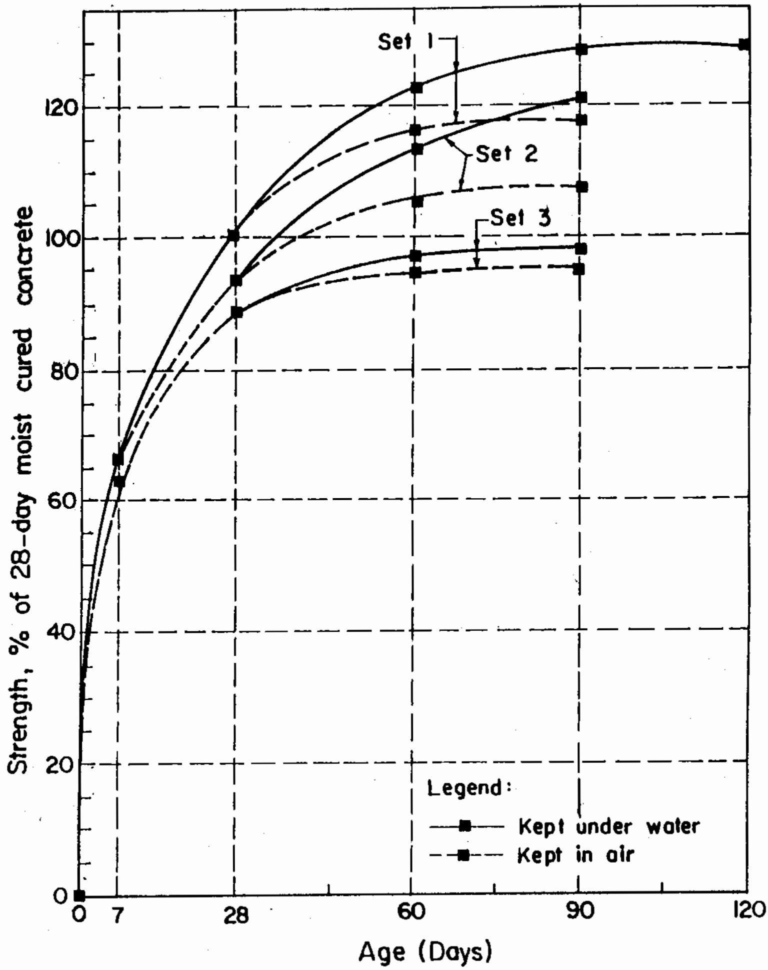

Fig 4. Compressive Strength of Concrete at Different Ages Under Different Curing Conditions as Obtained from Cylinder Tests. (Batch-2)

From the curves (Fig. 3 and Fig. 4) it is revealed that the early age strengths were not much affected by the curing condition. This must be due the fact that the initial moisture contained in concrete was itself sufficient for hydration of cement. However, ultimate strengths were seriously affected by the variation in curing condition.

The trend of Strength vs. Age curve was not much affected due to interruption at midway of curing (from 7th day to 28th day, Set 2, Fig. 4). Compared to the first set the trend of curve of the second set indicates that in spite of the break in curing the expected 28th day strength can be achieved if curing can be started after the 28th day. In this case, however, a longer time will be required to attain that strength.

In contrast to this, the specimens which were not cured at all (Set 2, Fig. 3 and Set 3, Fig. 4) failed to catch the trend of the first set. This may be due to the loss of water through evaporation from the fine pores of concrete and subsequent late curing failed to resaturate them. The chemical ageing may also be responsible for this occurrence.

In comparison to the results of stone aggregate concrete (Price 1951 and Portland Cement Association 1952) brick aggregate concrete showed less sensitivity to the absence of moist curing in rate of gain of strength in a distinct way (Appendix I).This feature manifests the behaviour of brick aggregate concrete as light weight aggregate concrete (Neville 1981).

This characteristics can be interpreted from the high absorption capacity and low specific gravity of the brick aggregates (Table 1). Most normal weight aggregates (fine and coarse) have absorption capacities in the range of 1-2% (Mindess and Young 1981). Abnormally high absorption capacities indicate high-porosity aggregates. Again, the specific gravities of the normal stones/ rocks are in the range of 2.5-2.8. A value well below this range is also an indication of higher porosity (Mindess and Young 1981), and characteristically, light weight aggregates tend to have high porosity. The higher porosity of aggregates is an indicative characteristics of higher possibility of resaturation during wetting and drying cycles than that of stone aggregates. Again, due to higher absorption capacity, there is a greater possibility of use of the pore water of aggregate in hydration process during the uncured period.

In regard to the duration of curing, the ACI suggests the 7 days moist curing for most structural concretes, or the time necessary to attain 70% of the specified compressive or flexural strength, whichever is less. For unreinforced mass concrete, minimum curing time is suggested to be longer: 2 weeks, or 3 weeks if a pozzolan is used. These recommendations are for the concretes placed and cured at temperatures above 4°C (ACI 308-81 1984).

But the Strength vs. Age curves of Set 1 (Fig. 3 and Fig. 4) reveal that the continuation of curing beyond the 28th day will help in gaining some more strengths. The continuation of curing up to 6 months (Batch1) and 4 months (Batch 2) indicated that it may be a viable option in some cases like roof slabs or road pavements to continue curing beyond the 28th day. It may provide around 25% more strength than the 28th day strength, with only one month's additional curing.

CONCLUSION

Curing of concrete is essential in attaining the desired strength of concrete. Continuous curing is the best technique to follow and curing at the early age is the most vital. The damage caused by the loss of strength due to absence of any curing at early age (1st four weeks) is irrecoverable.

Curing at any stage is beneficial to overcome the losses due to discontinuity in curing. The delayed curing can be helpful even in attaining the desired strength provided that the early age (say 1st one week) curing is not hampered. In such an event, curing for a longer duration is required.

It is seen that brick aggregate concrete is less sensitive to the interruption of moist curing in the gain of strength properties. This indicates a unique property of brick aggregate concrete in comparison to stone aggregate concrete. Evidently this property is related to higher porosity and lesser unit weight of brick aggregate concrete. Further research may, however, be initiated to ascertain in what way this is related to the durability property.

Furthermore, it is noted from the investigation that in case of continuous curing, the prolongation of curing even up to 60 days increases the strength of concrete by at least 25% of the 28-day strength. So in some practical cases it may be considered as viable and economic option for increasing the margin of safety against failure. This may get consideration for inclusion in the design criteria.

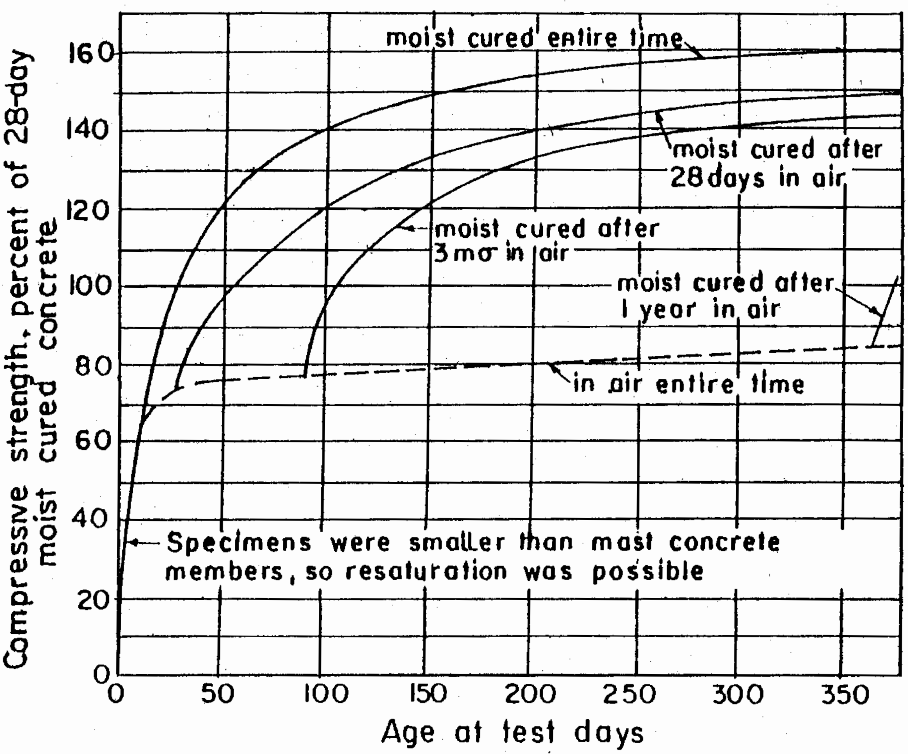

Fig. 5. Effect of curing conditions on compressive stength of stone aggregate oncrete, (Portland Cement Association 1952)

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FPS TO SI CONVERSION FACTORS

To convert	To	Multiply
inches (in)	millimetres (mm)	25.40
pounds per square inch (psi)	kilo pascals (kPa)	6.89
pounds per cubic feet (pcf)	newton per cubic meter (N/m^3)	156.84
pounds per cubic yard	newton per cubic meter (N/m^3)	1411.56