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Properties of internally cured concrete made of partially replaced stone chips with brick chips

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Abstract

With time, concrete has become one of the most popular construction materials. The modern industry utilizes this material a lot and has produced various beautiful, eye-catching and amazing structures. It is obtained by mixing cement, water, and aggregates in required proportions. The aggregates are usually derived from natural sources but in regions such as Bangladesh and parts of West Bengal, India where natural rock deposits are scarce. Due to gradual diminution stone chips are not available in different zones in Bangladesh and also the cost is higher than locally available brick chips, burnt-clay bricks are used as an alternative source of coarse aggregate. In Bangladesh, brick circulation is very high as coarse aggregate due to its availability and low cost. Some of the building owners used stone chips as Coarse aggregate in concrete in particular parts of their structure such as foundations, columns and used brick chips as coarse aggregate in concrete for other parts of the structure such as beams, slabs which lends the structure uneven and non-homogeneous strength, therefore, at the joints differential shrinkage is occurred and crack developed. Hence, the replacement of crushed stone by crushed brick n concrete may yield cost-effectiveness in making concrete as well as reduction of those problems. This paper presents an experimental investigation of the properties of concrete obtained by replacing stone aggregate by crushed clay-brick. Remaining concretes were made by replacing the stone aggregate by equal volume or brick aggregate while everything else was kept unchanged. The only variable considered in the study was the volumetric replacement 0%, 25%, 50%, 75%% and 100% of stone aggregate by brick aggregate with W/C ratio 0.5. Two mix proportions used in the study are 1:1.5:3and 1:2:4. It is revealed that the 7-WP curing method shows a better efficiency than the other method studied in this research with an average efficiency of 100% compared to its counterpart which is normally cured.

Keywords: Internal curing, brick chips, compressive strength, replacement.

1. Introduction

In recent years, a renewed interest has been observed in developing methods to incorporate internal curing as a tool to reduce shrinkage cracking. According to Dale Bentz, a researcher at the National Institute of Standards and Technology (NIST), it's often not possible to provide enough curing water for a pavement or other large construction sites surface at a sufficient rate to satisfy the ongoing chemical shrinkage [Bentz et al., 2005; ESCSI, 2006]. Internal curing (IC) assists the distribution of extra water throughout the entire microstructure, thus maintaining saturation of the cement paste during hydration. This in turn prevents paste self-desiccation and eventually, reduces shrinkage. So, shrinkage and cracking may be reduced through internal curing. Also, it reduces permeability and increases the durability of concrete. At the same time, proper hydration ensures increased production of C-S-H gel. As a result, stronger and improved concrete is produced. Moreover, if internal curing may be ensured, natural curing is not required, which is done either by spraying or ponding. Therefore, additional water required for natural curing may be saved through this process. From the perspective of Bangladesh, internal curing (IC) has a wide prospect. Due to the unavailability of modern equipment and unskilled labor, the external curing process cannot be achieved properly in many instances. Internal curing in concrete is usually ensured either by utilization of lightweight aggregates (LWA) or by the addition of superabsorbent polymers (SAP). The primary reason for using LWA or SAP is that both of them can absorb water during mixing and eventually, transfer the absorbed water to the paste during hydration. Natural or synthetic lightweight aggregates are commonly used LWA as internal curing agent within concrete. Production of synthetic lightweight aggregates is often quite costly and naturally occurring LWA is not available in Bangladesh. However, over burnt clay brick chips (BC) are very common in the country because of relatively low cost and ease of availability. Consequently, a good portion of general construction work of the country uses BC as primary coarse aggregate. Brick chips can also be used as lightweight aggregate since its weight is between 70 and 120lb/ft^3[ASTM C330, 2014]. However, concrete with BC usually has less strength and often has durability issues [Afroz et al., 2015 and Hossain, 2012]. On the other hand, in most of the construction work external curing method is employed. Such an external curing process requires proper awareness among the workers and contractors. Unfortunately, many local contractors do not have the required awareness and workers suffer from lack of skill to ensure proper external curing. As a result, general concreting work often experiences durability concerns. However, the use of BC in construction works is quite difficult to control due to their low cost and wide availability all over the country. Thus, the study on potential application of BC in the construction sector is extremely important from the context of Bangladesh. BC has the potential to be used as an internal curing medium within concrete. Proper internal curing through addition of BC could improve overall durability performance of general concreting work of the country in the absence of appropriate external curing. Moreover, the internal curing process using BC can be suitable for an area with water scarcity and may help construction during the dry season/dry weather. The present study aims to investigate the properties of internally cured concrete made with partial replacement of stone chips with brick chips. Increased cement hydration, the improved microstructure of the cementitious paste, less shrinkage, improved interfacial transition zone, lower permeability, increased strength and durability and reduced coefficient of thermal expansion is ensured by internal curing of concrete. Compensation for poor Jobsite curing as well as support for proper curing, tolerance of higher curing temperatures without cracking or strength reduction reduced early age curling and warping, reduced heat of hydration, reduced design loads and transportation costs because of lower concrete densities and improved workability and finish ability obtained because of additional IC water. Social advantages of IC have increased service life and improved economies by lowering life cycle costs. The main advantages of IC are as follows [Iffat et al., 2017]. It is found that internal curing has been extended to consider longer-term durability by measuring transport properties such as diffusion and sorptive coefficients. One such study has focused on measuring sorptivity according to the ASTM C1585 standard test method for cylindrical specimens of pastes and mortars with and without internal curing, cured under sealed conditions in double plastic bags [ASTM C1585, 2004]. It was observed that internal curing of concrete reduces depth of penetration of chloride and other ions and control corrosion.

2. Materials

Different types of tests were performed on stone chips, BC, sand and cement. Sieve analysis was conducted to get the gradation of aggregate. Specific gravity, absorption capacity, unit weight, and desorption tests were also done on aggregate. Normal consistency, setting time and mortar strength of cement were determined. This analysis was conducted to determine the gradation of aggregate sample used in the mix design. Fineness Modulus (FM) is a measure of coarseness or fineness of the material. Empirical factor obtained by summation of cumulative percent retained in US standard sieve divided by 100. Gradations of fine and coarse aggregate were obtained separately using method ASTM C136 [2006]. Bulk specific gravity is obtained from the ratio of aggregate and weight of an equal volume of water including permeable pores. Apparent specific gravity is obtained from the ratio of Oven Dry weight of aggregate and weight of an equal volume of water excluding permeable pores. Both types of specific gravity of the aggregate used in mixes were obtained in the laboratory following ASTM C128 [2012] standard.

Table 1
Specific gravity, absorption capacity and FM of materials

Materials	Unit Weight (kg/m^3)	Bulk Specific Gravity (OD)	Bulk Specific Gravity (SSD)	Absorption Capacity %	Fineness modulus
SC	1545	2.05	2.18	6.40	6.90
BC	1210	1.90	2.00	15.80	7.20
Sand	1683	2.20	2.40	7.00	2.72

Portland Composite Cement (PCC) was used in the test. The normal consistency test was done according to ASTM C187 [2011], setting time test was done according to ASTMC150 [2012] and the compressive strength test of mortar was done according to ASTM C150 [2014].

Table 2
Cement test results

Test Title	Results
Normal consistency (%)	29%
Initial setting time (minutes)	60
Final setting time (minutes)	210
28 days Compressive strength of mortar (MPa)	31.61

3. Methodology

Seven curing conditions were selected in this study to simulate concreting work underexposed field conditions. The seven curing conditions and their elaborate form are given in Table 3.

Table 3
Curing conditions of cylindrical sample

Concise form of curing Condition	Elaborate of curing condition
NC	Normal curing underwater
WP	With polythene cover
WOP	Without polythene cover
3-WP	Three days normal curing under water then with polythene cover
3-WOP	Three days normal curing under water then without polythene cover
7-WP	Seven days normal curing under water then with polythene cover
7-WOP	Seven days normal curing under water then without polythene cover

In one curing condition (WP), samples were placed outside the laboratory just after casting with polythene sheet covering. Whereas under (WOP) curing condition, samples were placed outside the laboratory without any covering just after casting. In cases of (3-WP) and (7-WP) curing conditions, samples were placed underwater for 3 and 7 days, respectively, and then kept outside the laboratory with polythene cover. For (3-WOP) and (7-WOP) conditions, the samples were submerged underwater for 3 and 7 days and then placed outside without cover. All samples were also placed under normal external curing conditions for comparison.

4. Results

The compressive strength of concrete was obtained by compression test on cylinder samples following ASTM C39. The ultimate compressive load and cross-sectional area of the tested cylindrical samples were measured and compressive strength was calculated. Figure 1 shows the compressive strength of 100% brick chips of concrete (1:1.5:3) for different curing conditions. Compressive strength of 18.35 MPa was found for the normal curing condition. Comparing with the normal curing condition other conditions are 52.4%, 82.3%, 122.5%, 68.8%, 122% and 122.5% for WOP, WP, 3-WP, 3-WOP, 7- and 7-WOP respectively. It is revealed that the 3-WP, 7-WP and 7-WOP curing conditions are ideal for internal curing options.

Figure 2 shows the compressive strength of 100% stone chips of concrete (1:1.5:3) for different curing conditions. Compressive strength was found 25.42 MPa for Normal curing condition. Comparing with the normal curing condition other conditions are 38.2%, 58.9%, 95.8%, 48.2%, 94.9% and 93.4% for WOP, WP, 3-WP,3-WOP,7-WP and 7-WOP. The results exposed that the 3-WP and 7-WP curing conditions are most suitable for internal curing.

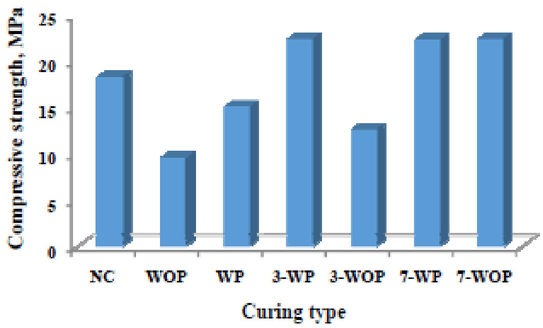

Fig. 1. Compressive strength of concrete for 100% brick chips at the age of 28 days [1:1.5:3]

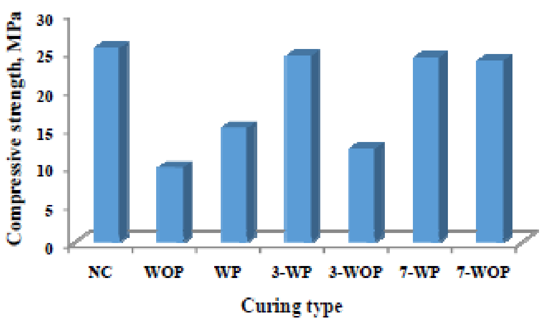

Fig. 2. Compressive strength of concrete for 100% stone chips at the age of 28 days [1:1.5:3]

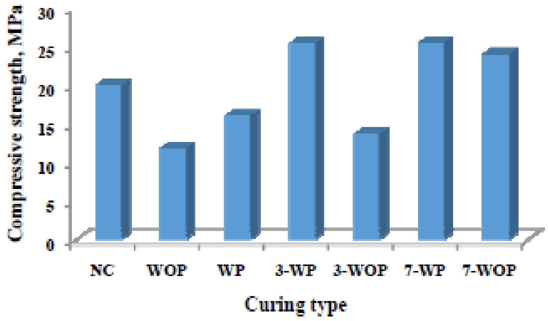

Fig. 3. Compressive strength of concrete for 75% brick chips and 25% stone chips at the age of 28 days [1:1.5:3]

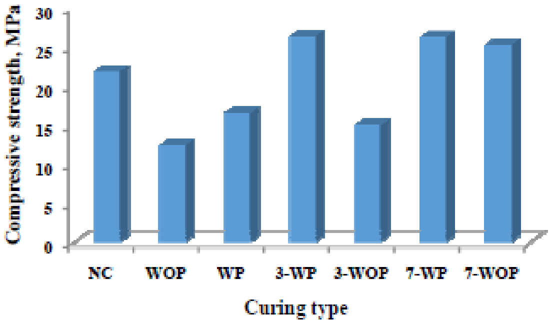

Fig. 4. Compressive strength of concrete for 50% brick chips and 50% stone chips at the age of 28 days [1:1.5:3]

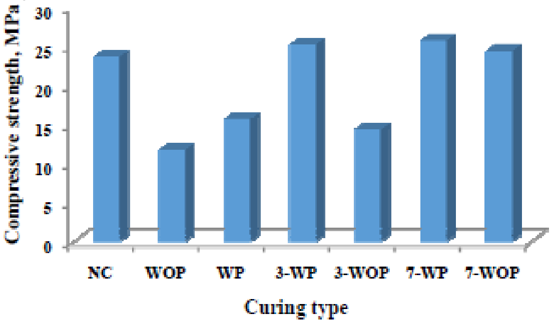

Fig. 5. Compressive strength of concrete for 25% brick chips and 75% stone chips at the age of 28 days [1:1.5:3]

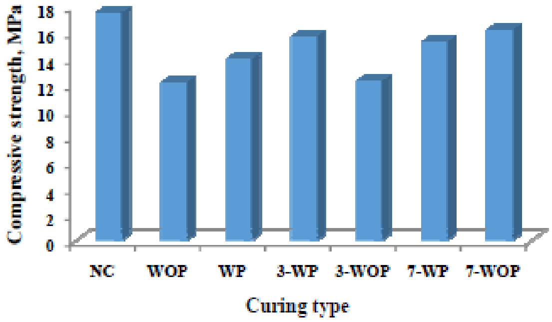

Fig. 6. Compressive strength of concrete for 100% brick chips at the age of 28 days [1:2:4]

Figure 3 shows the compressive strength of 75% brick chips and 25% stone chips of concrete (1:1.5:3) for different curing conditions. It was measured that compressive strength is 19.95 MPa for Normal curing conditions. According to normal curing condition, others curing condition are 59.1%, 80%, 127%, 68.4%, 127.3% and 120.1% for WOP, WP,3-WP,3-WOP,7-WP and 7-WOP respectively. It is revealed that the 3-WP, 7-WP and 7-WOP curing conditions are better for internal curing among other curing conditions.

Figure 4 shows the compressive strength of 50% brick chips and 50% stone chips of concrete (1:1.5:3) for different curing conditions. Compressive strength of 21.7 MPa was found for the normal curing condition. Comparing with the normal curing condition others conditions are 56.7%, 75.8%, 120.8%, 68.6%, 120% and 115.8% for WOP, WP,3-WP,3-WOP,7-WP and 7WOP respectively. It is exposed that the 3-WP, 7-WP and 7-WOP curing conditions are ideal for internal curing types.

Figure 5 shows the compressive strength of 25% brick chips and 75% stone chips concrete (1:1.5:3) for different curing conditions. Normal curing compressive strength was found at 23.56 MPa. Comparing with the normal curing condition other conditions are 49.6%, 66.5%, 106.6%, 60.9%, 108.9% and 103.4% for WOP, WP, 3-WP, 3-WOP, 7-WP and 7-WOP respectively. It is revealed that among them 3-WP, 7-WP, 7-WOP are better for internal curing.

Figure 6 shows the compressive strength of 100% bricks chips of concrete (1:2:4) for different curing conditions. It was found that in normal curing condition compressive strength is 17.53 MPa. Comparing with the normal curing condition others conditions are

69.3%, 79.6%, 89.4%, 69.9%, 87.1% and 92.4% for WOP, WP, 3-WP, 3-WOP, 7-WP and 7-WOP respectively. It is observed that the 7-WOP curing condition is ideal for internal curing types.

Figure 7 shows the compressive strength of 100% stone chips of concrete (1:2:4) for different curing conditions. It was measured that compressive strength is 21.35 MPa for Normal curing conditions. Comparing with the normal curing condition other conditions are 53.2%, 68.7%, 73.8%, 62.5%, 76.1% and 71.4% for WOP, WP, 3-WP, 3-WOP,7-WPand 7-WOP respectively.

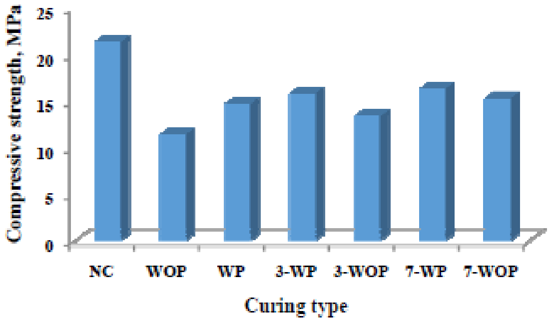

Fig. 7: Compressive strength of concrete for 100% stone chips at the age of 28 days [1:2:4]

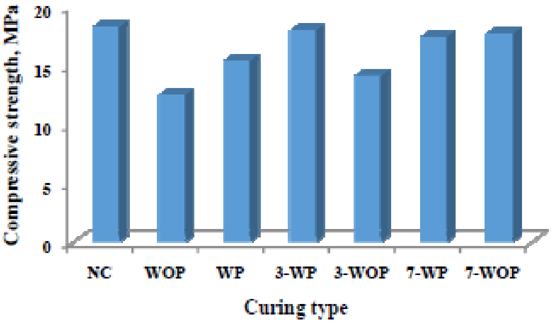

Fig. 8: Compressive strength of concrete for 75% brick chips and 25% stone chips at the age of 28 days [1:2:4]

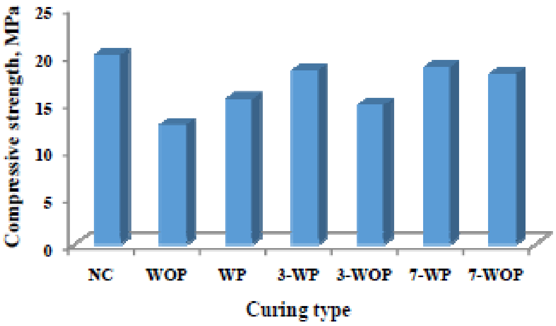

Fig. 9: Compressive strength of concrete for 25% brick chips and 75% stone chips at the age of 28 days [1:2:4]

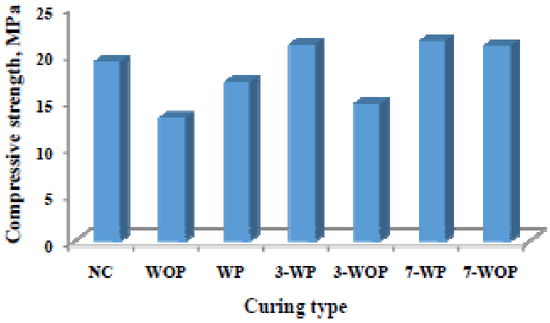

Fig. 10: Compressive strength of concrete for 50% brick chips and 50% stone chips at the age of 28 days [1:2:4]

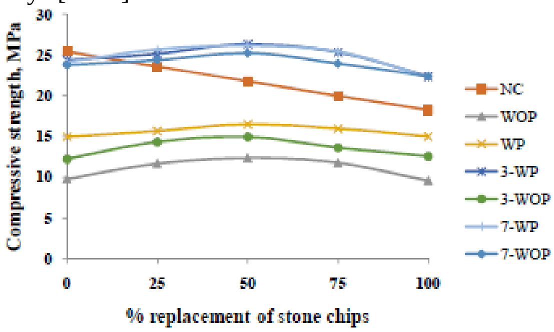

Fig. 11: Compressive strength of concrete for different replacement with various curing type [1:1.5:3]

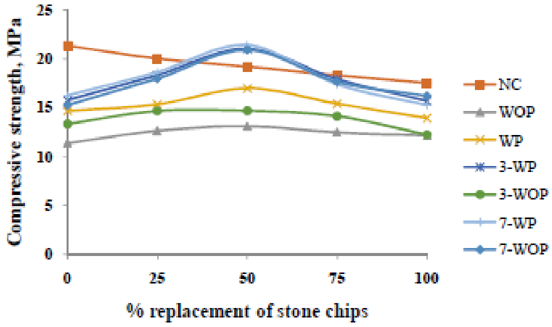

Fig. 12: Compressive strength of concrete for different replacement with various curing type [1:2:4]

Figure 8 shows the compressive strength of 75% brick chips and 25% stone chips concrete (1:2:4) for different curing conditions. Normal curing compressive strength was found 18.3 MPa. Comparing with the normal curing condition other conditions is 68%, 84.2%, 98%, 77.2%, 95% and 96.4% for WOP, WP, 3-WP, 3-WOP, 7-WP and 7-WOP respectively. It is observed that 3-WP, 7-WP and 7-WOP are ideal for internal curing.

Figure 9 shows the compressive strength of 25% brick chips and 75% stone chips concrete (1:2:4) for different curing conditions. Compressive strength of 20.01MPa was found for the normal curing condition. Comparing with the normal curing condition other conditions are 63.1%, 76.7%, 91.6%, 73.3%, 93.2% and 89.8% for WOP, WP, 3-WP, 3-WOP and 7-WP and 7-WOP respectively. It is revealed that the 3-WP curing conditions are ideal for the internal curing option.

Figure 10 shows the compressive strength of 50% brick chips and 50% stone chips concrete (1:2:4) for different curing conditions. Normal curing compressive strength was found 19.2 MPa. Comparing with the normal curing condition other conditions is 68.3%, 88.4%, 109.5%, 76.5%, 111.5% and 108.8% for WP, WOP, 3-WP, 3-WOP, 7-WOP and 7-WP respectively. The results exposed that the 3-WP, 7-WP and 7-WOP curing conditions are most suitable for internal curing.

Figure 11 shows the Compressive strength of concrete for different replacement with various curing type where the mix ratio is 1:1.5:3. This trend shows maximum compressive strength found in normal curing for 100% stone chips. 3-WP, 7-WP and 7-WOP gives better compressive strength for 50% replacement of stone chips and also observed 100% brick chips resulted in relatively lower strength as compared to the other three partial replacements. Hence, it should be noted that the amount of BC must be controlled as a partial replacement. Otherwise, a larger quantity of BC is likely to produce weaker concrete.

Figure 12 shows the Compressive strength of concrete for different replacement with various curing type where the mix ratio is 1:2:4. It is observed from this trend that maximum compressive strength found in normal curing for 100% stone chips and also shows 3-WP, 7-WP and 7-WOP gives better compressive strength for 50% replacement of stone chips. 100% of brick chips resulted in relatively lower strength as compared to other replacements. Hence, It should be noted that the amount of BC must be controlled as a partial replacement. Otherwise, a larger quantity of BC is likely to produce weaker concrete.

5. Conclusions

The following conclusions have been drawn from the experiments performed in this study.

- From the compressive strength test, it has been found that internally cured samples produced significantly higher strengths than that of control specimens when subjected to adverse curing conditions. It was revealed that 7-WP ensures about10% more strength than that of the normal curing.
- It is evident that on average similar i.e., 100% compressive strength gained when the concrete was cured using 7-WP, 7-WOP and 3-WP methods.
- It is evident from the observed results that the polythene sheet covering ensures an effective internal curing mechanism. Polythene sheet covering prevents loss of water through evaporation and eventually, more internal water remains available for cement hydration. The utilization of polythene sheet covering is a simple process since these sheets are less costly and can be used repetitively.

- Without polythene sheet cover also given an effective result in 100%stone chips for 1:1.5:3 ratio and 75% stone chips for 1:2:4 ratios.
- It has been found from the study that 75% replacement of brick chips in 1:1.5:3ratio and 25% replacement of brick chips in 1:2:4 ratio is relatively less effective in producing better concrete as compared to other replacement according to their compressive strength.

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References

Afroz, S., Rahman, F., Iffat, S., and Manzur, T. Sorptivity and strength characteristics of commonly used concrete mixes of Bangladesh. In Proceeding of International Conference on Recent Innovation in Civil Engineering for Sustainable Development, DUET, Bangladesh, 2015.

American Society for Testing of Materials (ASTM) Standards. Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates, ASTM C136, 2006.

American Society for Testing of Materials (ASTM) Standards. Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate, ASTMC128, 2012.

American Society for Testing of Materials (ASTM) Standards. Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, ASTM C39, 2014.

American Society for Testing of Materials (ASTM) Standards. Standard Specification for Lightweight Aggregates for Structural Concrete, ASTM C330, 2014.

American Society for Testing of Materials (ASTM) Standards. Standard Specification for Portland cement, ASTM C150/C150M, 2012.

American Society for Testing of Materials (ASTM) Standards. Standard Practice for Determination of Gas Content of Coal-Direct Desorption Method, ASTM D7569, 2010.

American Society for Testing of Materials (ASTM) Standards. Standard Test Method for Amount of Water Required for Normal Consistency of Hydraulic Cement Paste, ASTM C187, 2011.

American Society for Testing of Materials (ASTM) Standards. Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic- Cement Concretes, ASTM C1585, 2004.

American Society for Testing of Materials (ASTM) Standards. Standard Specification for Lightweight Aggregates for Structural Concrete, ASTM C330, 2014.

Bentz, D., Lura, P. and Roberts, J. Mixture Proportioning for Internal Curing, Concrete International, Vol. 27, No. 2, pp. 35-40, 2005.

Iffat, S., Manzur, T. and Noor, M.A. Durability performance of internally cured concrete using locally available low-cost LWA, KSCE Journal of Civil Engineering, Vol. 21, pp.1256–1263, 2017. https://doi.org/10.1007/s12205-016-0793-x

Iffat, S. Efficiency of internal curing in concrete using local materials with different curing conditions. M.Sc. in Civil Engineering (Structural) Thesis, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh, 2014.

The Expanded Shale Clay and Slate Institute (ESCSI). Expanded Shale, Clay and Slate Embodied Energy, 22225, Murray-Holladay Road, Suite 102Salt Lake City, UT United States 84117, 2006.