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Durability Performance of Internally Cured Concrete Using Locally Available Low Cost LWA

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Abstract

Curing of concrete is important to ensure both strength and durability. Loss of water through evaporation reduces the hydration rate and eventually results in limited strength and higher permeability. Generally, curing is done by supplying additional water from external sources to prevent the water loss. Such curing requires skilled labor and proper knowledge. However, in a developing country like Bangladesh, it is considered as an additional step and often neglected. Under such scenario, Internal Curing (IC) could be adopted to improve the overall quality of general concreting work. Utilization of locally available burnt clay chip aggregate commonly known as Brick Chips (BC) to produce internally cured concrete can be considered as an effective solution. The pore spaces of these aggregates absorb water during saturation process and later desorb water under favorable conditions of higher temperature and low relative humidity. As a result, no external curing water is needed. This study shows the durability performance of concrete having BC as internal curing medium. Stone chips have been partially replaced by BC since concrete with BC alone produces weaker concrete. Three commonly practiced water cement ratios of 0.4, 0.45 and 0.5 and five curing conditions were selected to simulate inside and outside environmental conditions. Three different percent replacements (10%, 20% and 30%) of stone chips by BC were selected. Control samples with stone chips were also made for comparison. Water permeability test and Rapid Chloride Permeability Test (RCPT) were performed. It is found that durability of internally cured concrete with polythene sheet covering is comparable to the durability of normally cured control concrete. Moreover, under adverse curing conditions with no supply of external water, internally cured concrete performed significantly better than control samples. Therefore, BC can be used as a cost effective internal curing material in Bangladesh to produce durable concrete.

Keywords: *internal curing, lightweight-aggregate, permeability, desorption, durability*

1. Introduction

Internal Curing (IC) or self curing refers to the process by which proper hydration of cement occurs because of the availability of additional internal water which is not part of the initial mixing water of a concrete mix (Bentz *et al.*, 2005). Light Weight Aggregates (LWA) are usually porous and can absorb considerable amount of water when kept immersed in water. A number of researches have shown that this absorbed water can be transferred to the paste during hydration (Bentz, 2000; ESCSI, 2012; Bentz and Weiss, 2010; Schlitter, 2010; Lura, 2003). Internal curing of concrete is usually carried out in two ways. One is by using LWA and the other is by using Super Absorbent Polymers (SAP). Like LWA, SAP can also supply absorbed water during curing period (Manzur *et al.*, 2015; Mather, 2004). However, high strengths are usually not ensured from LWA-concrete due to high porosity and lower density of aggregates. Consequently, compressive strength of concrete having only LWA as coarse aggregate is generally found to be quite low. LWA can be divided into two categories, one is naturally found and the other one is artificially manufactured by mechanical treatment of industrial byproducts, waste materials, etc. The industrial byproducts are pulverized fly ash, blast furnace slag, industrial waste, sludge, etc. (Obla *et al.*, 2007). The additional water for internal curing is typically supplied through addition of saturated lightweight aggregate (LWA) in the concrete (Bentz and Weiss, 2010). A study conducted in Newfoundland, Canada shows that 50% replacement of coarse aggregate by pre-wetted shale (a form of naturally occurring LWA) improves the mechanical properties of concrete (ESCSI, 2012). Benefits of internal curing include increased hydration and strength development, reduced autogenous shrinkage and cracking, reduced permeability, and consequently, increased durability (Bentz *et al.*, 2005; Bentz and Weiss, 2010; Geiker *et al.*, 2004; and Tamimi *et al.*, 2008). The impact of internal curing begins immediately after mixing i.e. during the initial hydration of cement and benefits of internal

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curing have been observed at ages as early as 2 days (Bentz *et al*., 2005; Bentz and Weiss, 2010; Kim and Bentz, 2008).

In Bangladesh, a large portion of construction works have been carried out using burnt clay chips as coarse aggregate commonly known as Brick Chips (BC). BC are used due to their relative low cost and wide availability as compared to conventional stone chips. However, concrete having BC as coarse aggregate are weaker in strength (Hossain, 2012) and also have durability issues (Afroz *et al.*, 2015; Bosunia and Chowdhury, 2001). In addition, external curing method is used in most of the construction work. Such external curing process requires proper knowledge and expertise of the workers. However, many local contractors do not have the required awareness, knowledge and skill to ensure proper external curing. Also, there are scarcity of trained laborer and appropriate equipments. As a result, durability of general concreting work is often not satisfactory in the country. Consequently, concrete with BC has been considered as weaker concrete and in many instances is not recommended. However, due to low cost and ease of availability throughout the country, the use of BC is extremely difficult to control. Thus, study on potential advantages of BC as coarse aggregate is of immense importance from the context of Bangladesh. A recent investigation shows that BC have high desorption capacity and can be used as an effective internal curing medium within concrete mix (Iffat, 2014). Therefore, stone chips can be partially replaced by saturated BC to perform internal curing mechanism within concrete. Such internal curing will ensure proper hydration and eventually, will result in comparable strength and durability of conventional concrete. Moreover, it will lessen the additional water required for external curing. Unfortunately, no significant study on BC as internal curing medium is available which could be used as a guideline for producing internally cured concrete with better durability performance. Nevertheless, it is extremely important to have recommended mix proportions for making internally cured concrete having BC as a partial replacement of stone chips. With this end in view, a comprehensive investigation on durability of concrete with BC as internal curing medium has been performed in the current study. It is found that concrete with BC as internal curing medium showed better durability performance as compared to conventional concrete with 100 percent stone chips when subjected to adverse curing conditions. The preliminary results of this technique are extremely encouraging and exhibit enormous potential to save large amount of water required for external curing process. This method can also reduce depletion of natural aggregates since a substantial portion of naturally occurring stone chips is replaced by the manufactured BC.

2. Material

Portland composite cement CEM II (BS EN 197-1, 2000) was used in this study. Stone Chips (SC) of 19 mm (3/4 inch) downgraded size were used as coarse aggregate and BC was used as partial replacement of stone chips as internal curing agent. Local sand (collected from Sylhet, Bangladesh) was used as fine aggregate. Sieve analysis was conducted to determine the gradation of both coarse and fine aggregates. Gradation was determined following ASTM C136 (ASTM C136, 2001) method. Gradation curves of both coarse and fine aggregates are shown in Fig. 1. Fineness Modulus (FM) of stone chips, sand and BC were found as 8.42, 2.43 and 6.37, respectively. Bulk specific gravity of BC was found as 1.693 and 1.959 on Oven Dry (OD) and Saturated Surface Dry (SSD) basis, respectively as per ASTM C128 (ASTM C128, 2001). Moreover, it was found that BC had absorption capacity of 25.73% and unit weight of 1110 kg/m^3. ASTM C29 (ASTM C29, 2003) test procedure was followed to determine the unit weight of aggregates. It was found from the desorption test that BC samples can desorb around 24.5% of water of its OD weight (Iffat, 2014).

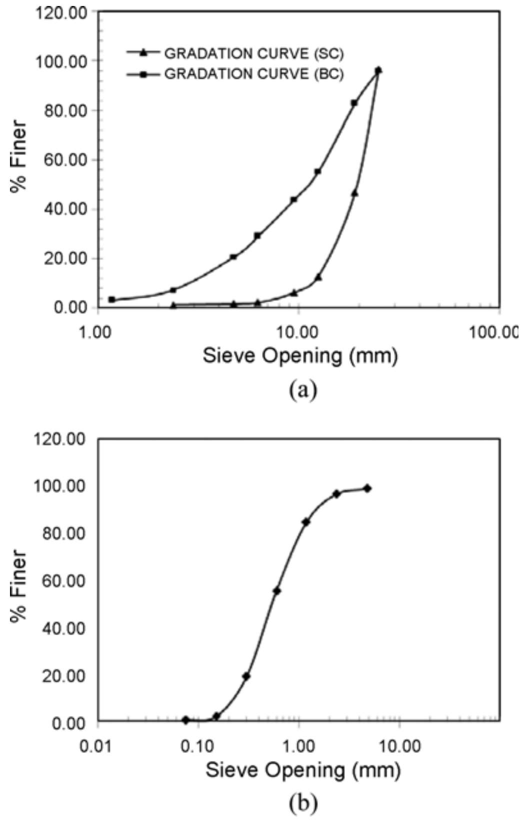

Fig. 1. Gradation Curves for: (a) Coarse, (b) Fine Aggregates

Initially, a mix design with mix proportion of 1: 1.55: 2.3 on volume basis was developed using the SC and Sylhet sand to produce concrete having a minimum target compressive strength of 20.5 MPa for water cement ratio of 0.5. Such target strength and water content were selected to represent the general concreting work of the country. Mix designs were done on SSD basis. Aggregates were collected in air dry condition and then, in the laboratory, were converted to SSD condition. Before mixing, moisture from surface of the aggregates was removed properly. Three mixes with no partial replacement of stone chips were made as control samples with three different water cement ratios of 0.4, 0.45 and 0.5. Another nine mix designs (having similar

Table 1. Mix Design for 1 Cubic Meter of Concrete

Water Cement Ratio	Water (Kg)	Cement (Kg)	FA (Kg)	Percent replacement of SC by BC	SC (Kg)	BC (Kg)
0.4	104.31	260.78	448.43	0%	662.08	0
				10%	595.87	66.21
				20%	529.66	132.42
				30%	463.45	198.63
0.45	115.84	257.42	442.65	0%	653.56	0
				10%	588.20	65.36
				20%	522.85	130.71
				30%	457.49	196.07
0.5	127.07	254.15	437.03	0%	645.26	0
				10%	580.73	64.53
				20%	516.21	129.05
				30%	451.68	193.58

mix proportion and three different water cement ratios of control specimens) with three different partial replacements (10%, 20% and 30%) of stone chips with BC were made. Partial replacements of SC were done on mass basis. The volume of internally cured concrete was also calculated to investigate the effect of partial replacement on overall volume of the specimens. It was found that such partial replacement in the range of 10% to 30% on mass basis had insignificant effect on total volume of concrete. Table 1 shows the details of all concrete mixes. No admixture was used. The average temperature during casting and curing period was recorded as 34 degree Celsius and Relative Humidity was recorded as 73% that represents typical local summer weather condition.

3. Experimental Setup

Normal curing conditions, denoted as “NC”, were simulated by keeping samples fully submerged under water to ensure proper external curing. Control samples with three different water cement ratios were kept under NC condition. In addition to normal curing, four different curing conditions were simulated in this study. Abbreviations of these different curing conditions are provided in Table 2. Two sets of each type of samples were kept inside the laboratory to simulate curing in interior conditions (under shade). One set was covered with polythene sheets (ILWP) and another one was kept without polythene cover (ILWOP). The other two sets were kept outside the laboratory to simulate curing under natural open conditions. Similar to interior curing conditions, one set was covered with polythene sheet (OLWP) and the other one was kept without polythene cover (OLWOP). All these four curing conditions are quite common in general construction sites of the country. Control samples (with no partial replacement) were also kept under these four simulated curing conditions for comparison. Finally, Compressive strength test according to ASTM C39 (ASTM C39, 2003) and two types of durability tests; water permeability test according to EN Standard (BS EN 12390-8, 2009) and rapid chloride permeability test (RCPT) according to ASTM Standard (ASTM C 1202, 1997) were performed. The RCPT test provides reliable information on permeability characteristics of concrete samples in terms of chloride ingress within a short period of time (Grace and Company, 2006; Ptefier *et al.*, 1994; Yang and Chiang, 2006). For this reason, in addition to water permeability test, RCPT tests were performed to investigate the effect of internal curing on overall durability performance of concrete.

Table 2. Abbreviations for Different Curing Conditions used in the Study

Curing Conditions	Symbol
Normal Curing Under Water	NC
Inside Lab with Polythene	ILWP
Inside Lab without Polythene	ILWOP
Outside Lab with Polythene	OLWP
Outside Lab without Polythene	OLWOP

3.1 Compressive Strength Test

Cylindrical concrete samples of dimension 100 mm × 200 mm were kept under different curing conditions for up to 28 days just after mixing. At 3, 7 and 28 days, compressive strength tests were performed. Universal testing machine was used to apply compressive load on specimens at a loading rate of 0.15 to 0.35 MPa per second. The calibrated load was used to determine compressive strength.

3.2 Water Permeability Test

For water permeability test, 150 mm × 150 mm cubic samples were prepared and kept in different curing conditions for 28 days. Water permeability test was performed on 28 days cured samples. Cubes were properly air dried before test and placed in the permeability test machine (Fig. 2). A constant pressure head of 50 meter was maintained for 48 hours for all samples and then the head difference was measured. The cubes were then split and depth of water penetration was determined. Finally, water permeability coefficient was calculated using the depth of water penetration.

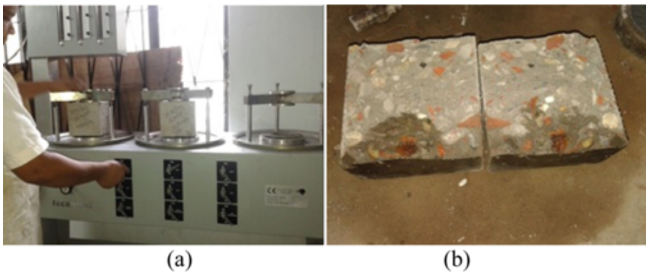

Fig. 2. Water Permeability Test: (a) Experimental Set Up, (b) Split Cubes

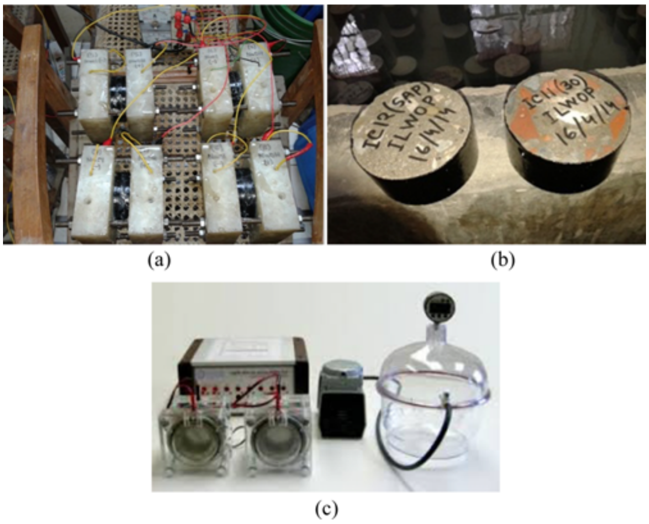

Fig. 3. Chloride Permeability Test: (a) Experimental Setup, (b) Cylindrical Core Samples, (c) Schematic Diagram

3.3 Chloride Permeability Test

Chloride permeability test (RCPT) was performed on 50 mm thick core samples cut from concrete cylinders (100 mm × 200 mm) after 28 days of curing. The setup for RCPT is shown in Fig. 3 (Iffat *et al*., 2014). The sides of the 50mm thick cylindrical specimens were coated with epoxy, and after drying of epoxy coating, samples were put in a vacuum chamber for 3 hours. The specimens were vacuum saturated for 1 hour with de-aerated water and allowed to soak for 18 hours. Samples were then placed in the test device. The left-hand side (–) of the test cell was filled with 3% NaCl solution. The right-hand side (+) of the test cell was filled with 0.3N NaOH solution. The system was then connected with the power source and a 60-volt potential was applied for 6 hours (Fig. 3). Readings were taken at every 30 minutes interval. At the end of 6 hours, samples were removed from the cell and the amount of charge (in coulombs) that passed through the specimens was calculated.

4. Results and Discussion

4.1 Compressive Strength Test Results

Variation of compressive strengths among different internally cured samples with respect to control samples under NC is provided in Table 3. ILWP samples with 20% stone chips replaced by BC exhibited around 4.6% higher strength than that of NC-control samples. In case of OLWP samples with 10% replacement; around 2.6% higher strength was found as compared to NC-control samples. For 20% replacement of OLWP samples, around 7.7% increase in strength was observed. For all other cases of internally cured samples, less compressive strength was observed in comparison with NC-control samples. However, in all instances, internally cured samples yielded higher strength than that of control samples when subjected to similar curing conditions except NC.

Table 3. Percent Increase in Compressive Strength Due to Internal Curing in Comparison with Control Samples under Normal Curing

Percent increase or decrease in strength				
W/C 0.4	ILWP	ILWOP	OLWP	OLWOP
10%	-3.8	-9.9	2.6	-12.8
20%	4.6	-2.8	7.7	-7.9
30%	-8.9	-13.0	-4.6	-14.3

4.2 Water Permeability Test Results

Water permeability test results of both control and internally cured samples with respect to water cement ratio under different curing conditions are shown in Figs. 4 through 7. Samples designated as 0% replacement in the graphs represent control samples kept under similar simulated curing condition of internally cured samples. It is observed that water permeability increases with water cement ratio in all cases. Such behavior was expected since a lower water cement ratio generally yields high performance concrete (Philleo, 1991). However, internally cured samples with higher water cement ratio showed relative rapid increase in permeability as compared to NC-control samples. It is also found that control samples under NC condition exhibited less permeability than internally cured samples. On contrary, control samples under similar simulated curing condition showed considerable poor performance. It is, therefore, obvious that high permeable concrete is likely to be produced in the absence of proper external curing mechanism. Fig. 8 shows a comparison between water permeability of internally cured samples having different percent of partial replacement and water cement ratio of 0.40. A particular trend can be observed from Fig. 8. In all cases of internally cured samples, 20% replacement produced the least permeable concrete for a given water cement ratio. Moreover, internally cured samples under OLWP condition performed best among all simulated curing conditions and exhibited similar permeability as compared to NC-control samples. In OLWP condition, samples were subjected to relatively higher temperature which was beneficial for proper hydration of cement. It is also observed that covering samples with polythene sheet resulted in less permeability. This is due to the fact that such covering ensures prevention of water loss through concrete surface by evaporation. Such improvement in permeability reflects that

Table 4. Percent Decrease in Water Permeability Due to Internal Curing

Percent reduction in water permeability				
W/C 0.4	ILWP	ILWOP	OLWP	OLWOP
10%	58.5	70.0	74.7	63.5
20%	74.9	79.9	83.1	76.8
30%	57.6	66.8	71.8	57.7

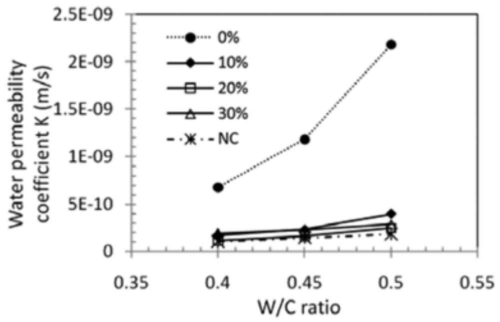

Fig. 4. Water Permeability of Internally Cured Samples Under ILWP Condition and Control Samples Under both ILWP and NC with Respect to w/c Ratio

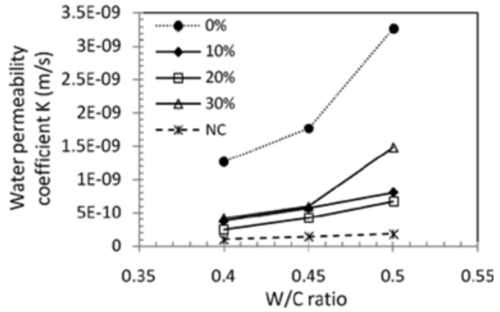

Fig. 5. Water Permeability of Internally Cured Samples Under ILWOP Condition and Control Samples Under Both ILWOP and NC with Respect to w/c Ratio

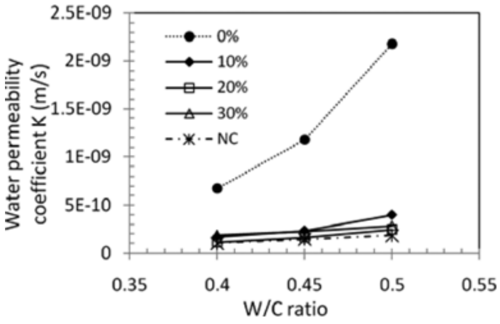

Fig. 6. Water Permeability of Internally Cured Samples Under OLWP Condition and Control Samples Under Both OLWP and NC with Respect to w/c Ratio

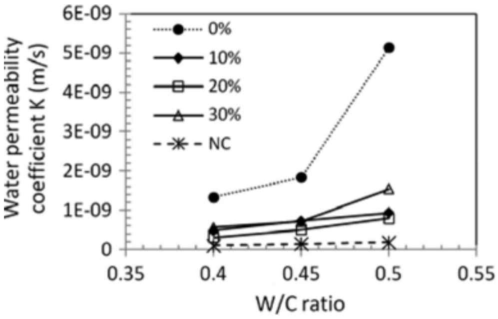

Fig. 7. Water Permeability of Internally Cured Samples Under OLWOP Condition and Control Samples Under Both OLWOP and NC with Respect to w/c Ratio

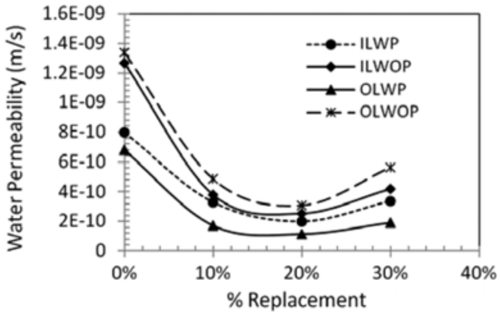

Fig. 8. Variation in Water Permeability with Respect to Percent Replacement for Both Internally Cured and Control Samples Under Different Curing Conditions

effective internal curing can be achieved by using BC as internal curing medium. Table 4 shows the percent reduction in water permeability of the internally cured samples with respect to control samples under similar curing condition except NC. It is observed that for samples under OLWP condition, 20% partial replacement achieved about 83% less permeability than that of control samples.

4.3 Chloride Permeability Test Results

Chloride permeability of control and internally cured samples with respect to water cement ratio are shown in Figs. 9 through 12 for different curing conditions. It is observed that, like water permeability, chloride ingress increases with the increase in water cement ratio for both control and internally cured samples. However, effect of water cement ratio on chloride permeability is found to be more pronounced for internally cured samples than that of NC- control samples. Similar to water permeability, it is noticed that internally cured samples having 20% replacement under OLWP condition performed best in chloride permeability tests among all internally cured samples. Although control samples under NC condition showed the least permeability, these samples (control) exhibited significantly high chloride permeability as compared to internally cured samples when kept under similar simulated curing conditions.

Table 5 shows ranges of chloride permeability as per ASTM C1202 (ASTM C1202, 1997). From Table 5, it can be said that, if more than 4000 coulomb charges pass through a concrete sample, it can be defined as highly permeable concrete. On the other hand, when less than 4000 coulomb charges pass through, moderate chloride permeability is ensured. From Figs. 9 to 12, it is noticed that control samples under NC condition showed

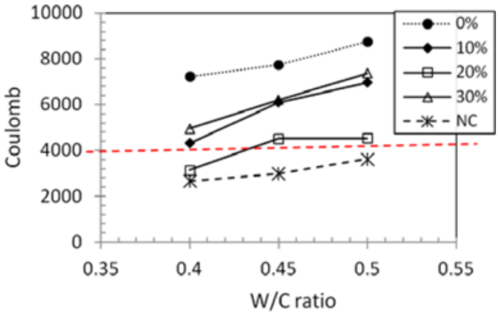

Fig. 9. Chloride Permeability of Internally Cured Samples Under ILWP Condition and Control Samples Under Both ILWP and NC with Respect to w/c Ratio

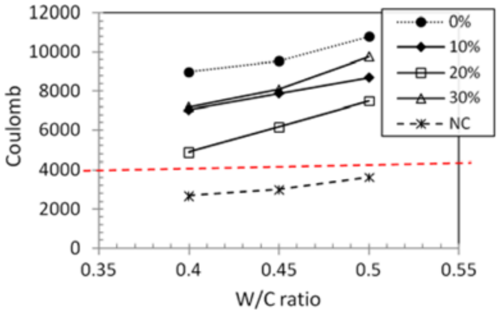

Fig. 10. Chloride Permeability of Internally Cured Samples Under ILWOP Condition and Control Samples Under Both ILWOP and NC with Respect to w/c Ratio

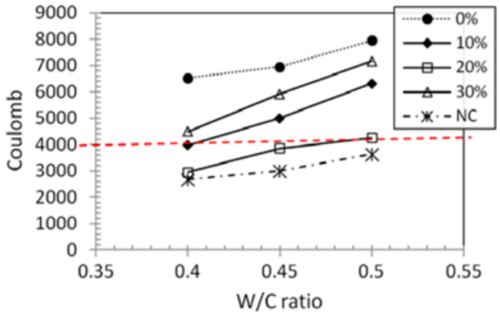

Fig. 11. Chloride Permeability of Internally Cured Samples Under OLWP Condition and cOntrol Samples Under Both OLWP and NC with Respect to w/c Ratio

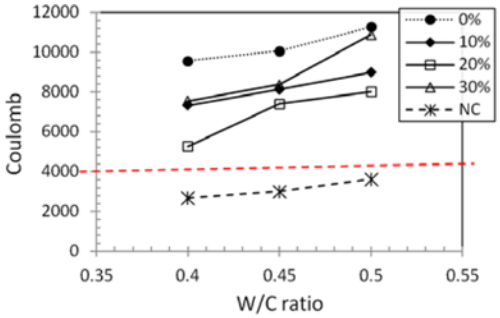

Fig. 12. Chloride Permeability of Internally Cured Samples Under OLWOP Condition and Control Samples Under Both OLWOP and NC with Respect to w/c Ratio

Table 5. Chloride Permeability Based on Charge Passed

Charge Passed (Coulombs)	Chloride Permeability
>4,000	High
2,000-4,000	Moderate
1,000-2,000	Low
100-1,000	Very Low
<100	Negligible

moderate chloride permeability for all water cement ratios considered in the study. It is also observed that internally cured samples under OLWP condition exhibited moderate permeability for all water cement ratios for 20% partial replacement. For OLWP condition, 10% replacement also showed moderate permeability for water cement ratio of 0.40. In case of ILWP, internally cured samples with 20% replacement and water cement ratio of 0.40 fell in to the moderate permeability zone (Fig. 9). Samples without polythene sheet covering resulted in high permeable concrete irrespective of percent replacement and water cement ratio.

Variations in chloride permeability with changes in percent replacement of internally cured samples for different curing conditions are plotted in Fig. 13. In Fig. 13, chloride permeability test results of samples having water cement ratio of 0.40 are shown since mixes with this water cement ratio showed better performance in all cases. An obvious trend, similar to water permeability, is evident which shows 20% replacement is the optimum amount of BC as internal curing medium to produce less permeable concrete. The favorable condition was achieved when samples were kept outside lab and covered with polythene sheets (OLWP curing condition). Relative higher temperature as well as prevention of water evaporation in OLWP condition ensured proper hydration of cement which eventually resulted in concrete with improved durability performance. Numerically, around 50% lower chloride permeability was obtained for internally cured samples having 20% replacement as compared to control samples under OLWP curing condition. These samples (internally cured OLWP samples with 20% replacement) exhibited similar permeability when compared to control samples under NC condition. Also, under OLWP condition, significant reduction in chloride permeability than control samples is observed for internally cured samples having both 10% and 30% partial replacements. Such decrease in permeability, thus, reflects that effective internal curing can be achieved by partial replacement of stone chips with saturated light weight BC if favorable conditions can be maintained. Table 6 provides the percent reduction in chloride permeability of the internally cured samples with respect to control samples under similar curing conditions except NC. From Table 6, it is evident that significant improvement in chloride permeability can be achieved through addition of BC as internal curing medium.

It is obvious that addition of saturated BC as partial replacement of conventional stone chips resulted in better permeability performance in the absence of proper external curing process.

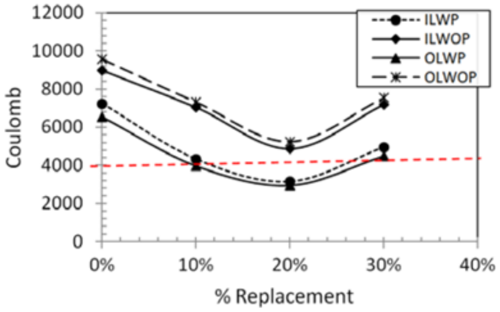

Fig. 13. Variation in Chloride Permeability with Respect to Percent Replacement for Both Internally Cured and Control Samples Under Different Curing Conditions

Table 6. Percent Decrease in Chloride Permeability Due to Internal Curing

Percent reduction in passing Charge				
W/C 0.4	ILWP	ILWOP	OLWP	OLWOP
10%	40.2	21.5	39.0	23.5
20%	56.5	45.7	54.7	45.2
30%	31.5	19.9	31.1	21.1

Conventional concrete, with stone chips as coarse aggregate (termed as control samples in this study), exhibited the lowest permeability under submerged curing condition. However, control samples, placed under simulated curing condition with no external supply of water, showed significantly poor performance. This is due to unavailability of water within the mix that is necessary for proper hydration of cement. BC has the ability to absorb large amount of water during saturation due to their porous structure. Partial replacement of stone chips with saturated BC provides an additional source of water within concrete since BC can desorb sufficient amount of absorbed water at relatively higher temperature and lower humidity conditions (Iffat, 2014). The internal temperature and relative humidity within concrete is conducive for desorption of BC particularly during early age of hydration. It is observed that partial replacement by BC produced relative lower permeable concrete in all cases of simulated curing condition. The primary reason behind such better performance is the desorption capacity of BC that provides additional water to ensure proper hydration. Better hydration causes pore refinement within concrete by producing more silicate hydrates and eventually, produces less permeable concrete. Since, control samples and internally cured samples were placed in identical conditions; it is obvious that presence of saturated BC within internally cured samples was responsible for less permeability of concrete. In general, concrete with only brick aggregates have permeability issues. There are primarily two reasons for such high permeability of brick aggregate concrete. Firstly, water within concrete finds a channel to pass through porous brick aggregate. Secondly, size and shape of brick aggregate are difficult to maintain and presence of long flaky particles results in weaker interfacial transition zone with higher porosity. Hence, amount of BC must be controlled as partial replacement. Otherwise, higher amount of BC will produce weaker concrete. This is also evident from the obtained results as 30% partial replacement exhibited relative higher permeability as compared to other two percent replacements. All internally cured samples under OLWP conditions showed better performance in both permeability tests. This also supports the internal curing ability of saturated BC. Relative higher temperature under OLWP condition accelerated the hydration process and created a favorable internal condition (higher temperature and lower humidity) within concrete for desorption of BC. Moreover, covering of samples in OLWP prevented the evaporation loss and ensured availability of more water for hydration. Control samples under OLWOP condition displayed the worst performance due to high rate of evaporation loss. On the other hand, internally cured samples under this OLWOP condition performed significantly well as compared to control samples and eventually proved the effectiveness of internal curing ability of BC.

5. Conclusions

It is, therefore, evident that saturated BC can be considered as an effective internal curing medium within concrete as partial replacement of conventional stone chips. Internally cured samples, having 20% BC and polythene sheet covering achieved almost similar water and chloride permeability as compared to proper externally cured conventional concrete with no partial replacement. Thus, 20% BC as internal curing medium appears to be an alternative solution to external curing method. In addition, internally cured concrete performed significantly well in the absence of proper external curing mechanism. Therefore, partial replacement of stone chips by BC can be recommended to produce better quality concrete particularly when proper external curing method cannot be ensured. However, water cement ratio is recommended to keep low at around 0.40 for producing low permeable concrete. Also, internally cured concrete should be kept under polythene cover to ensure maximum benefit of internal curing. Utilization of polythene sheets will not pose any difficulty since these sheets are cheap, easily available and require no special equipment for covering. These polythene sheets are reusable too. Such internal curing method does not require any skilled labor or technique. It also has significant environmental impact since this method can lessen the additional water requirement of conventional external curing as well as the demand for natural aggregate to produce concrete. In addition, unit cost of concrete is reduced since BC is cheaper. So, production of internally cured concrete using BC can be considered as a cost effective technique for producing durable concrete for a developing country like Bangladesh.

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