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Relation between Properties of Internally Cured Concrete and Water Cement Ratio

T. Manzur, S. Iffat, M. A. Noor

***Abstract*—**In this paper, relationship between different properties of IC concrete and water cement ratio, obtained from a comprehensive experiment conducted on IC using local materials (Burnt clay chips- BC) is presented. In addition, saturated SAP was used as an IC material in some cases. Relationships have been developed through regression analysis. The focus of this analysis is on developing relationship between a dependent variable and an independent variable. Different percent replacements of BC and water cement ratios were used. Compressive strength, modulus of elasticity, water permeability and chloride permeability were tested and variations of these parameters were analyzed with respect to water cement ratio.

***Keywords*—**Compressive strength, concrete, curing, lightweight, aggregate, superabsorbent polymer, internal curing.

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I. Introduction

COMPRESSIVE strength of concrete is the most common performance assessment criteria used by civil engineers all over the world. Such strength test results are used for quality control and acceptance of concreting work [1]. Properties of concrete depend on proper hydration of cement. Adequate amount of water is required to ensure proper hydration process. This water is usually provided during mixing of concrete ingredients. A substantial portion of mixing water evaporates from concrete resulting in poor concrete quality. Generally, extra water is supplied from outside to counter act such loss of water. This process is commonly known as curing process. However, in many developing or underdeveloped countries, proper curing process is often not ensured due to lack of awareness and proper knowledge. As a result, hydration of cement is hindered and quality of concrete suffers. In such situation, Internal Curing (IC) can be adopted. IC refers to the process by which the hydration of cement occurs because of the availability of additional internal water, which is not part of the initial mixing water [2]. Internal curing of concrete is usually done in two ways; by using Light Weight Aggregates (LWA) or by using super absorbent polymers (SAP). Porous LWA absorbs sufficient amount of water during mixing which can be supplied within concrete mix under favorable temperature and relative humidity. This process of realizing absorbed water is termed as desorption process [3]-[5]. Nevertheless, high strengths are usually not achieved from LWA concrete due to high porosity and lower density. Therefore, partial replacement of conventional coarse aggregate with LWA can be considered as an effective solution. In Bangladesh, use of burnt clay chips (BC) in construction work as coarse aggregate is very common. BC is used due to their availability and relative low cost as compared to stone chips. Moreover, BC is porous and lightweight and has the ability to absorb and desorb water under favorable condition. Hence, IC using BC can be very effective in Bangladesh. In this study, BC has been used as percent replacement of stone chips in concrete to produce internally cured concrete. In addition, SAP is used as IC material in some cases. This paper presents the relationship between compressive strength, modulus of elasticity, water and chloride permeability with water cement ratio for IC concrete. Generally harden concrete is characterized by its compressive strength and density [6]. Modulus of elasticity is the capability of concrete to deform elastically, defined as the slope of axial stress-strain diagram [7]. Durability of concrete is its ability to resist weathering action, chemical attack, abrasion, or any process of deterioration. Durability is related to its permeability. Permeability dictates the rate at which aggressive agents can penetrate to attack the concrete and its embedded steel [8]. Prediction of concrete behavior is considered as one of the most active areas of research. Many studies on predicting behavior of normal concrete are found [9], [10]. However, no authentic study has been found on predicting behavior of IC concrete. Therefore, this paper will assist concrete researchers to predict behavior of IC concrete and conduct further study in this field.

Relationships developed in this study are based on the simplest linear model. This model involves only one independent variable and the true mean of the dependent variable changes at a constant rate as the value of the independent variable increases or decreases [11]. Thus, the functional relationship between the true mean of Yi, denoted by $\sum Yi$, and Xi is the equation of a straight line:

$$\sum Yi = \alpha + \beta Xi \quad (1)$$

α is the intercept in (1), the value of $\sum Yi$ when $X = 0$, and β is the slope of the line, the rate of change in $\sum Yi$ per unit change in X.

II. Research Significance

Simplified relation between water cement ratio and compressive strength, water cement ratio and water permeability, water cement ratio and chloride permeability

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and compressive strength and modulus of elasticity has been developed for internally cured concrete. In this experiment 10%, 20% and 30% stone chips were replaced by BC. Three water cement ratios of 0.4, 0.45 and 0.5 were selected. From these relations, properties of concrete can be easily determined for a given mix proportion and water cement ratio.

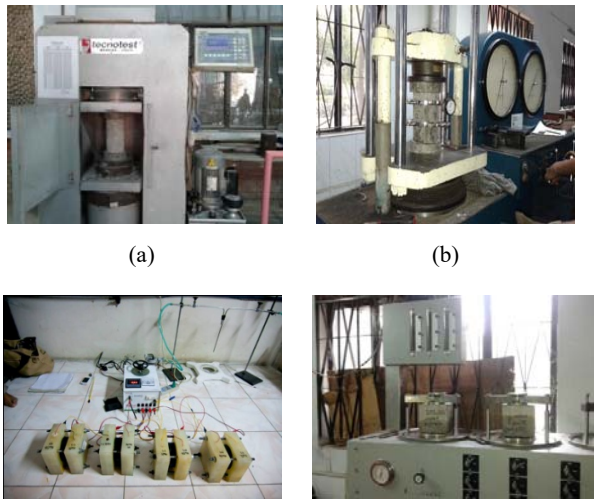
III. Experimental Program

All necessary properties of the ingredients were tested in laboratory. In order to determine gradation of aggregate, sieve analysis was conducted according to ASTM C136 method [12]. Bulk specific gravity and absorption capacity of aggregates was obtained according to ASTM C128 [13], unit weight were found using ASTM C29 [14]. The normal consistency of the cement was measured as per ASTM C187 [15]. The initial setting time and compressive strength of cement mortar were determined according to ASTM C191 [16] and ASTM C109 - 13 [17] respectively. The material properties are shown in Table I.

TABLE I
Material Properties Test Results

Test title	Results	Units
Normal Consistency of Cement	27.5	Percentage
Initial setting time of Cement	3.00	Hours
28 day Compressive strength of mortar	29.3	MPa
Unit Weight of SC	1560	kg/m^3
Bulk Specific Gravity of SC (OD)	2.646	----
Absorption Capacity of SC	0.6	%
Unit Weight of Sand	1570	kg/m^3
Bulk Specific Gravity of Sand (SSD)	2.632	----
Absorption Capacity of Sand	1.1	%
Unit Weight of BC	1010	kg/m^3
Bulk Specific Gravity of BC (OD)	1.693	----
Absorption Capacity of BC	25.7	%
Absorption Capacity of SAP	100	%

Total twelve mixes were prepared for the experiment. Nine mixes were made with three replacement levels (10%, 20% and 30% stone chips replacement with BC) and three water cement ratios (0.4, 0.45 and 0.5). Three mixes were also made using SAP as an IC material with stone chips as coarse aggregate. Sodium Poly-acrylate (from diapers) was used as SAP. The dosage was kept as 1.25 gm per kg of cement. Also super plasticizer (1% of cement weight) was used in these mixes containing SAP. The super plasticizer was used to increase workability of polymer used concrete mix. Cylindrical concrete samples of 100mm by 200mm and cubes of 150mm in size were made and kept at natural environment under polythene cover for natural curing up to 28 days. Compressive strength tests [18], modulus of elasticity [19] and chloride permeability [20] were done on cylindrical concrete specimens according to ASTM standards. Water permeability test was performed on cube specimens according to British standard [21], [22]. Relevant images of the experiment are shown in Fig. 1.



(a) (b) (c) (d)

Fig. 1 Images of the experiment (a) compressive strength tests (b) modulus of elasticity test (c) chloride permeability test (d) water permeability test

IV. Results and Analysis

Relationship between compressive strength and water cement ratio, modulus of elasticity, compressive strength, chloride permeability and water cement ratio, and water permeability and water cement ratio have been developed for different replacement [23]. These relations were developed for 28 days internally cured concrete specimens.

Fig. 2 shows the best-fit lines for the compressive strength obtained from mixes having different water cement ratio and different percent replacement of stone chips with BC and SAP. From this figure, following relationships have been determined. Here fc' is compressive strength of concrete in MPa and W/C is water cement ratio. Linear relationship is observed between strength and water cement ratio.

i. $fc' = -55(W/C) + 51.5$ [20% replacement]
ii. $fc' = -58(W/C) + 51$ [10% replacement]
iii. $fc' = -53(W/C) + 47.5$ [30% replacement]
iv. $fc' = -83(W/C) + 57.5$ [Using SAP]

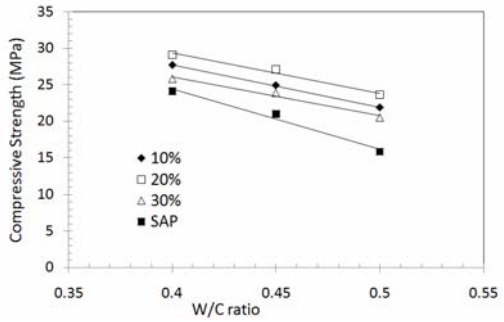


Fig. 2 Effect of water cement ratio on compressive strength

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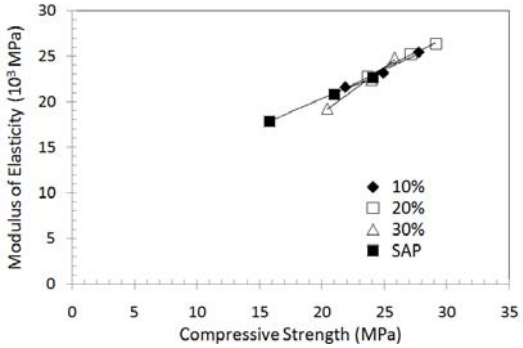


Fig. 3 Effect of compressive strength on modulus of elasticity

Fig. 3 shows the best-fit curve for modulus of elasticity and compressive strength for mixes with different percent replacement and SAP. From this figure following relationships have been developed. Here MOE is Modulus of elasticity in MPa and fc' is compressive strength of concrete in MPa.

i. $MOE = 4890\sqrt{(fc')}$ [20% replacement]
ii. $MOE = 4850\sqrt{(fc')}$ [10% replacement]
iii. $MOE = 4800\sqrt{(fc')}$ [30% replacement]
iv. $MOE = 4620\sqrt{(fc')}$ [Using SAP]

Fig. 4 represents the best-fit curve for chloride permeability with respect to water cement ratio for different percent replacement and SAP. From this figure, following relationships were determined. Here C is total charge in Coulomb and W/C is water cement ratio.

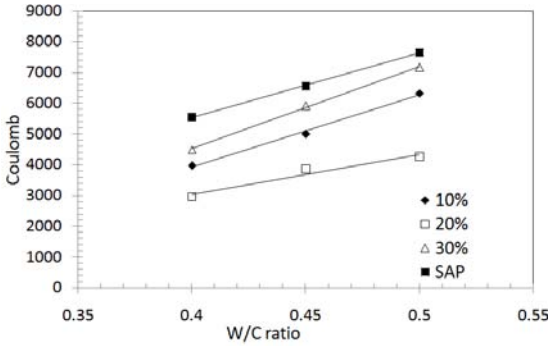


Fig. 4 Effect of water cement ratio on chloride permeability

i. $C = 12990\,(W/C) - 2150$ [20% replacement]
ii. $C = 23470\,(W/C) - 5450$ [10% replacement]
iii. $C = 26650(W/C) - 6130$ [30% replacement]
iv. $C = 21000\,(W/C) - 2860$ [Using SAP]

From Fig. 5 following relationships have been determined between water permeability and water cement ratio. Here K is water permeability constant of concrete in meter/second and W/C is water cement ratio.

i. K=1E^{-9} (W/C)-4E^{-10} [20% replacement]
ii. K=2E^{-9} (W/C)-8E^{-10} [10% replacement]
iii. K=1E^{-9} (W/C)-2E^{-10} [30% replacement]
iv. K=1E^{-8} (W/C)-4E^{-9} [Using SAP]

A trend is evident from all developed relations that maximum strength and minimum durability can be achieved if the percent replacement lies between 10% and 30%. It is also observed that utilization of SAP as IC resulted in lowest strength, and modulus and higher chloride and water permeability.

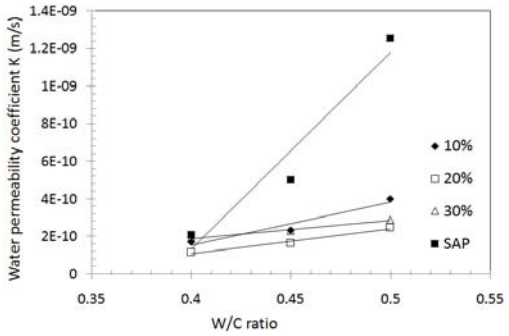


Fig. 5 Effect of water cement ratio on water permeability

V. Conclusion

In this study, relations between water cement ratio and properties of internally cured concrete are developed. For given water cement ratio, compressive strength, chloride permeability and water permeability of IC concrete can easily be determined for 10%, 20% and 30% partial replacement of stone chips with BC. In addition, elastic modulus of internally cured concrete can be found for a particular compressive strength and partial replacement levels of 10, 20 and 30%. Besides these above mentioned replacement levels, IC concrete properties for other replacement levels between 10 and 30% can also be predicted. Parallel lines can be drawn in between the given curves or straight lines of 10%, 20% and 30% replacements for a proposed percent replacement level. From these parallel lines, compressive strength, modulus of elasticity, chloride permeability and water permeability can easily be determined for any percent replacement within 10%-30%. A particular trend is also evident for both strength and permeability. Both strength and durability increases with percent replacement of stone with BC. However, after certain level of substitution, strength and durability start to decrease. So, less than 10% or more than 30% replacement by BC can be considered as not necessary for internally cured concrete. Also from the equations of SAP, expected results of strength and durability can be calculated for any water cement ratio.

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