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Relation Between Density and Compressive Strength of Hardened Concrete

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Abstract

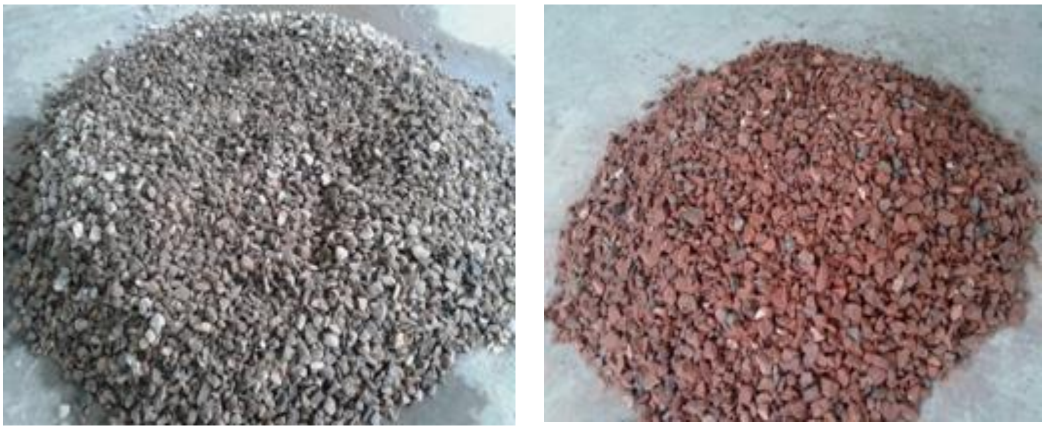
Concrete must has to ensure satisfactory compressive strength and durability. The mechanical properties of concrete are highly influenced by its density. A denser concrete generally provides higher strength and fewer amount of voids and porosity. Smaller the voids in concrete, it becomes less permeable to water and soluble elements. So water absorption will also be less and better durability is expected from this type of concrete. In this paper an experimental program conducting on compressive strength, density, absorption capacity and percent voids of hardened concrete is described. The variation of these properties with maturity of concrete was main focus of this experiment. Comparison is made between two types of concrete's property test results. One of them is lightweight concrete made with crushed brick (BC) as primary coarse aggregate. Crushed brick is a locally available construction material in Indian subcontinent. Another type of concrete is a denser one, made with crushed stone (SC) as primary coarse aggregate. The comparisons on test results are presented with respect to time. It was observed from the experiment that, strength and density increases with maturity of concrete and percent void and absorption capacity decreases with time. Better results were obtained from stone aggregate concrete than brick aggregate concrete in cases of all of the tests.

Keywords: Concrete; density; absorption; void; compressive strength.

1. Introduction

Concrete is a non-natural conglomerate stone made essentially of Portland cement, water, and aggregate. Cement enhances the binding property of concrete. A chemical reaction called hydration takes place between the water and cement, and concrete normally changes from a plastic to a solid state [1]. The density and compressive strength of concrete cement paste are affected by several parameters like water cementitious materials ratio, supplementary cementitious materials, use of admixture, curing, cement type, etc [2]. Curing is the procedure to endorse hydration of cement, and consists of a control of temperature and moisture movement from and into the concrete [3]. Proper curing application has significant impact on density and compressive strength of concrete [4]. The water-cement ratio (W/C) is defined as the proportion by mass of free water to cementitious material in a concrete mix [5]. Structural lightweight concrete is defined as structural concrete made with low-density aggregate that has an air-dry density of not more than 1840 kg/m^3 and a 28-day compressive strength of around 17.25 MPa [6]. Generally, lightweight aggregate concrete absorbs more impact energy than normal weight concrete [7]. The density of normal weight concrete lies within the range of 2,200 to 2,600 Kg/m^3 [8]. The primary purpose of lightweight concrete is to reduce the dead load of a concrete structure [9]. Also, this type of concrete is used to improve buoyancy of the structures [10]. But introducing lightweight aggregate in concrete construction often results poor strength and durability performance of concrete, if proper quality control protocol is not maintained. So, instead of using lightweight aggregate, air entraining admixture can be used to reduce density of concrete [11].

The optimization of concrete density to improve structural efficiency (the strength to density ratio), reduce transportation costs, and also enhance the hydration is accomplished by replacing part of the normal-density aggregates (coarse aggregate, fine aggregate, or both) with comparable amounts of low-density aggregate [12]. Using this approach, concrete densities from 1,842 to 2,370 kg/m^3 can be produced to meet specific project requirements [12]. The uncertainties associated with the parameters affecting the density and compressive strength of cement paste makes it difficult to exactly estimate such properties [13, 14]. Also, no definite conclusion can be drawn in terms of the effect of the density and surface texture of lightweight aggregate on the durability of concrete [15]. Through hydration process, concrete gains strength, become denser and loses its porosity. In this paper, influence of time on concrete's compressive strength, density, voids and absorption capacity are discussed.



(a) (b)

Figure 1. (a) Crushed Stone (SC) (b) Crushed Brick (BC)

2. Concrete preparation

Mix proportion of cement, fine aggregate and coarse aggregate was kept as 1:1.5:3 (Volume basis) in this study. Water cement ratio was kept constant as 0.45. Two types of mix designs were conducted. One of them was prepared with 3/4 inch downgraded crushed stone and 1/2 inch downgraded crushed stone (Figure 1 (a)) were mixed together in a ratio of 1:1 and used as coarse aggregate. Sylhet sand was used as fine aggregate. OPC (Ordinary Portland Cement) was used as binding material in this experiment. Similar type of another mix design was made with crushed brick (Figure 1(b)) as coarse aggregate. Similar to stone aggregate, the ratio of 3/4 inch downgraded crushed brick to 1/2 inch downgraded crushed brick was kept also as 1:1. All necessary properties of the ingredients were tested in laboratory. Gradation test of aggregate was conducted according to ASTM C136 method [16]. Bulk specific gravity and absorption capacity of aggregates was obtained according to ASTM C128 [17], density were found using ASTM C29 [18]. From aggregate density test results shown in Table 1, it can say that, SC is denser than BC. Total 72 cylindrical (100mmx200mm) concrete specimens were prepared for 21, 24, 28, 29, 30, 32, 34, 36, 40, 42, 45 and 56 day test. 36 of these 72 cylinders were made for density test and rest 36 cylinders were prepared for compressive strength test. All samples kept fully submerged under saturated lime water up to 28 days to ensure curing.

TABLE1: COARSE AGGREGATE'S DENSITY TEST RESULTS

Aggregate	Dry loose weight (kg/m^3)	Dry rodded unit weight (kg/m^3)
SC	1460	1590
BC	980	1170

3. Density test

After 28 days curing, one set (3 cylinders) of concrete specimen were taken out from storage for density test according to ASTM C 642 [19], for testing at particular day. These specimens were turned to SSD (Saturated Surface Dry) condition by removing water from the surfaces. Then SSD weight of samples in air (C) was measured. Next the specimens were placed in oven at a temperature of 100 to 110°C for 24 h. After that weight of the specimen was measured. This is oven dry weight of samples in air (A). After that, the specimens were placed under water in a bucket and weight under water (D) was obtained. Temperature of water at test day (T) was also recorded and water density (ρ) was calculated for that temperature. Then from "Equation 1", density of concrete was calculated. Density test results are shown in Figure 2. From this test results, it can easily be said that density increases with days. But rate of density change is low. Concrete with SC shows more density values than concrete with BC.

$$\text{Dry density (bulk density), } g_1 = A\rho/(C-D) \qquad (1)$$

Here,

A= mass of oven-dried sample in air, (gram)
C= mass of saturated surface-dry sample in air, (gram)
D= mass of sample in water after immersion, (gram)
ρ=density of water at T^{0}C (kg/m^3)

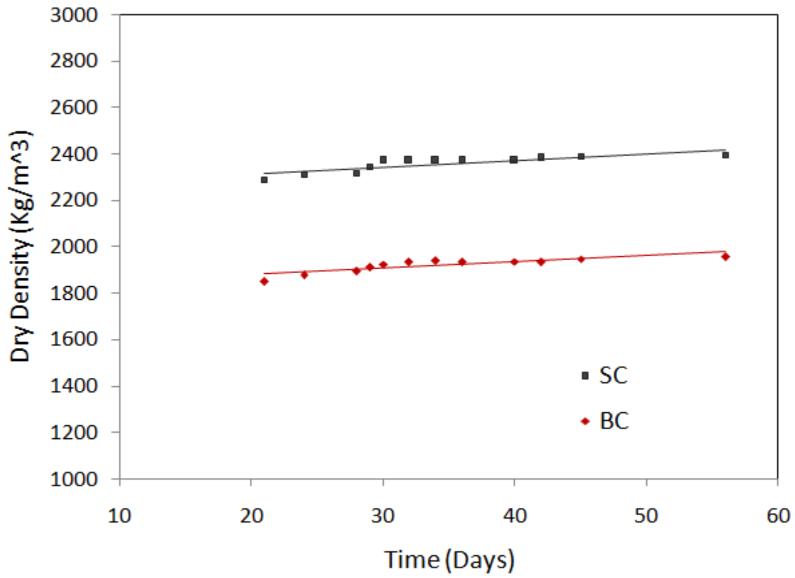


Figure 2. Effect of time on dry density of concrete

4. Absorption capacity and percent void test

Absorption capacity of concrete was estimated according to ASTM C 642 [19]. In order to determine absorption capacity of hardened concrete, data obtained from density test were used.

"Equation 2" was used to evaluate absorption capacity of concrete. The absorption test results are shown in Figure 3. From Figure 3, it is observed that, absorption capacity decreases with time. BC concrete absorbs more water than SC concrete. As the experiment was performed of hardened concrete, so less water absorption is experienced in cases of brick concrete. Otherwise higher rate of water absorption would be found. $100(C-A)/A$ Hydration in concrete occurs mainly within first seven days, and water absorption capacity and permeability of concrete start to reduce after that time.

Absorption Capacity= ……..……………………………… (2)

Percent void in concrete was calculated according to ASTM C642 [19]. In order to determine void% of hardened concrete, also data obtained from density test were used. "Equation 3 and 4" were used to evaluate void% remained in concrete. The void test results are shown in Figure 4. From this test results, it is found that, percent void in concrete reduces with time. Similar to absorption capacity test of concrete, fewer amounts of voids were found in cases of SC concrete than BC concrete.

Apparent density, $g_2= A/(A-D)$……….……………………………… (3)

Volume of permeable pore space, %voids= $100\ (g_2 - g_1)/g_2$……………… (4)

Abbreviations of A, C and D are mentioned in previous sections.

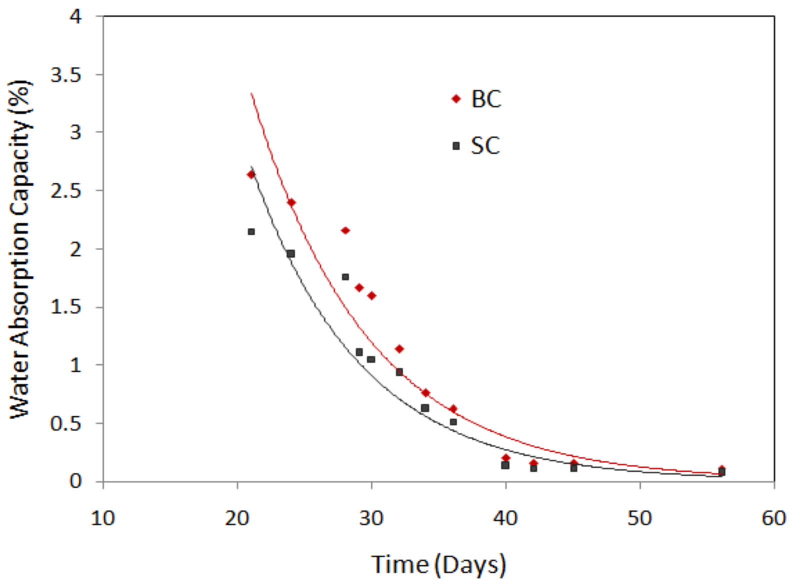


Figure 3. Effect of time on absorption capacity of concrete

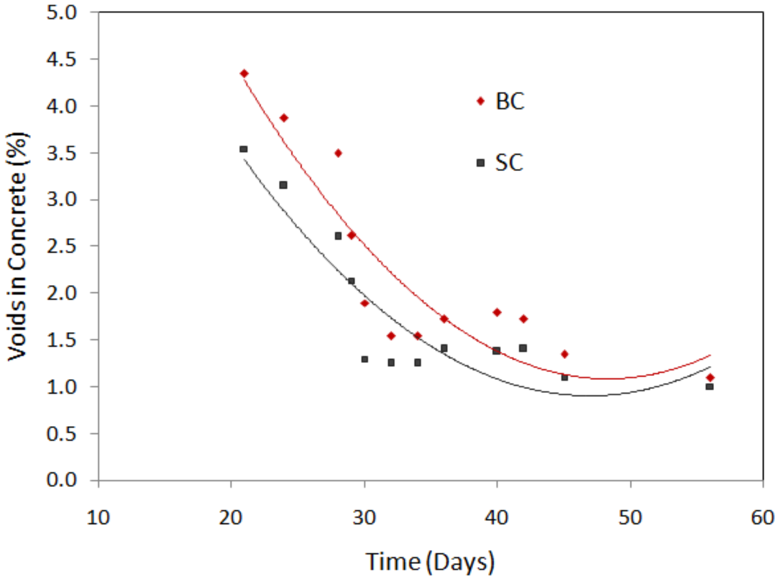


Figure 4. Effect of time on percent void remained in concrete

5. Compressive strength test

Similar to density test, after 28 days curing, one set (3 cylinders) of concrete specimen were made ready for compressive strength test at required age according to ASTM C 39 [20]. The diameters of the cylinders were measured and cross-sectional areas were estimated according to ASTM C 39. Universal testing machine was used to apply compressive load on specimens at a required loading rate. The cylinders were placed within the bearing blocks, the axis of the specimens were aligned properly and compression was applied. The compressive strength of the specimen was calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen. Compressive strength test results are shown in Figure 5. Compressive strength increases with days. More compressive strength is found from SC concrete than BC concrete. When compressive loading is applied to BC concrete, mortar and aggregate fails together. As brick aggregate has lower compressive strength than stone, brick start to fail earlier than similar type of SC aggregate concrete. So, compressive strength of BC concrete is also found much lower than SC concrete.

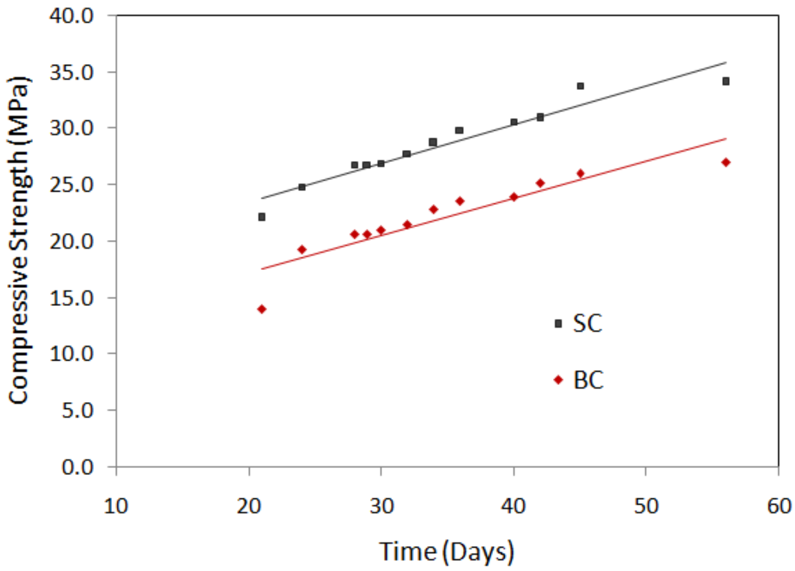


Figure 5. Effect of time on compressive strength of concrete

6. Supplementary findings

From this experiment, relationship between density of concrete and compressive strength has been developed for both SC and BC concrete. Figure 6 demonstrates the best fit lines for the density obtained from samples showing different compressive strength. From this figure following relationships have been determined. Relation between compressive strength and density for SC concrete and BC concrete are shown through "Equation 5" and "Equation 6", respectively. Here, "D_s" is density of SC concrete in kg/m^{3}and "C_s" is compressive strength of SC concrete in MPa. Similarly, "D_b" is density of BC concrete in kg/m^3 and "C_b" is compressive strength of BC concrete in MPa. Linear relationship is observed between strength and density. From these relationships, concrete density can be predicted for a particular compressive strength though density test could not be performed.

$$D_s = 8.6C_s + 2110 \quad (5)$$
$$D_b = 8.2C_b + 1740 \quad (6)$$

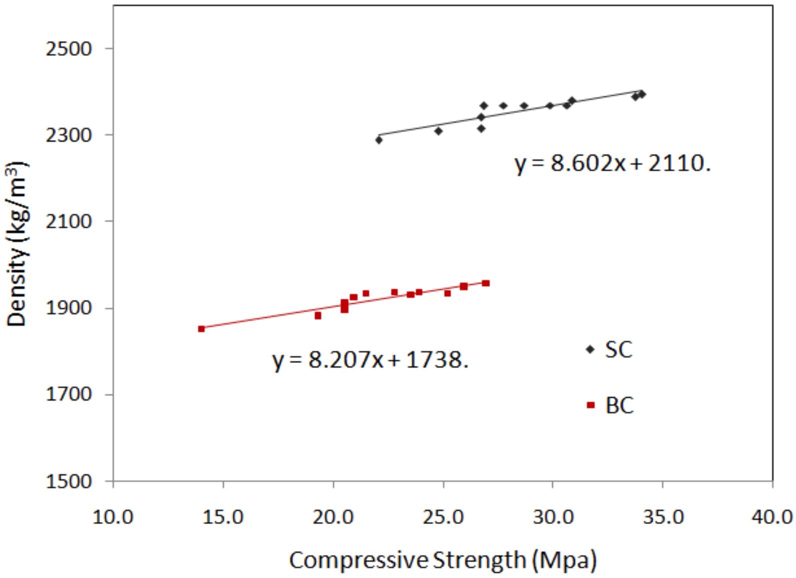


Figure 6. Effect of compressive strength on density of concrete

Value of coefficient of determination (R^2) for SC concrete is found from "Equation 5" as 0.8 and for BC concrete is found from "Equation 6" as 0.9. However, more samples are needed for the experiment to get more perfect analysis results. Better correlation between density and compressive strength is expected if more experiments are conducted.

7. Recommendations

It is necessary to ensure the hydration process through proper application of curing methods, adequate quality control measures and also maintenance of structure. Locally used brick aggregate concrete yields low strength and poor durability performance than stone aggregate. So, it is wiser to mix up BC with SC to achieve a better performance. Also, in cases of using BC, silica fume, fly ash or other supplementary cementitious material should be used with OPC in order to obtain satisfactory performances.

8. Conclusions

It is important to ensure structural safety through utilizing proper construction materials. Among these materials, concrete is a promising one. Concrete must have to guarantee adequate compressive strength, density, a minimum percent of void and minimum water absorption through the surface. Adequate strength and density is required to sustain a certain loading. Minimum void and absorption capacity reduce water permeability of concrete. From this experiment it is observed that, compressive strength and density increases with time and void and absorption capacity reduces with time. Mainly hydration process leads to strength gaining and attaining a certain level of durability. Concrete with SC yielded more compressive strength and density than concrete with BC. Also, it is observed that BC concrete is more permeable (having more amount of voids) than SC concrete. From this experiment results, density of concrete can easily be predicted through “Equation 5” and “Equation 6” if density test could not be performed.

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