Water Permeability Properties of Concrete made from Recycled Brick Concrete as Coarse Aggregate

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Abstract. Water Permeability characteristic of concrete made from recycled brick concrete as coarse aggregate was investigated and compared with concrete made from crushed virgin clay brick and natural stone aggregate. For this, concrete samples of three different compressive strengths 17.2, 20.6 and 24.1 MPa were prepared as per ACI mix design methods from each of these aggregates. These concrete samples were then tested for compressive strength and water permeability using the AT 315 machine as per BS EN 12390-8: “Depth of Penetration of Water under Pressure”. Apart from these, porosity and bulk density were also measured in hardened concrete. Compressive strength of concrete produced from virgin brick and recycled brick concrete was found to be lower than the design strength at 28th day. Coefficient of water permeability of concrete made from recycled brick concrete as coarse aggregate was found to be higher than that of virgin brick and natural stone aggregate concrete of equivalent strength by 350 to 400%. Water permeability was found to be directly related to compressive strength and porosity in hardened concrete.

1. Introduction
Concrete is the principal ingredient in rapidly expanding construction industry of Bangladesh. As there are no major source, natural stone is in short supply and hence expensive in Bangladesh and parts of India. Hence, crushed burnt clay bricks are extensively used as an economic alternative coarse aggregate in construction of midrise residential and factory buildings, rigid pavements as well as small and medium span bridges and culverts [1]. In recent years, many old buildings mainly constructed from brick aggregate concrete are demolished to give away space for new construction. Disposal of demolition waste from these brick aggregate concrete buildings has become a big problem for construction industry. As a consequence, a number of researches are going on examining potential use of recycled brick concrete as coarse aggregate in new concrete production [2]. The durability properties like water permeability, creep and shrinkage has always been a concern for virgin brick aggregate concrete (VBAC) and recycled brick concrete aggregate concrete (RBCAC) [2]. Water permeability is an important parameter regarding durability of concrete. For VBAC and RBCAC, this is even more important issue as both of these aggregates are far more porous and hence permeable than granite and other natural stone aggregate [3-4]. There are a number of works that have been reported till today on durability properties of VBAC and RBCAC [1-8]. Recently, permeability of VBAC has been extensively examined [9]. However, RBCAC is different from VBAC due to presence of micro cracks in recycled brick concrete aggregate and high porosity resulting from those cracks. Recycled aggregate are found to be softer compared to its virgin form. Hence, this is understandable that
water permeability would be different in RBCAC than VBAC or natural stone aggregate concrete (SAC). To get comprehensive idea regarding water permeability of RBCAC, an experimental program was conducted at Bangladesh University of Engineering and Technology, Dhaka, Bangladesh. In that project, comparative water permeability behavior of SAC, VBAC and RBCAC were evaluated. For these, concrete samples of three different strength i.e. 17.2 (2500 psi), 20.6 (3000 psi) and 24.1 (3500 psi) MPa were prepared using natural stone, crushed virgin clay brick and recycled brick concrete aggregate. These samples were then subjected to water permeability testing using European standard AT 315 machine as per BS EN 12390-8: “Depth of Penetration of Water under Pressure” [10]. Test results were analyzed to examine the difference in water permeability associated with VBAC and RBCAC. Moreover, compressive strength, porosity and bulk density in hardened concrete were also measured. Influence of these properties on water permeability behavior of corresponding concrete was also investigated.

2. Material Used

2.1 Cement.
Ordinary Portland cement (Type 1) having 28 days compressive strength of 44 MPa as per ASTM C 150 [11] was used for preparation of all concrete samples. By using one type of cement the effect of varying the types of coarse aggregate in concrete was investigated.

2.2 Fine Aggregate.
For maintaining uniformity, one type of natural coarse sand was used throughout the experimental work. Sieve analysis of fine aggregate was carried out in accordance to ASTM C136 [12]. The resulting gradation curve of sand was found to fit within the limits set out in ASTM C33 [13]. Unit weight of fine aggregates was also determined in accordance with ASTM C29 [14] whereas water absorption and specific gravity of fine aggregate was found in accordance with ASTM C128 [15]. From these testing procedures, Fineness Modulus, unit weight, water absorption and specific gravity of fine aggregate were found as 2.55, 1640 Kg/m3, 1.23% and 2.69, respectively.

2.3 Recycled Brick Concrete Aggregate.
In this work, brick aggregate concrete from a recently demolished building was collected. From the collected concrete chunks, cores were extracted and later tested for compressive strength using universal testing machine to assess the quality of brick aggregate concrete. The average recycled concrete core compressive strength was found to be 16.1 MPa. Afterwards, brick concrete chunks were broken by manual labor into small pieces to produce recycled brick concrete aggregate. This sizing of recycled brick was done in a way so that grading limits set out in ASTM C33 [13] could be maintained. Before preparing concrete, different relevant properties of aggregate were measured. This includes bulk density as per ASTM C29 [14], fineness modulus as per ASTM C33 [13], absorption capacity, specific gravity at saturated surface dry (SSD) condition as per ASTM C127 [16] and field moisture content as per ASTM C566 [17]. Test results are reported in Table 1.

2.4 Clay Bricks and stone aggregate.
Virgin Bricks were collected from a brick manufacturing factory located in Dhaka region. Before these bricks were crushed down to aggregate, compressive (crushing) strength test was conducted according to ASTM C 67 [18]. Results of this test show that crushing strength of brick varied between 14 to 29 MPa. Brick aggregate was produced by breaking down whole new bricks on a solid concrete surface using a hammer. Natural sandstone boulders crushed by a stone crusher were used as stone aggregate. Size of both brick and natural stone aggregate were maintained in such a way that that grading limits set out in ASTM C33 [13] was strictly maintained. All relevant properties of brick and natural stone aggregate that include bulk density, fineness modulus, absorption capacity, specific gravity and field moisture content were measured as per relevant ASTM standards and are reported in Table 1. As can be seen from Table 1, absorption capacity of virgin brick and recycled brick concrete aggregate are much higher than natural
stone aggregate concrete. Specific gravity at SSD condition for natural stone aggregate is also approximately 20 to 22% higher than brick and recycled brick concrete aggregate.

### 3. Testing Scheme

#### 3.1 Mix Design and Mixing Method.

A total of nine mix design as per ACI 211 [19] were prepared to conduct the experimental program. Three mixes were made from each of the aggregate type to produce SAC, RBAC and VBAC for target strength of 17.2, 20.6 and 24.1 MPa considering water cement ratio of 0.75, 0.69 and 0.63, respectively. Mix design ratios are shown in Table 2. Since water absorption of virgin brick and recycled brick concrete aggregate was much higher, these aggregates were submerged in water for 48 hour and later wiped to achieve SSD condition prior to adding to the concrete mixture [2, 3, 6]. Otherwise, a large part of water from mix design calculation would had soaked by these aggregates and would not be available to react with cement changing the water cement ratio of the entire mix. This procedure was followed for natural stone aggregate as well. Water absorbed in the aggregate was in addition to the water requirement from mix design calculation as shown in Table 2. For each mix design, nine cylinders (100mm x 200mm) were prepared for compressive strength test at 3, 7 and 28 days. Three cubes (100mm x 100mm x 100mm) were also prepared for each of the mix to measure density, water absorption, and voids in the hardened concrete. Additionally, for each mix design, three cubes (150mm x 150mm x 150mm) were prepared for permeability test.

#### Table 1. Properties of Different Aggregate

| Aggregate Type       | Bulk density (kg/m³) | Fineness Modulus | Specific gravity (SSD) | Absorption capacity (%) | Field Moisture content (%) |
|----------------------|----------------------|-------------------|------------------------|--------------------------|---------------------------|
| Natural Stone        | 1591                 | 7.42              | 2.67                   | 0.5                      | 1.8                       |
| Virgin Brick         | 1115                 | 7.29              | 2.10                   | 8.96                     | 17.96                     |
| Recycled Brick       | 1101                 | 7.25              | 2.04                   | 11.24                    | 17.77                     |

#### Table 2. Concrete Mix Design (Quantity in kg for single batch)

| Strength (MPa) | w/c  | Cement | Coarse Aggregate | Fine Aggregate | Water |
|---------------|------|--------|------------------|----------------|-------|
| Natural Stone | 17.2 | 0.75   | 16.9             | 56.3           | 56.3  | 12.7 |
| 20.6          | 0.69 | 18.5   | 56.3             | 55.0           | 12.7  |
| 24.1          | 0.63 | 20.2   | 56.3             | 53.6           | 12.7  |
| 17.2          | 0.75 | 16.9   | 70.8             | 57.0           | 12.7  |
| Brick         | 20.6 | 0.69   | 18.5             | 70.8           | 55.7  | 12.7 |
| 24.1          | 0.63 | 20.2   | 70.8             | 54.3           | 12.7  |
| Recycled Brick | 17.2 | 0.75   | 16.9             | 56.5           | 54.0  | 12.7 |
| Brick         | 20.6 | 0.69   | 18.5             | 56.5           | 52.7  | 12.7 |
| Concrete      | 24.1 | 0.63   | 20.2             | 56.5           | 51.3  | 12.7 |

#### 3.2 Water Permeability Testing.

European standard AT 315 apparatus was used to determine the water permeability of concrete according to BS EN 12390-8 [10]. The apparatus was connected to a normal air compressor capable of ensuring at least 5 bar compressed air continuously and equipped with dehumidifier and oil filter. Connection then was made to the laboratory water supply and to a drainage system. A specimen was subjected to test when its age was at least 28 days. For testing, the specimen was placed on the apparatus in such a manner that the
water pressure act on the test area which actually is a 75mm diameter area at the center of the bottom surface of the cube sample. Water pressure of \((500 \pm 50)\) kPa for \((72 \pm 2)\) hours was applied on this surface. After the pressure had been applied for the specified time, the specimen was removed from the apparatus. The face on which the water pressure was applied was wiped to remove excess water. The specimen was then split in half, perpendicularly to the face on which the water pressure was applied. As soon as the split face has dried to such an extent that the water penetration front could be clearly seen, maximum depth of penetration under the test area was recorded and measured to the nearest millimeter. Figure 1 shows example of such penetration area and marked penetration front in a brick aggregate concrete sample.

The depth of water penetration inside the specimen can be converted to its equivalent coefficient of water permeability using Valenta’s equation [20]:

\[
k = \frac{e^2}{2ht} v \text{ m/s}
\]

Where, \(e\) = depth of penetration of concrete in meters; \(h\) = hydraulic head in meters; \(t\) = time under pressure in seconds, and \(v\) = the fraction of the volume of concrete occupied by pores. The value \(v\) represents discrete pores, such as air bubbles, which do not become filled with water except under pressure, and can be calculated from the increase in the mass of concrete during the test.

4. Results and Discussion

4.1 Compressive strength of concrete.
Strength of concrete samples were measured through crushing of cylinder specimens using universal testing machine. Figure. 2(a), 2(b) and 2(c) show compressive strength that was observed for three different design strength i.e. 17.2, 20.6 and 24.1 MPa respectively for SAC, VBAC and RBCAC. For all sample type, compressive strength was measured at the age of 3, 7 and 28 days. Observation of Figure. 2(a), (b) and (c) shows that at 28th day, design strength could not be achieved for VBAC and RBCAC. VBAC compressive strength at 28th day was approximately 7% lower the design compressive strength. Whereas, for RBCAC, measured compressive strength at 28th day was found to be approximately 11% lower than the corresponding target strength. This is in accordance to the findings of the previous researchers, where use of brick and recycled aggregate achieved lower compressive strength compared to the target strength [5,6,7]. Additionally, from these results, it apparent that compressive strength of concrete produced using virgin brick aggregate was slightly higher than that of concrete produced using recycled brick concrete as coarse aggregate keeping all other parameters constant. Observation of Figure. 2(a), (b) and (c) also indicate that at early age i.e. 3rd day after casting, VBAC shows slightly higher compressive strength than SAC for 17.2 and 20.6MPa target strength concrete. However, rate of strength gain decreased for VBAC and RBCAC compared.

4.1.1 Porosity, absorption and bulk density of concrete.
Porosity, absorption and bulk density of concrete are important parameters that affect its permeability. For all types of concrete in this work, these parameters were measured as per ASTM 642 [21]. Relationship between design strength and porosity, absorption and bulk density of concrete made from different
aggregates are shown in Figure 3(a), 3(b) and 3(c), respectively. As can be seen from these figures, for equivalent design compressive strength, orosity and water absorption in RBCAC is approximately twice of that found in SAC. VBAC has higher porosity and water absorption than SAC but much lower than RBCAC. Porosity in VBAC was found to be approximately 35% higher than SAC. Bulk density of RBCAC was found to be approximately 15% lower than SAC of corresponding strength. Bulk density of VBAC was found to be slightly higher than RBCAC but much lower than SAC. Both VBAC and RBCAC possess much higher porosity and absorption than SAC.

4.1.2 Coefficient of Permeability for different concrete.
Coefficient of permeability for three different types of concrete was measured as per BS EN 12390-8 [10]. Figure 4(a) shows coefficient of permeability for SAC, VBAC and RBCAC with respect to design strength in concrete. As can be seen from these figures, coefficient of permeability decreased with increase in design strength. For concrete with comparatively lower design strength, i.e. 17.2 MPa, coefficient of permeability in VBAC is approximately twice the value of SAC. For this design strength in RBCAC, coefficient of permeability was even higher and found to be approximately 300% of corresponding value in SAC. However, as design compressive strength was increased from 17.2 to 24.1 MPa, coefficient of permeability in VBAC decreased rapidly and approached a value similar to SAC. Coefficient of permeability in RBCAC also decreased with increased compressive strength but still showed much higher value than VBAC and SAC. Coefficient of permeability in RBCAC was found to be 350 to 400% higher than corresponding SAC of equivalent compressive strength. And, coefficient of permeability was found to be higher than VBAC by approximately 200%. Hence, RBCAC should be used with extreme caution. Figure.

Figure 2 Compressive strength comparisons with the age of concrete for (a) 17.2 MPa (b) 20.6 MPa and (c) 24.1 MPa design strength.

VBAC is approximately twice the value of SAC. For this design strength in RBCAC, coefficient of permeability was even higher and found to be approximately 300% of corresponding value in SAC. However, as design compressive strength was increased from 17.2 to 24.1 MPa, coefficient of permeability in VBAC decreased rapidly and approached a value similar to SAC. Coefficient of permeability in RBCAC also decreased with increased compressive strength but still showed much higher value than VBAC and SAC. Coefficient of permeability in RBCAC was found to be 350 to 400% higher than corresponding SAC of equivalent compressive strength. And, coefficient of permeability was found to be higher than VBAC by approximately 200%. Hence, RBCAC should be used with extreme caution. Figure.
Figure 4(b) shows variation of coefficient of permeability with respect to porosity of concrete. Explicably, increase in porosity of concrete was associated with increased coefficient of permeability.

Figure 3 Relationship between compressive strength and (a) Porosity (b) Absorption and (c) Bulk Density for concrete made from different aggregates

Figure 4 Relationship between Coefficient of Permeability and (a) Design strength (b) Porosity for concrete made from different aggregates

5. Conclusion
Coefficient of permeability for three different types of concrete having three different coarse aggregate, i.e. natural stone, virgin crushed clay brick and recycled brick concrete were measured in this work. For this concrete samples were prepared and different tests were conducted on those samples to measure compressive strength, porosity, water absorption, bulk density and coefficient of permeability. It was found that design compressive strength as per ACI mix design could not be achieved at 28th day for VBAC and RBCAC Porosity and water absorption was found to be almost twice in RBCAC with respect to
corresponding value for SAC. It has also been found that coefficient of permeability increased with
decrease in design strength and vice versa for all types of concrete. Additionally, it has been observed that
coefficient of permeability in RBCAC is 350 to 400% higher than SAC of corresponding compressive
strength. Coefficient of permeability was also found to be much higher than VBAC. Hence RBCAC should
be used with care and may not be used for important elements of structures or buildings without
implementing appropriate precaution against permeability related durability problems.

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