PARAMETRIC STUDY ON PERMEABILITY OF CONCRETE MADE OF BRICK CHIPS

by

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The project titled "**PARAMETRIC STUDY ON PERMEABILITY OF CONCRETE MADE OF BRICK CHIPS**" submitted by Mohammad Anwar Hossain, Student Number-**040504317P**, Session-**April 2005**, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of **MASTER OF ENGINEERING IN CIVIL ENGINEERING (STRUCTURAL)** on **July 31, 2011.**

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It is hereby declared that this project or any part of it has not been submitted elsewhere for the award of any degree or diploma.

………………………………………..

Mohammad Anwar Hossain

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ABSTRACT

Permeability characteristic of concrete made from brick aggregate concrete is evaluated and compared with concrete made from stone aggregate. For this, four different classes of brick according to Bangladesh standard are selected. Several tests are conducted on whole new brick as well as aggregate prepared from them before concrete samples were prepared. These tests include crushing strength, absorption, LA abrasion and density. Using brick aggregate prepared from these four different classes of bricks, concrete samples are prepared using ACI mix design methods. Strength of concrete that could be achieved using brick aggregate varied between 14 to 28 MPa. Simultaneously, concrete samples were prepared from stone aggregate as well. Like brick, representative tests are conducted on stone aggregate. Strength of concrete achieved using stone aggregate concrete varied between 24 to 46 MPa. These samples were then tested for permeability using the AT 315 machine which applies water at a certain pressure on concrete samples for a specified period of time. Water pressure and duration of its application were fixed as per EN 12390-8: "Depth of Penetration of Water under Pressure". Results of permeability test indicate that permeability of concrete made from brick aggregate is far greater than that of concrete made from stone aggregate of identical strength. This increase in permeability depends on classes of bricks used. For example, concrete prepared from S class brick is about 200% more permeable than concrete of identical strength but made from stone aggregate. Further, it was found that permeability of concrete made from brick aggregate is directly influenced by crushing strength of brick, absorption and LA abrasion value of brick aggregate. All of these parameters showed linear variation with permeability of concrete prepared from them.

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Chapter – 1

INTRODUCTION

1.1 Introduction

In many areas of the world such as Bangladesh and parts of West Bengal, India, where natural rock deposits are scarce, burnt clay bricks are used as an alternative source of coarse aggregate. In Bangladesh the use and performance of concrete made with broken brick as coarse aggregate are quite extensive and satisfactory. Clay can be burnt easily and the product may be a source of coarse aggregate for concrete. In spite of extensive use of brick aggregate concrete in this regions and the apparent satisfactory performance of the structures already built, no systematic investigation on its properties and behavior was conducted and properly documented. The current designs for brick aggregate concretes are based on intuition and accumulation of experience, rather than on sound experimental evidence.

The practical experiences confidently showed us that the maximum range of compressive strength of concretes made with brick aggregate but without using any admixtures is around 3000 psi. However higher strength concrete (fc'much greater than 3000psi) can be used advantageously in compression members such as columns and piles. The reduction in size will lead to reduced dead load and subsequently to reduce total load on the foundations system. Smaller column size also means more available floor space to use. The relatively higher compressive strength per unit volume will also significantly reduce the dead load of flexural members. In addition, higher strength concrete possessing a highly dense micro structure is likely to enhance long-term durability of the structure.

The mix proportion of the concrete is usually done either by the ACI method (1994) or the BS method (1985). In both methods, the coarse aggregate is the crushed natural stone, the unit weight of this concrete ranges from 140 to152 pounds per cubic foot (pcf) (Nilsonand Darwin, 1997), where as brick aggregate concrete weighing between 125-130 pcf can be termed as medium weight concrete in comparison with normal weight and light weight concrete (Akhteruzzaman and Hasnat1983). Besides, the texture and surface roughness of brick aggregates concrete are different from those of stone aggregate. So the properties of brick aggregate concrete may not follow exactly the same trends as those of stone aggregate concrete. Consequently, the present code specifications, which are based on stone aggregate concrete, may not be applicable for brick aggregate concrete. This is even truer for 'permeability' of concrete since brick aggregate itself is known to be more porous and absorb more water than stone aggregate.

Permeability determines relative ease with which concrete can become saturated with water. In case of reinforced concrete, the ingress of moisture and of air will result in the corrosion of steel. Since this leads to an increase in the volume of the steel, cracking and spilling of the concrete cover may follow. Permeability of concrete is also of interest in relation to water tightness of liquid-retaining and some other structures. Furthermore, ingress of moisture into concrete affects its thermal properties as well. All these lead to the fact that permeability is the most important parameter for concrete durability (Neville and Brooks, 1990). Among various parameters that significantly influence the permeability of concrete include water to cement ratio, air content, coarse aggregate absorption, concrete cure method, and cure time (Mahboob et.al, 2003).

Numerous works has been done elsewhere in the world to examine the exact effects of these parameters on permeability of concrete. Several models and equations have been proposed to quantify these influences. However, very little work has been done yet to examine the effect of brick chips as coarse aggregate on permeability of concrete. This area is of special interest in the context of Bangladesh since a large portion of concrete related construction work is done using concrete made of brick chips as coarse aggregate. It is apparent that porous nature of brick chips aggregate will significantly influence overall permeability characteristics of concrete. Additionally, properties of brick chips may vary appreciably from site to site and may leads to concrete with notable differences in permeability characteristics. Therefore, attention should be given to identify different properties of brick aggregate that influence permeability of concrete made from them. Furthermore, efforts should also be given on determining their exact extent of influence.

Several brick and brick chips properties that may influence the permeability of concrete include ultimate strength of brick, fineness modulus of brick chips and brick absorption. Other factors that may affect permeability include strength of concrete made from it, curing of concrete and mix design that will determine percent volume of brick chips and cement paste in the total concrete matrix. Main objective of this research work is to test the effect of these parameters on permeability of concrete made from brick chips and compare it to crushed stone aggregate. For this, a large number of tests on samples varying these parameters are tested. Results from these tests were fitted statistically to examine the effects of various parameters and relative sensitivities. Well defined relation of these parameters to concrete permeability is the desired outcome from this research. The paper presents the results of compressive strength of brick, compressive strength of concrete, density, absorption, w/c ratio, volume of coarse aggregate, volume of cement content of various concrete mixes produced with different types of coarse aggregates crushed from new bricks. These results were compared to results' obtained for concretes produced with crushed stone.

1.2 Objectives of the Project

As per discussion on the previous section, the aim of this research work is to observe the permeability characteristics of concrete prepared from brick aggregate and compare it with that of concrete made from stone aggregate. This study is also aimed to create a relationship between permeability and ultimate compressive strength using different types of brick chips (in terms of absorption and strength) at different ratio.

Therefore, the objectives of this study may be stated in following form:

- To compare permeability of concrete prepared from brick and stone aggregate.
- To establish a relationship between the strength and penetrability of concrete
- To identify the parameters that affect the permeability
- To identify relative importance of different aggregate parameters that affect permeability
- To establish relationship between permeability of concrete and different parameters of aggregate as well as concrete.

1.3 Scope of the Project

Scope of this work is limited to normal strength concrete prepared from both brick and stone aggregate. Permeability is related to depth of penetration of water inside concrete sample that can be found after subjecting pressurized water on concrete samples using AT 315 machine. ACI mix design methods are used to design mix different strength of concrete. To achieve workability for concrete mix having low water cement ratio (i.e. 0.4) admixture is used. However, affect of applying admixture on permeability of concrete is neglected.

1.4 Organization of the Project

The project is organized into five chapters. Each chapter is integrated with the preceding chapter, as well as containing the main body, followed by a number of subsections (if necessary) regarding the title of the chapter.

Chapter 1 *Introduction*	The first chapter presents the overall perspective of the research, also mentioning the objectives and scopes the project.
Chapter 2 *Literature review*	In the second chapter the literature review corresponding to this project is covered. All the relevant literatures about permeability or testing are discussed here.
Chapter 3 *Testing Scheme*	The third chapter covers the experimental programs of the project. In this chapter the batches of concretes to be tested & their corresponding constituents is stated And how & through what equipment and condition the experiment was carried out that is also discussed.
Chapter 4 *Results and Discussions*	In this chapter the analysis from the experimental data is carried out through graphs & table. A discussion on the analysis is also done.
Chapter 5 *Conclusions and Recommendations*	Finally in chapter five the recommendation for better structural service with respect to permeability for different types of aggregate in aspect of different socio-economic and environmental condition is given. This chapter is also presents the key findings of the study. It also discuss with the limitations occurred or facing during the study.

Chapter – 2

LITERATURE REVIEW

2.1 General

Many aspects of the concrete durability are improved by reducing the permeability of concrete. The ACI 318 Building code addresses an exposure condition for concrete intended to have a low permeability when exposed to water by requiring a maximum w/c ratio of 0.50 and a minimum strength of 4000 psi. This recognizes that a lower water cement ratio is important to control the permeability of concrete.

The problem with the code requirement is that one parameter of water cement by itself does not assure the owner that compliance with this requirement will not adversely affect other properties of concrete. With the extensive use of supplementary cementations materials and innovative chemical admixtures, a concrete mixture can be optimized for a low permeability in more ways than by just controlling the w/c ratio.

Penetration of water and consequent corrosion is one of the main causes of damage to hydraulic concrete structures. Under hydraulic pressure, concrete will be permeated and corroded by water, resulting in damage to the hardened cement paste. Permeability is thus one of the most important properties of hydraulic concrete structures.

Concrete is an artificial stone manufactured from a mixture of binding materials and inert materials with water. Concrete = Binding materials + Inert materials + water.

Concrete is considered as a chemically combined mass where the inert material acts as filler and the binding material acts as binder. The most important binding material is cement. The inert materials used in concrete are termed as ‘aggregates’. The aggregates are of two types (1) fine aggregate and (2) coarse aggregate.

The magical credit of concrete lies in its capability to take care of compression when it is used as building material. Again for the properties like, while plastic, it can be deposited and made to fill forms of any practical shape, high fire and weather resistance, use of locally available cheap ingredients for its preparation have made it popular as construction material.

However, like other engineering materials concrete is also not above limitations. This is brittle material with relatively small tensile strength to its compressive strength, which prevents its economic use in structural members subjected to tension. Considerable volume instability in terms of shrinkage and creep invites special problems too. Finally, the overall picture of its weakness can be attributed to its low strength to weight ratio. But no doubt, advantages of concrete have left its limitations far behind on the way of popularity.

Coarse aggregate gives the volume to the concrete and fine aggregate makes the concrete denser by filling the voids of coarse aggregate. Water hydrates and sets the cement, which thus acts as a binder for all the ingredient particles of concrete. Thus the ultimate properties of concrete in terms of its strength, durability and economy largely depend on the various properties of its ingredients. So the different relevant properties of these materials and their effect on the manufacturing process of concrete and the final mix have been critically analyzed and presented in the subsequent articles of this chapter.

Found on several ways, the water is the most important fluid on nature. Among its properties, is noticeable the capacity to penetrate in small pores or cracks, and the capacity of dissolve a large amount of substances.

Several researches refer and attest the great importance of the water molecule on the concrete structure, especially on the first ages, caused by the cement hydration and consequent hardness of the concrete and after the reduction, or the ceasing of the hydration reactions, may cause the deterioration of the concrete. However, the presence of water after the hardness of the concrete and after the reduction, or the ceasing of the hydration reactions, may cause the deterioration of the concrete or of the steel bar present on the structure. The water take action as a direct agent (lixiviation) or transporting noxious substances, such as chloride ions, sulfate ions and acid, or components that can activate and propel many chemical reactions that speed up the degradation process of the matrix, proportioning this way a substantial reduction of the durability and the use life of the concrete and reinforced concrete structures.

Some authors emphasize that the permeability of the water is the most important factor to esteem the durability under the most diverse conditions of service of a structure. Therefore concrete must be projected and manufactured for the environment to which it goes to be displayed, because the permeability is related to the porosity that varies in accordance to the composition of the concrete, its factor water cement, its age and even though with its form of launching. In this paper, will be evaluated permeability and the compressive strength of the concrete with different compositions, water cement factors, making possible to generate correlation curves, suggesting a standard of reference and analysis of the permeability in function of some variable of the concrete.

2.2 Available Permeability Related Studies

Many works has been done elsewhere in the world to examine the exact effects of these parameters on permeability of concrete. Several models and equations have been proposed to quantify these influences. However, very little work has been done yet to examine the effect of brick chips as coarse aggregate on permeability of concrete. This area is of special interest in the context of Bangladesh since a large portion of concrete related construction work is done using concrete made of brick chips as course aggregate.

Some studies are found in the literature. Akhtaruzzaman and Hasnat(1983) investigated the various engineering properties of concrete using crushed brick as coarse aggregate. Khaloo(1994) studied the properties of concrete using crushed clinker brick as coarse aggregate. In both the above-mentioned studies, investigations were also done by comparing the properties of brick aggregate concrete with those for stone aggregate concrete. On the other hand, studies were done by Mansuretal(1999) comparing the properties of stone aggregate concrete with those of equivalent brick aggregate concrete obtained by replacing stone with an equal volume of crushed brick, everything else remaining the same.

The present study reports primarily at to achieve permeability of concrete using crushed brick as coarse aggregate. Various properties of brick aggregate concrete are also studied and compared with those determined following the codal specifications for stone aggregate concrete.

2.3 Necessity of Permeability Study

Concrete deterioration can be due to adverse mechanical, physical, or chemical causes, as mentioned earlier. It is often the case where one or more deteriorative mechanisms are at work by the time a problem is identified. In fact, in terms of deterioration of concrete due to physical or chemical causes, the mobility of fluids or gases through the concrete are nearly always involved. The overall susceptibility, or penetrability of a concrete structure, especially when compounded by additional environmental or exposure challenges, is the key to its ultimate serviceability and durability. Low porosity/ permeability/ penetrability of concrete to moisture and gas is the first line of defense against: frost damage, acid attack, sulfate attack, corrosion of steel embedment’s and reinforcements, carbonation, alkali-aggregate reaction, and efflorescence to name a few of the most prominent concrete ailments.

The permeability of concrete can be measured by determining the rate of flow of moisture through concrete. Since the porosity of concrete resides in the paste, the permeability of concrete should be cement aggregate interface. It should be noted that the flow of water through concrete is of interest in construction aside from consideration of durability. Impermeable concrete is required for water retaining structures and high quality construction work.

Water does not easily move through the very small gel pores and that permeability is controlled by an interconnecting network of capillary pores. As hydration proceeds, the capillary network becomes increasingly tortuous as interconnected pores are blocked by formation of C-S-H. This is accompanied by a continuous decrease in permeability coefficient and the time at which complete discontinuity of capillary pores occurs is a function of the w/c ratio. In concrete with a w/c ratio greater than 0.70, complete discontinuity of capillary pores can never be achieved, even with continuous moist curing the concrete will have relatively high permeability.

If the paste are allowed to dry and then rewetted, permeability coefficient is higher. This may be due to change is pore size distribution, that occur on shrinkage and which allow capillary pores to become partially interconnected again.

The effect is more marked in concrete since cracking at the paste aggregate interface will create further opportunities for water flow. Even in saturate concrete, permeability will be increased by imperfect consolidation or excessive segregation of materials, which can create bleeding channels within the paste.

2.4 Factors Determining Permeability of Concrete

Porosity of concrete: The permeability of concrete is not a simple function of its porosity, but depends also on the size, distribution and continuity of the pores. Hydration of cement: In fresh concrete the flow of water is controlled by the size, shape and concentration of the original cement grains. With the progress of hydration permeability decreases rapidly because the gel gradually fills some of the original water-filled space. In a mature paste, the permeability depends on the size, shape and concentration of gel particles and on whether or not the capillaries have become discontinuous.

1. Water/cement ratio: For a particular degree of hydration lower the permeability lower the water/cement ratio.
2. Cement properties: Coarser cement and low strength paste promote permeability.
3. Permeability of the aggregate: Aggregate with low permeability reduces the permeability of the concrete.
4. Curing: Steam-cured concrete is generally less permeable than wet cured concrete.
5. Entrained air: Air entrainment increases permeability, but lowers the water/cement ratio requirement. So the net effect is not address.

Sulphate resistance, resistance to efflorescence (both are controlled by reducing permeability), resistance to temperature changes (ensured by lower coefficient of thermal expansion), fire resistance (associated with low thermal conductivity), abrasion resistance (promoted by lower cement content and lower slump) etc. are important requirements for a durable concrete. In general it can be said that higher durability is obtained with high strength concrete.

2.5 Permeability testing

Testing concrete for permeability has not been generally standardizes. So that the values of the coefficient of permeability quoted in different publications may not be comparable, in such tests as are used, the steady-state flow of water through concrete due to a pressure differential is measured, and Darcy's equation is used to calculate the coefficient of permeability, K.

There is a further problem with permeability testing, namely that, in good quality concrete to a certain depth, and an expression has been developed by Valenta to convert the depth of penetration into the coefficient of permeability, k (in meters per second) equivalent to that used in Darcy's law:

$$k = \frac{e^2 v}{2ht} \text{ m/sec.}$$

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 of v represents discrete pores, such as air bubbles, which do not become filed with water except under pressure, and can be calculated from the increase in the mass of concrete during the test.

The hydraulic head is applied by pressure which usually 0.5MPa. The depth of penetration is found by observation of the split surface of the test specimen (moist concrete being darker) after a given length of time, this is the value of e in Valenta's expression giver above.

It is also possible to use the depth of penetration of water as a qualitative assessment of concrete: a depth of less than 50 mm classifies the concrete as ‘impermeable’ a depth of less than 30 mm, as ‘impermeable under aggressive condition (Properties of Concrete, A.M.Neville, Fourth Edition, P-495).

This European Standard has been prepared by Technical Committee CEN/TC 104 "Concrete performance, production, and placing and compliance criteria", the secretariat of which is held by DIN.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

This standard is one of a series concerned with testing concrete. It is based on the draft International Standard ISO (DIS) 7031 - Concrete hardened Determination of the depth of penetration of water under pressure.

A draft for this standard was published in 1996 for CEN enquiry as pr EN 12364. It was one of a series of individually numbered test methods for fresh or hardened concrete. For convenience it has now been decided to combine these separate draft standards into three new standards with separate parts for each method, as follows:

- Testing fresh concrete (EN 12350)
- Testing hardened concrete (EN 12390)
- Testing concrete in structures (EN 12504)

The series EN 12390 includes the following parts where the brackets give the numbers under which particular test methods were published for CEN enquiry:

EN 12390 Testing hardened concrete

Part 1: Shape, dimensions and other requirements of specimens and moulds (former prEN12356 : 1996)

Part 2: Making and curing specimens for strength tests (former prEN12379 : 1996)

Part 3: Compressive strength of test specimens (former prEN12394 : 1996)

Part4: Compressive strength - Specification for testing machines (former prEN12390 : 1996)

Part 5: Flexural strength of test specimens (former prEN12359 : 1996)

Part 6: Tensile splitting strength of test specimens (former prEN12362 : 1996)

Part 7: Density of hardened concrete (former prEN12363 : 1996)

Part 8: Depth of penetration of water under pressure (former prEN12364 : 1996)

Test Method for Water Permeability of Concrete Using Tri axial Cell (CRD-C 163-92, Issued 1 Sep. 1992) and Standard Test Method for Water Permeability of Concrete (CRD-C 48-92, Issued 1 Dec. 1992) can be used. But AT 315 does not support the test procedure.

Chapter – 3

TESTING SCHEME

3.1 Introduction

Concrete is one of the most widely used construction materials in the world. This is due to its simplicity, superior properties and low cost. However, there are a few major flaws in the properties of concrete such as the low tensile strength and porosity. The occurrence of internal pores sowed to the nature of concrete itself. Hardened concrete is a direct product of the hydration reaction processes which involve the reaction between water and cement particles. In all cases, the left over water in concrete, once dried out, will turn into pores (mostly capillary pores) in various sizes. These pores are connected either to each other directly or through the gel pores. The existing of high volume of pores put concrete it the risk of being penetrated by water, gas, or other chemical substances which could be harmful to concrete and slowly, lead to the deterioration of structures.

Often, the deterioration process starts with the occurrence of the surface cracks (due to the poor tensile strength, shrinkage, etc.) and then follow by the migration of the gases or liquids into the inner-concrete (through the surface-cracks and the pores). Some unknown gases or chemical substances can react with concrete and cause the lost integrity and properties. Example of such reactions include the carbonation reaction between carbon dioxide gas and calcium hydroxide (cause the leaching of bicarbonate) which makes concrete surface become porous, decay and permeable, or the chloride induced-corrosion in rebar which causes by the loss of protective film around the rebar due to the decreasing pH value.

For concrete made from crushed clay bricks, porosity is more important issue. Since, brick itself is a highly porous element, it adds to the permeability characteristics of concrete are made from it. However, there is very few test result that are evaluate. For this an extensive testing program is conducted in this study.

This chapter describes the testing method. The apparatus is used, materials is considered and standards on permeability testing.

3.2 Materials Used

Materials used in this study consisted of Portland cement Type I, sand, brick aggregate and stone aggregate.

3.2.1 Cement

The cement used was (Type I) ordinary Portland cement with a 28 days minimum compressive strength of 25MPa according to ASTM C 595 -94a. By using one type of cement the effect of varying the types of coarse aggregate in concrete was investigated.

3.2.2 Fine Aggregate

One type of fine aggregate was used throughout the experimental work so as to keep the fine aggregate variable constant. The sieve analysis was carried out in accordance with ASTM C117-84 and ASTM C136-84a, unit weight of aggregates was determined in accordance with ASTM C 29/C 29 M-91a where as absorption and specific gravity of fine aggregate was found in accordance with ASTM C128-84.

Table: 3.1 Properties of Sand Used in Concrete

Fine Aggregate	F.M.	Unit Weight (Kg/m^3)	Absorption (%)	Specific Gravity (S.S.D)
Sand	2.70	1630	1.26	2.66

3.2.3 Bricks

BDS 208:2002 classify brick into three categories name S, A, B grade. These grades are defined by Table 3.2.

Table 3.2: Classifications of Bricks

Grade	Mean Compressive Strength MPa	Maximum Water Absorption (%)
S	27.45	10
A	17.15	15
B	13.75	20

Those brick samples which could not satisfy any of these requirements were treated as "inferior" class brick.

In this work, seven types of brick samples collected from different brick field considered. Before these bricks were crushed down to aggregate compressive (crushing) strength test was conducted accordance with ASTM C 67-09. The test results were shown in table 3.3.

3.2.4 Crushed Brick and Stone Aggregates

Natural crushed 20 mm downgraded crushed stone was used in this investigation. The new brick aggregate was produced by breaking down whole new bricks on a solid metal plate using a hammer. The large brick pieces were crushed again to smaller sizes and sieved until the grading of the aggregates complied with the grading limits set out in ASTM C 33-93.

The grading limit of all aggregates was kept constant throughout the investigation so that the grading variable would not influence workability and strength when used in concrete.

Table: 3.3 Properties of Brick Used in Aggregate

Brick Type	Frog Mark	Compressive strength(MPa)	Classification as per BDS 208:2002.
1	NHB	28.25	S
2	MBS	18.30	A
3	MHB	17.25	A
4	NBM	14.85	B
5	MSB	13.95	B
6	PBC	12.70	---
7	KHD	11.95	---

Before making concrete by brick aggregate and stone aggregate, different properties were measured at same standard of unit weight of aggregates in accordance with ASTM C 29/C 29 M-91a, absorption and specific gravity test accordance with ASTM C 127-88, Los Angeles abrasion test accordance with ASTM C 131-89. These are presented in table 3.4 and 3.5.

The results in Table 3.4 and 3.5 shows that in general, as expected, the stronger bricks produced higher values of density. The results also show that the brick aggregates have a lower density than the crushed stone aggregate. This means that if brick aggregates are used in making concrete they should produce concrete of a lower density than crushed stone aggregate.

Table: 3.4 Properties of Brick Aggregate Used in Concrete

Brick Type	Frog Mark	Specific Gravity (S.S.D)	Density of brick aggregate(Kg/m^3)	Absorption (%)	LA Abrasion value (%)	Classification as per BDS 208:2002.
1	NHB	2.16	1450	9.8	39.25	S
2	MBS	2.10	1400	13.40	44.10	A
3	MHB	2.06	1390	14.05	44.80	A
4	NBM	2.02	1380	14.60	46.10	B
5	MSB	1.97	1350	17.90	49.50	B
6	PBC	1.85	1300	21.20	52.50	---
7	KHD	1.82	1280	22.25	53.25	---

Table: 3.5 Properties of Crushed Stone Aggregate used in concrete

Sl. No.	Crushed Stone Type	Unit Weight (Kg/m^3)	Absorption (%)	LA Abrasion value (%)	Specific Gravity (S.S.D)
1	Stone- 1	1580	1.62	28.70	2.63
2	Stone - 2	1550	1.93	30.85	2.20
3	Stone - 3	1615	0.82	25.20	2.69
4	Stone -4	1605	1.22	26.90	2.67
5	Stone - 5	1590	1.36	27.70	2.64

Sieve analysis results are shown in Table-3.6 and 3.7 limits set by ASTM C 33-93. We also plotted in the same figure. It may be seen that the size distribution of coarse aggregate used in this work is within the limit. The grading limit of all aggregates was kept constant throughout the investigation so that the grading variable would not influence workability and strength when used in concrete.

Table: 3.6 Sieve Analysis of Brick Aggregate Used in Concrete

Sieve size	Sieve opening (mm)	Weight Retaining (gm)	Percent Retaining by Weight	Cumulative Percent retained	Percent passing by	Grading limits %
1”	25.4	-	-	-	100	100
¾”	19	365.23	7.30	7.30	92.69	90-100
3/8”	9.51	3227.63	64.55	71.85	28.14	20-55
No. 4	4.75	1203.92	24.07	95.93	4.06	0-10
No.8	2.38	152.39	3.04	98.98	1.01	0-5
PAN	-	50.81	1.01	100	-	-
Total	-	5000	-	-	-	-

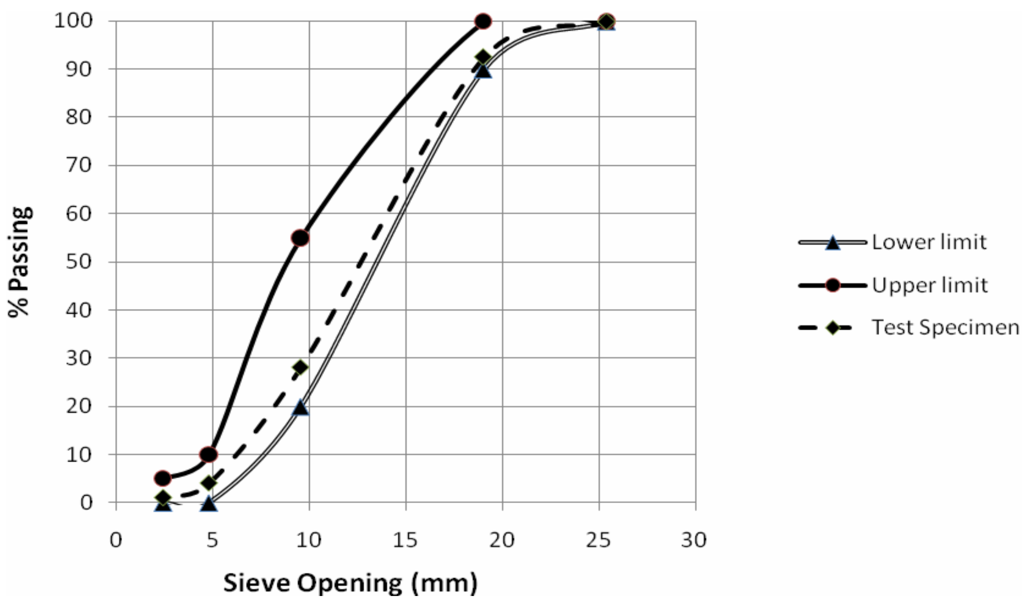

Fig.3.1: Grading Curves for Brick Aggregate

Table: 3.7 Sieve Analysis of Stone Aggregate Used in Concrete

Sieve size	Sieve opening (mm)	Weight Retaining (gm)	Percent Retaining by Weight	Cumulative Percent retained	Percent passing by	Grading limits %
1”	25.4	-	-	-	100	100
¾”	19	331.36	6.62	6.62	93.37	90-100
3/8”	9.51	3327.75	66.55	73.18	26.81	20-55
No. 4	4.75	1118.85	22.37	95.55	4.44	0-10
No.8	2.38	185.83	3.716	99.27	0.72	0-5
PAN	-	36.19	0.72	100	-	-
Total	-	5000	-	-	-	-

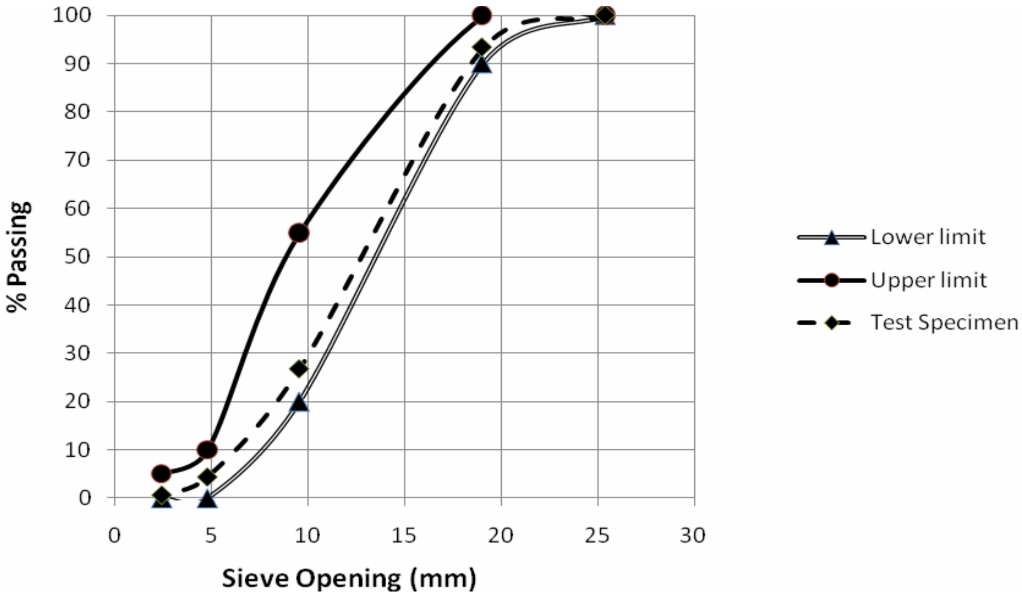

Fig.3.2: Grading Curves for Stone Aggregate

3.2.5 Admixtures

A super plasticizing admixture (ASTM C494-92, Type - F) (1% of cement) was added to the mixing water used to produce crushed stone and brick concrete in case of w/c ratio 0.40.

3.3 Mix Design

3.3.1 Introduction

Standards mix design method may be used for brick aggregate concrete as well (khalaf). The ACI method of mix design was used in this work.

Concrete having three characteristics strength I.e.20MPa (w/c ratio 0.60), 30Mpa (w/c ratio 0.50), and 40MPa (w/c ratio 0.40) vary both stone and brick aggregate were targeted in the mix design. Using the procedure described in ACI (ACI 211.1-91[14.5]), that of coarse aggregate, fine aggregate, cement and water were evaluated. These are shown in table 3.8. In practice, the mix design evaluated with w/c ratio of 0.4 could not satisfy the workability requirement. Therefore, small percentage (1% of cement) of super plasticizer was added to make it more suitable for sample production.

The absorption of crushed new brick was found to be a value between 9.8 and 22.25% by weight in relation to the material in its dry state (Khalaf and De Venny 2002). Since the concrete mix design method used is based on the aggregate being in a SSD condition, it was therefore necessary to saturate the crushed brick aggregates before mixing to prevent the concrete from becoming "too dry." This was achieved by submerging the aggregate in a bucket of water for a period of 30 min. Previous tests have shown that 30 min is a practical duration of time for soaking the aggregate as additional submersion for a further 24 hours produces only an increase of about 2% water absorption (Hansen 1992). After submersion the aggregate was towel dried to remove any excess water that was on the surface of the material. The brick aggregate should be in a SSD condition before mixing.

For all mixes used in this investigation, 21 batches for brick aggregate and 15 batches for stone aggregate of concrete were produced in accordance with the relevant American Standards to make (150x300) mm cylinder for compressive strength at 28 days (3 cylinders for each) and (150x150) mm cubes for permeability testing (3 cubes for each). The only difference in the mixing process was that prior to mixing the brick aggregates were soaked in water for a period of half an hour. The stone aggregate that was used as a control, was not presoaked as it was already in a SSD condition prior to mixing.

For all mixes ordinary Portland cement and fine aggregate were added to the crushed brick and stone aggregate to produce concrete. The level of workability was monitored using the slump (ASTM C 143-90a).

Table: 3.8 Mix Design Chart

Aggregate Types	Mix Design					
	w/c=	Cement	Fine Aggregate	Coarse Aggregate	Water	Admixture
		Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3
S	0.4	440	578	1000	176	4.4
	0.5	360	634	1000	180	
	0.6	300	684	1000	180	
A	0.4	440	592	966	176	4.4
	0.5	360	648	966	180	
	0.6	300	698	966	180	
A	0.4	440	571	959	176	4.4
	0.5	360	627	959	180	
	0.6	300	678	959	180	
B	0.4	440	549	952	176	4.4
	0.5	360	606	952	180	
	0.6	300	656	952	180	
B	0.4	440	545	931	176	4.4
	0.5	360	601	931	180	
	0.6	300	652	931	180	
Inferior	0.4	440	560	897	176	4.4
	0.5	350	626	897	175	
	0.6	300	667	897	180	
Inferior	0.4	440	546	883	176	4.4
	0.5	360	602	883	180	
	0.6	300	645	883	180	
Stone-1	0.4	440	722	1075	176	4.4
	0.5	360	779	1075	180	
	0.6	300	829	1075	180	
Stone-2	0.4	440	743	1050	176	4.4
	0.5	360	799	1050	180	
	0.6	300	849	1050	180	
Stone-3	0.4	440	698	1115	176	4.4
	0.5	360	755	1115	180	
	0.6	300	805	1115	180	
Stone-4	0.4	440	705	1100	176	4.4
	0.5	360	762	1100	180	
	0.6	300	812	1100	180	
Stone-5	0.4	440	715	1085	176	4.4
	0.5	360	772	1085	180	
	0.6	300	820	1085	180	

3.3.2 Mixing, Placement, and Curing Procedures

Mixture machine was used for casting of concrete. Trial mix was done for very case before the final mix. Before batching out the materials, moisture content of coarse and fine aggregates was measured and moisture adjustment was made. The sides of the mixture machine were buttered with mortar before mixing. To ensure the quality strength in the matrix, the following format was followed for mixing concrete.

- Added coarse aggregate and some of the mixing water before starting the mixer.
- Started the mixer and added the fine aggregates, cement and any mineral admixture are used. Finished by adding the remainder of mixing water.
- Mixed the ingredients for 3 minutes. Then after a rest period of 30 seconds, mixed the ingredients for another 2 minutes.

After this initial mixing, the concrete was generally tested for its fresh properties. The slump of the concrete was determined by standard procedure. For batches where the slump was found unacceptable after initial mixing, the slump test was reincorporated for extra 15 to 30 seconds, and concrete were ready for placement.

Fig.3.3: Concrete mixer machine

Fig.3.4: Pouring of aggregate in mixer machine

Fig.3.5: Mixing of concrete

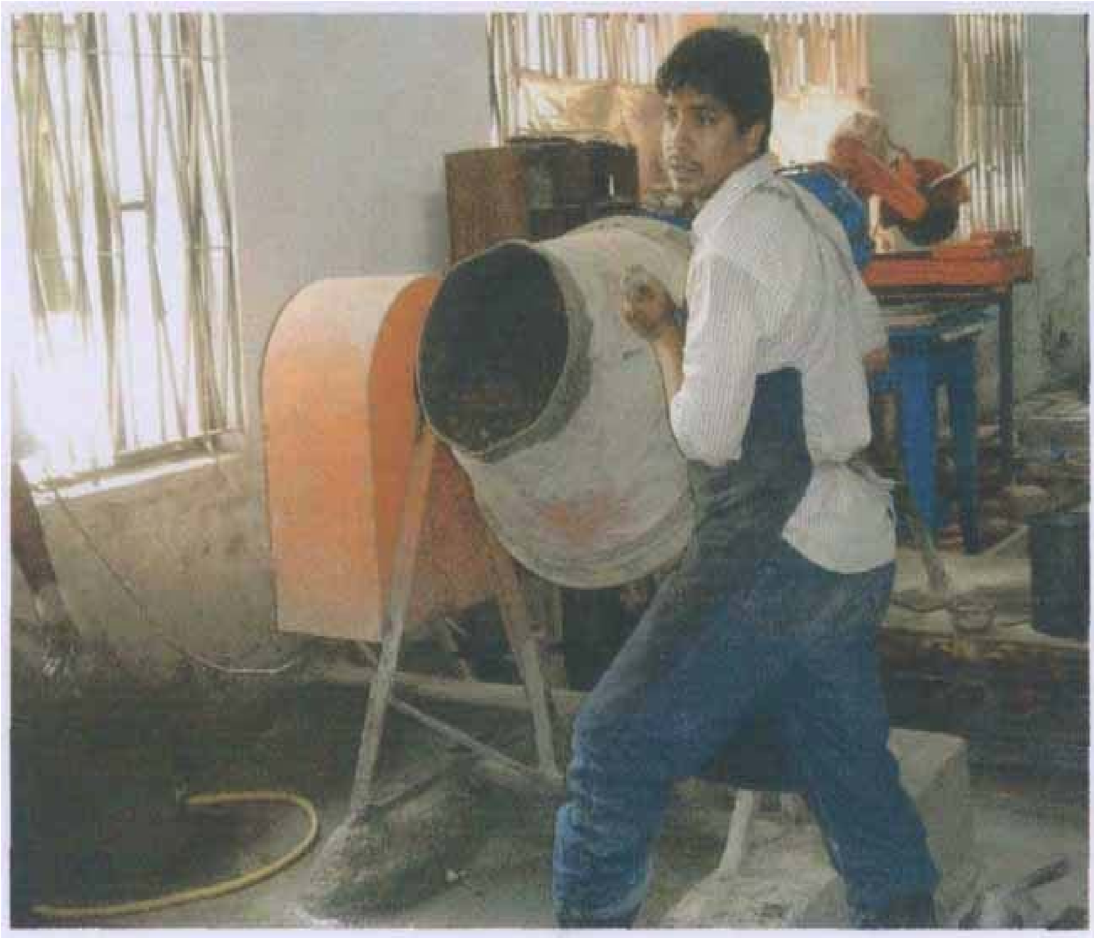

Fig.3.6: Mixing of concrete

Fig.3.7: Fresh concrete

Fig.3.8: Concrete compaction & vibration

Fig.3.9: Curing of cylinders and cube

Fig.3.10: Concrete cylinder to be test

Fig.3.11: Concrete cube to be tested

3.3.3 Slump Test

This is a test used extensively in site work all over the world. The apparatus for this very simple test consists primarily of a hollow mould in the form of a frustum of a cone having the dimension as 200mm at bottom, 100mm at top and 300mm high.

It is placed on a smooth surface with the smaller opening at the top and filled with concrete in three layers. Each layer is tamped 25 times with a standard 16mm diameter steel rod, rounded at the end and the top surface is struck off by means of a screening and rolling motion of the tamping rod. The mould must be firmly held against its base during entire operation.

Immediately after filling, the cone is slowly lifted and the unsupported concrete will now slump. The decrease in the height of measured to the slumped concrete is called slump and it is measured to the nearest 6mm. Depending on the mix three distinct types.

1. True slump: It consists of a general subsidence of the mass without any breaking up.
2. Shear slump: Instead of slumping evenly all around, one half of the cone sides down an inclined plane. It is indicative of lack of cohesion, harsh mixes, and mixes prone to segregation, concrete unsuitable for placement, etc.
3. Collapse slump: Collapse of concrete indicates a lean, harsh or a very wet mix.

The slump test may be considered to be a measure of the shear resistance of concrete to flowing under its own weight. In order to reduce the influence on slump of the variation in the surface friction, the inside of the mould and its base should be moistened at the beginning of every test and prior to lifting of the mould the area immediately around the base of the cone should be cleaned from concrete which may have dropped accidentally.

The slump test is subjected to the following special limitations -

1. It is not a suitable method for very wet or very dry concrete.
2. It does not measure all factors contributing to workability, nor is it always representative of the placing of the concrete.
3. Wide variation of slump can be obtained in different samples from the same mix.
4. With different aggregates the same slump can be recorded for different workability.
5. The test is reasonably reproducible with only skilled operations.

However, despite these limitations, the slump test is very useful on site to check day-to-day or hour-to-hour variation in the quality of mix. Changes in slump on a given job generally indicate that a change has occurred in the aggregate or in the amount of water or admixture being used. This should be a warning demanding an investigation and a remedial action if necessary.

Fig.3.12: Slump test of concrete.

Concrete of the specimens had been properly compacted. Each and every cylindrical and cubic specimen was compacted by two layers. In each layer, vibrator was used for compaction. After the compaction of these specimens, scaling and hammering were done to get a void free surface of the specimens. The compaction of the concrete clearly visualized by the fig. 3.14

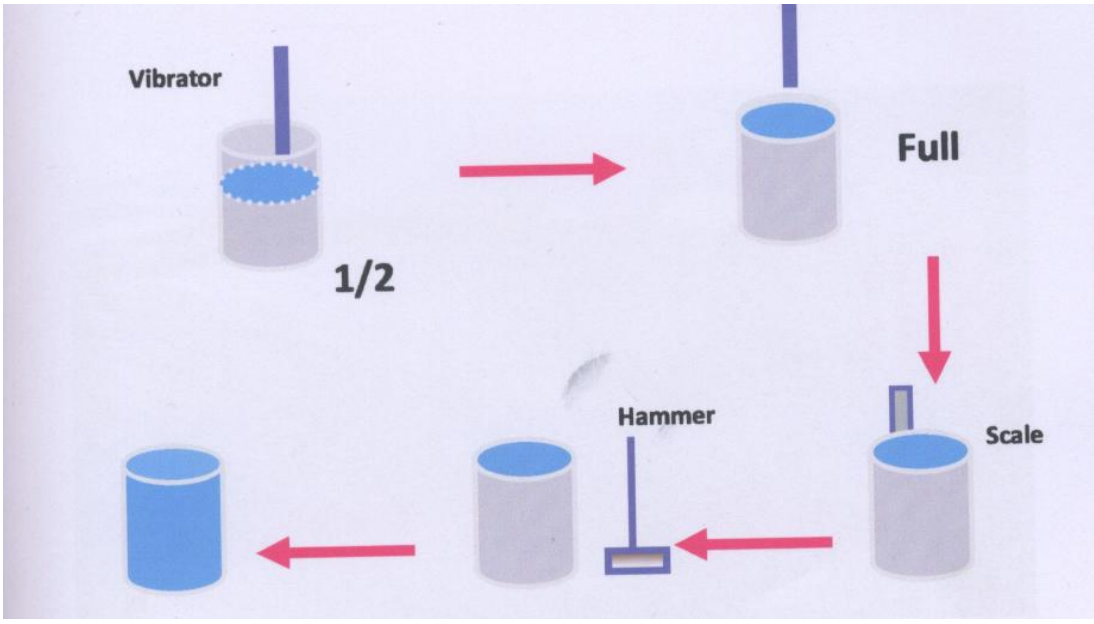

Fig.3.13: Compaction procedure

Fig.3.14: Concrete pouring in cylinder

Curing of the specimens was completely ensured after the casting. Normal tape water was used for the curing procedure. Before crushing those specimens, all the specimens were places into the water tank for under water curing and the duration were 28 days.

3.4 Compressive strength test

The Universal Testing machine was used to do compressive strength test for all the concrete specimens. Before the test of the cylindrical specimens, capping was done over those specimens to get uniform and smooth surface for concentrated loading. Loading was 4 KN/sec applied by the Universal Testing Machine over the specimens. Crushing pattern and crack surface picture were also taken for the specimens. Test standard was ASTM C 39-93a. These test result were presented in table 3.9 and 3.10

Fig. 3.15: Compressive strength test

Table: 3.9 Compressive Strength of Crushed Brick Aggregate Concrete

Aggregate type	Concrete Compressive strength (MPa)					
	Target			Achieved at 28 days		
	w/c = 0.4	w/c = 0.5	w/c = 0.6	w/c = 0.4	w/c = 0.5	w/c = 0.6
S	40	30	20	27.95	23.80	19.45
A	40	30	20	24.80	21.55	18.30
A	40	30	20	22.50	20.85	17.75
B	40	30	20	21.70	20.65	17.40
B	40	30	20	21.05	19.80	16.70
Inferior	40	30	20	19.50	18.45	16.20
Inferior	40	30	20	18.45	17.05	14.65

Table: 3.10 Compressive Strength of Crushed Stone Aggregate Concrete

Aggregate type	Concrete Compressive strength (MPa)					
	Target			Achieved at 28 days		
	w/c = 0.4	w/c = 0.5	w/c = 0.6	w/c = 0.4	w/c = 0.5	w/c = 0.6
Stone 1	40	30	20	39.30	30.05	23.55
Stone 2	40	30	20	33.30	27.95	21.35
Stone 3	40	30	20	46.20	34.50	26.25
Stone 4	40	30	20	43.70	32.75	25.30

Stone 5	40	30	20	41.25	30.95	24.10

3.5 Permeability Testing

3.5.1 Testing Apparatus

AT 315 was used to determine the impermeability of concrete to water according to EN 12390-8 “Depth of Penetration of Water under Pressure”. 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.

Fig.3.16: Testing machine AT 315

The test specimen, of given dimensions placed in equipment in such a manner that the water pressure act on the test area and the pressure applied continuously indicated. The water pressure applied to the surface of the test specimen from the bottom. A necessary seal is made of rubber. The dimensions of a test area were half of the length of the edge of the test surface.

Fig. 3.17: Specimen on the testing machine

3.5.2 Test specimen

The specimen was cubic of 150mm size.

3.5.3 Test Procedure

a) Preparation of the test specimen

Immediately after the specimen is de-molded, roughen the surface to be exposed to water pressure, with a wire brush.

b) Application of water pressure

The test was started when the specimen is at least 28 days old. Placing the specimen in the apparatus and applying water pressure of (500 ± 50)kPa for (72 ± 2) hours. During the test, periodically observation of the appearance of the surfaces of the test specimen not exposed to the water pressure to note the presence of water.

Fig. 3.18: Air Compressor

Fig 3.19: Connection between air compressor & specimen testing machine

c) Examination of specimen

After the pressure has been applied for the specified time, the specimen was removed from the apparatus. Wipe the face on which the water pressure was applied to remove excess of water.

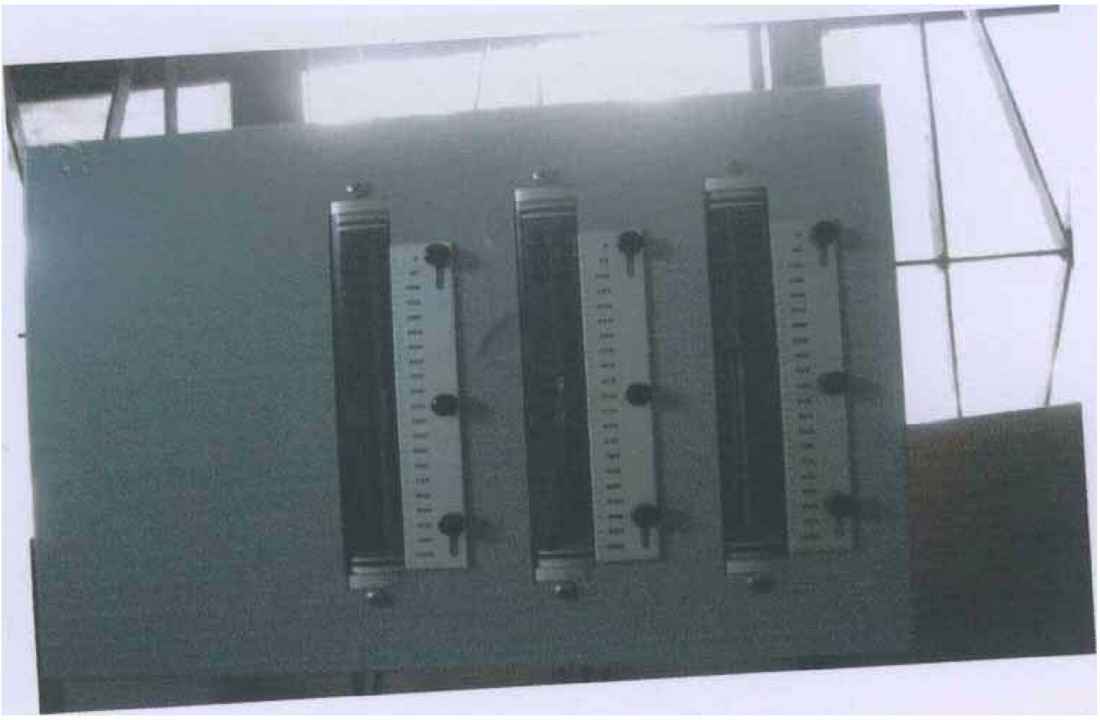

Fig. 3.20: Water volume measuring scale

The specimen was split in half, perpendicularly to the face on which the water pressure was applied. When splitting the specimen, and during the examination, place the face of the specimen exposed to the water pressure on the bottom. As soon as the split face has dried to such an extent that the water penetration front can be clearly seen, the water front on the specimen and maximum depth of penetration under the test area recorded and measured it to the nearest millimeter.

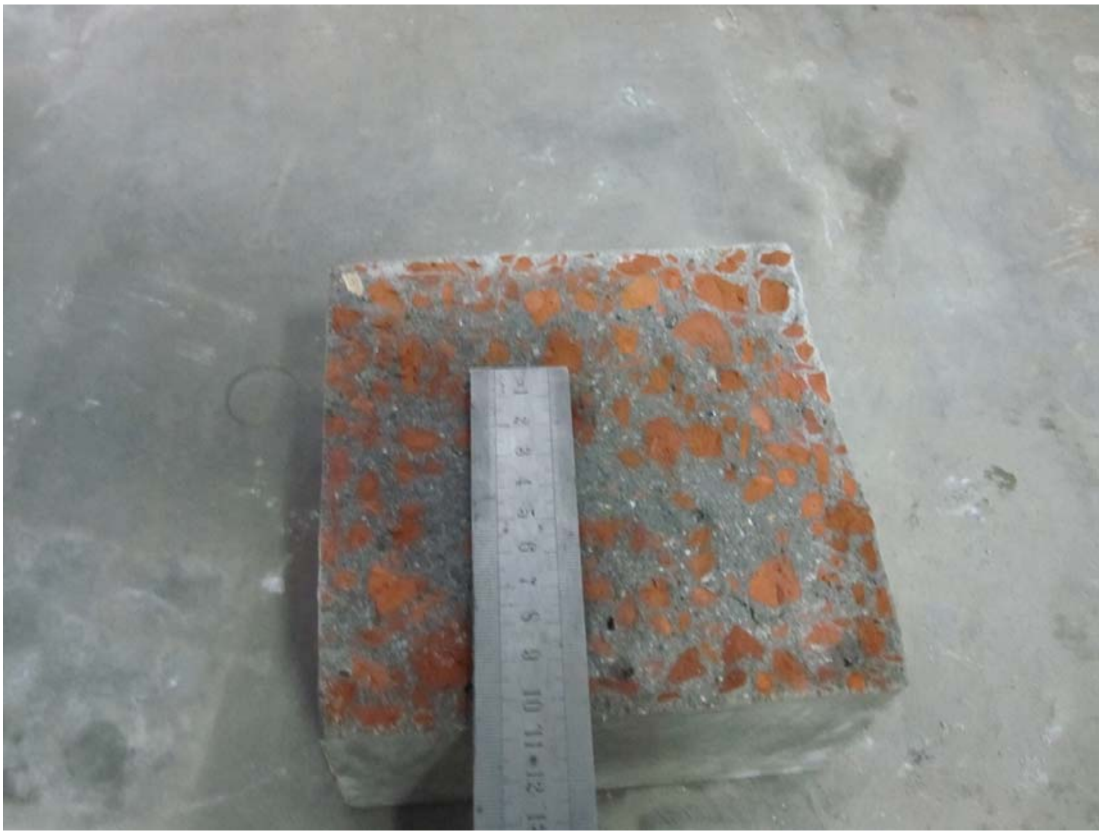

Fig 3.21: Depth of penetration of water (brick aggregate concrete)

Fig 3.22: Depth of penetration of water (brick aggregate concrete)

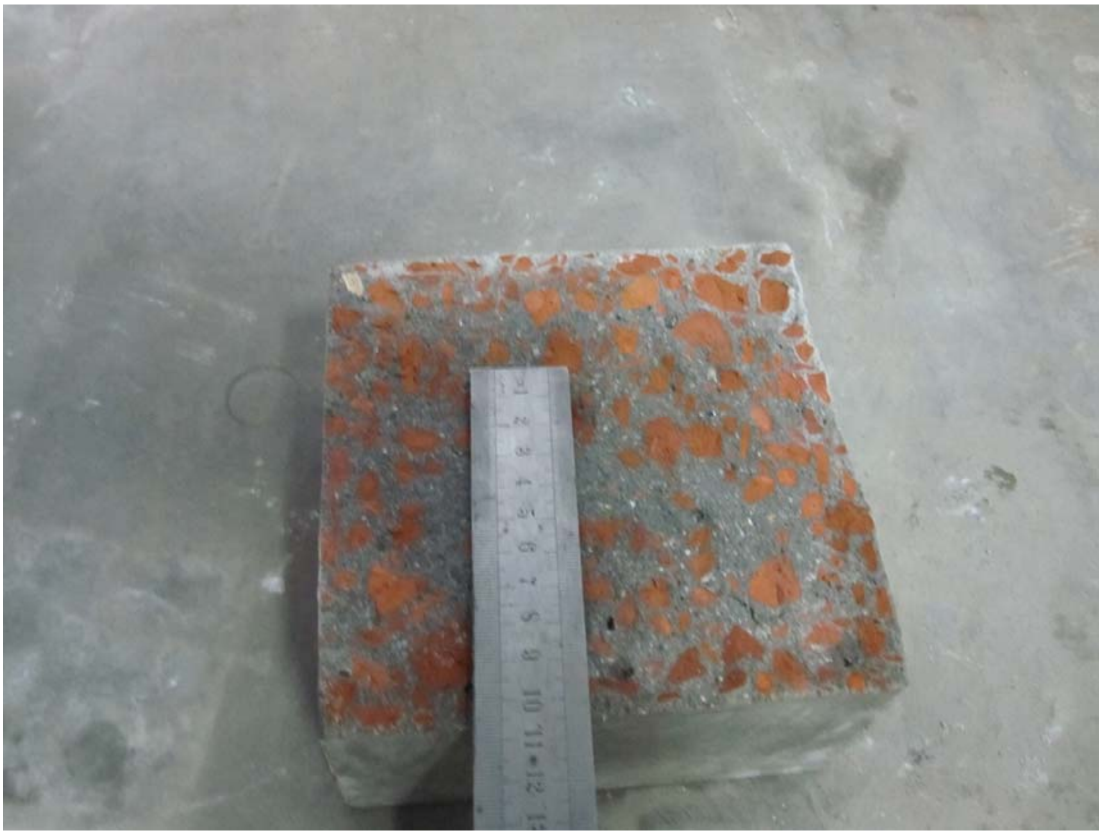

Fig 3.23: Depth of penetration of water (brick aggregate concrete)

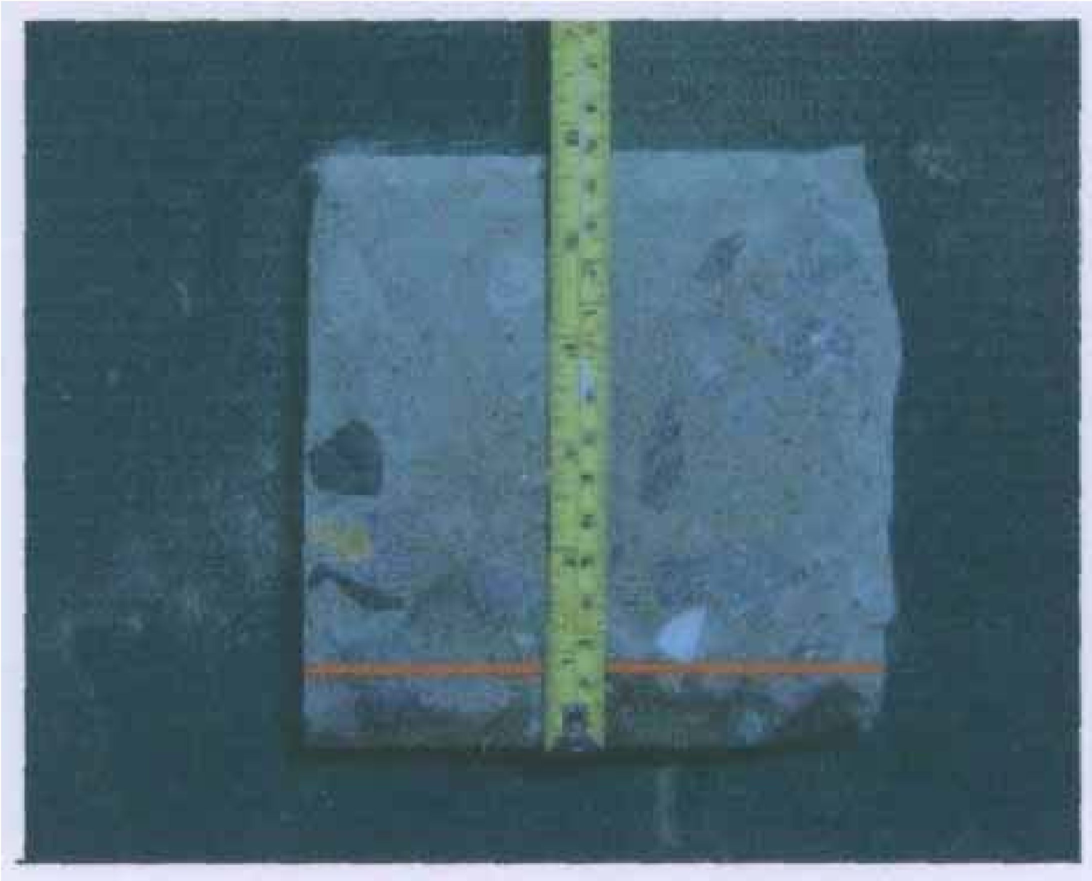

Fig 3.24: Depth of penetration of water (stone aggregate concrete)

d) Test result

The maximum depth of penetration, expressed to the nearest millimeter, was the test result. Then permeability measured by following equation:

$$k = \frac{e^2 v}{2ht} \text{ m/sec.}$$

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.

Chapter – 4

RESULTS AND DISCUSSIONS

4.1 Introduction

Based on the testing methods, materials and apparatus described in previous chapters, several permeability tests were conducted on representative concrete samples produced from both brick and stone aggregate concrete. Main objectives of this testing scheme were to identify the extent of influence of significant parameters of brick and brick aggregate on permeability of concrete made from them. Further, comparative permeability behavior was also examined between brick and stone aggregate concrete of identical strength. The main parameters that were considered include compressive strength of concrete, crushing strength and absorption of brick aggregate, Los Angeles abrasion as well as unit weight of brick.

4.2 Compressive Strength and Permeability

As described in section 3.3, three different strength of concrete i.e. 20, 30 and 40 MPa were targeted using both brick and stone aggregate. However, as stated before, using brick aggregate, 40 MPa concrete could not be achieved. Four different category of bricks were used, namely, S, A, B and inferior, to prepare concrete samples. Those were then subjected to permeability testing as per EN 12390-8. Test results on those samples are provided in Table 4.1 and 4.2.

Table: 4.1 Results of Crushed Brick Aggregate Concrete

Aggregate type	Density of concrete (Kg/m^3)			Compressive Strength (MPa)			Permeability		
				28 days			$x10^{-11}$m/s		
	w/c = 0.4	w/c = 0.5	w/c = 0.6	w/c = 0.4	w/c = 0.5	w/c = 0.6	w/c = 0.4	w/c = 0.5	w/c = 0.6
S	2198	2174	2164	27.95	23.80	19.45	2.20	2.53	2.95
A	2178	2154	2144	24.80	21.55	18.30	3.85	4.45	4.90
A	2150	2126	2117	22.50	20.85	17.75	4.30	4.70	5.15
B	2121	2098	2088	21.70	20.65	17.40	4.55	4.85	5.15
B	2096	2072	2063	21.05	19.80	16.70	5.40	5.80	6.05
Inferior	2077	2048	2044	19.50	18.45	16.20	6.25	6.55	6.95
Inferior	2049	2025	2008	18.45	17.05	14.65	7.15	7.35	7.85

Table: 4.2. Results of Crushed Stone Aggregate Concrete

Aggregate type	Density of concrete (Kg/m^3)			Concrete Compressive strength (MPa)			Permeability		
				28 days			$x10^{-11}$m/s		
	w/c = 0.4	w/c = 0.5	w/c = 0.6	w/c = 0.4	w/c = 0.5	w/c = 0.6	w/c = 0.4	w/c = 0.5	w/c = 0.6
Stone 1	2417	2394	2384	39.30	30.05	23.55	0.090	0.520	1.050
Stone 2	2413	2389	2379	33.30	27.95	21.35	0.175	0.595	1.150
Stone 3	2433	2410	2400	46.20	34.50	26.25	0.019	0.390	0.805
Stone 4	2425	2402	2392	43.70	32.75	25.30	0.046	0.445	0.895
Stone 5	2420	2397	2385	41.25	30.95	24.10	0.065	0.460	0.955

These results are again represented in Fig. 4.1 to elaborate comparative permeability characteristics of brick and stone aggregate concrete. As can be seen from this figure, permeability of concrete made from stone aggregate remain within 0.02 to 1.2 X 10^{-11} m/s range. Whereas, for concrete made from brick aggregate, permeability varies from 2.2 to as high as 7.85 X 10^{-11} m/s. To make the comparison clearer, these results are plotted in Fig. 4.2 for identical strength of both stone and brick aggregate concrete. In this, permeability of stone aggregate concrete is taken as the base value. Clearly, for a concrete having identical strength but made from different classes of bricks, permeability is far greater than what we get from stone aggregate concrete. This increase in permeability for different classes of bricks is graphically represented in Fig. 4.2. From this, it may be seen that quality of bricks affects permeability of concrete markedly. For example, for S class brick of strength 25 MPa, permeability is about 200% more than the base value of stone aggregate concrete. Whereas, for B class bricks, increase in permeability is about 425%. Alarmingly, for inferior bricks, increase in permeability is about 550% i.e. 5.5 times of what we get in stone aggregate concrete.

From the test results, equations are developed relating strength of concrete to its corresponding permeability which is shown in Fig. 4.3 and Fig.4.4. As can be seen from graphs and which is well evident from the equations, permeability of concrete made from brick aggregate is less sensitive to strength than concrete made from stone aggregate. However, permeability of brick aggregate concrete always remains higher because of their constant term in the linear equation formulated. Following equations are developed so that permeability of brick aggregate concrete may be evaluated when its strength and water cement ratio is known:

$y = (-0.9991x + 22.777) \times 10^{-11}$ for brick aggregate concrete, w/c = 0.6

$y = (-0.7197x + 19.789) \times 10^{-11}$ for brick aggregate concrete, w/c = 0.5

$y = (-0.4922x + 15.778) \times 10^{-11}$ for brick aggregate concrete, w/c = 0.4

$y = (-0.0694x + 2.6399) \times 10^{-11}$ for stone aggregate concrete, w/c = 0.6

$y = (-0.0316x + 1.4727) \times 10^{-11}$ for stone aggregate concrete, w/c = 0.5

$y = (-0.0136x + 0.6393) \times 10^{-11}$ for stone aggregate concrete, w/c = 0.4

A good correlation adjusting among the three equations can be express as

$y = (-2.45xa^{1.75} + 39.50a) \times 10^{-11}$ for brick aggregate concrete

$y = (-0.52xa^{4} + 15.90a^{3.5}) \times 10^{-11}$ for stone aggregate concrete

Where,

'y' is the permeability in m/s; 'x' is the compressive strength in MPa and 'a' is the water cement ratio.

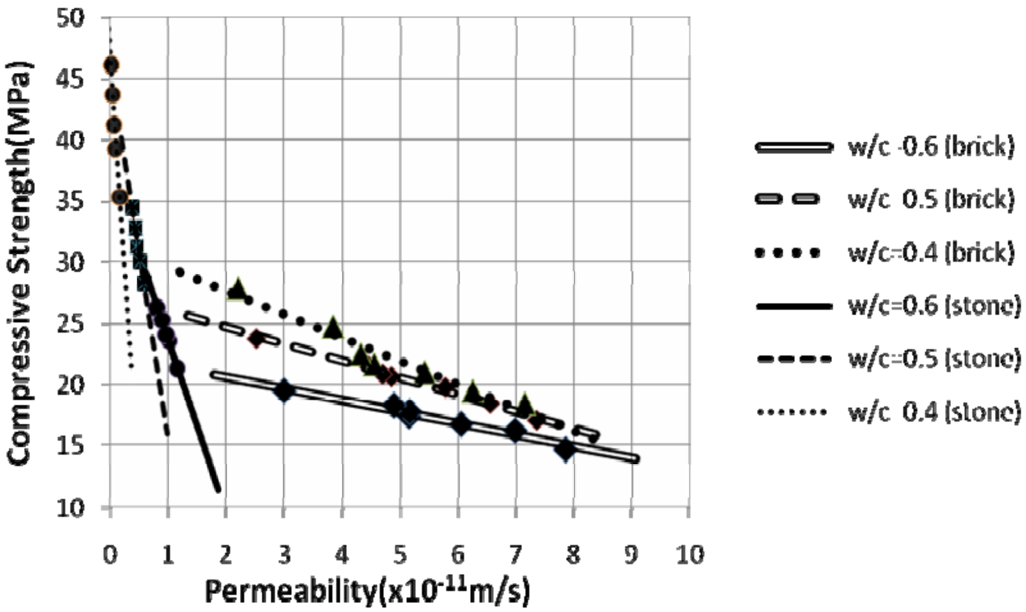

Fig.4.1: Relationship between compressive strength and permeability

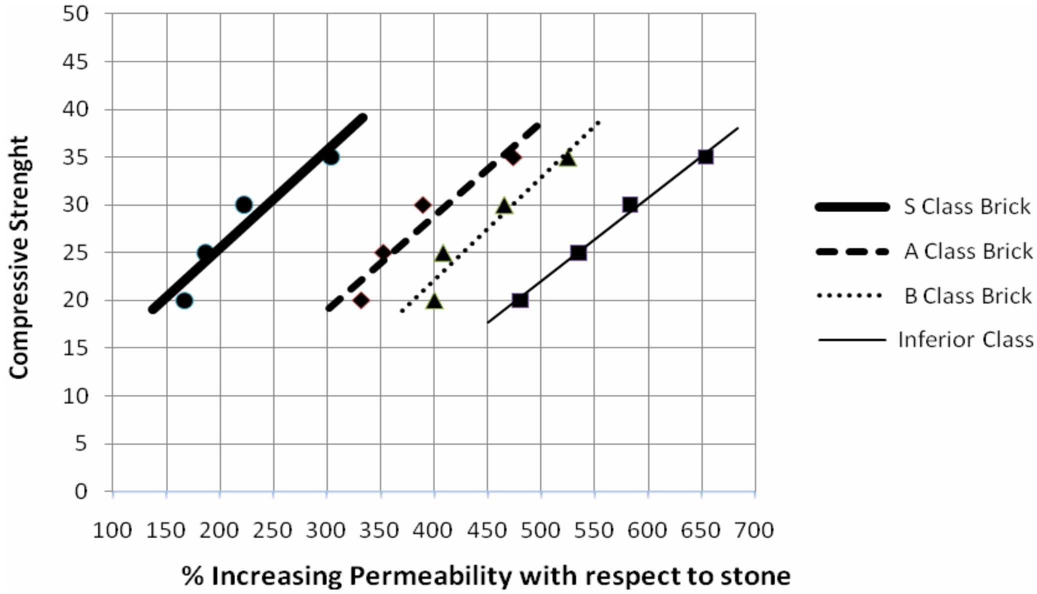

Fig .4.2: Relationship between compressive strength and % increasing permeability With respect to stone

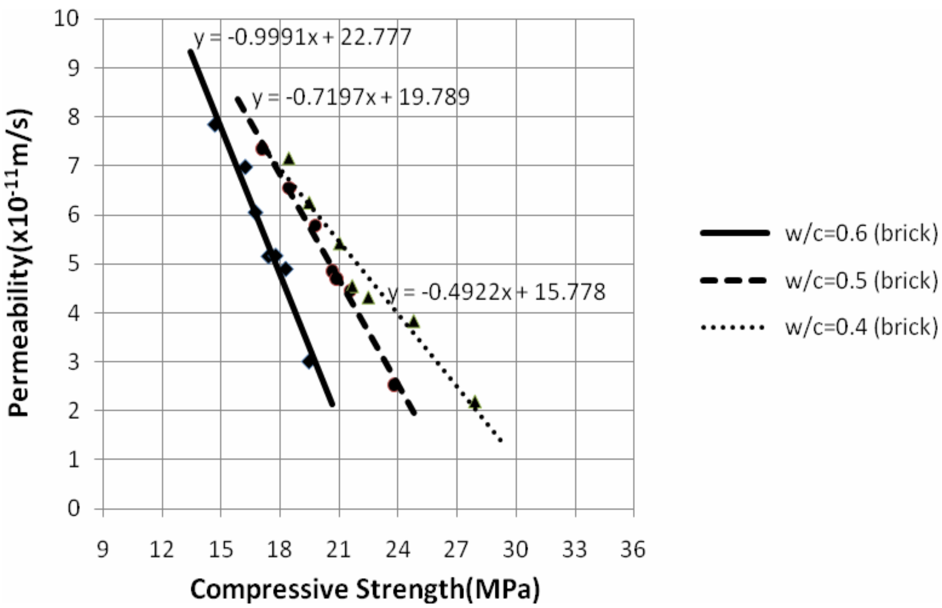

Fig. 4.3: Relationship between compressive strength and permeability with equation (brick aggregate concrete)

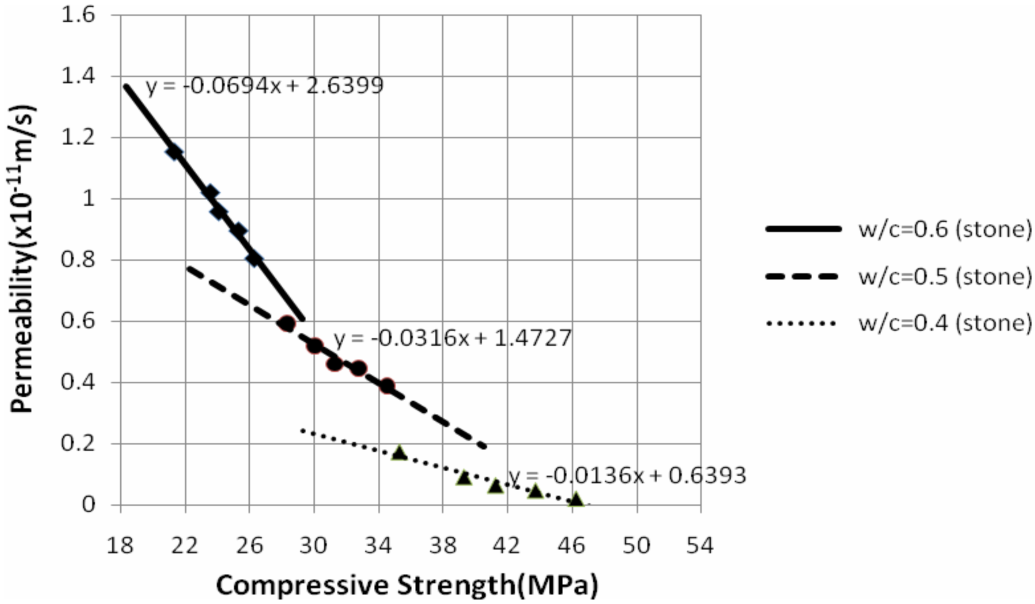

Fig. 4.4: Relationship between compressive strength and permeability with equation (stone aggregate concrete)

4.3 Crushing Strength and Permeability

The crushing strength and permeability are graphically shown in Fig. 4.3. Linear variation is observed between crushing strength of bricks and permeability of concrete made from it. Understandably, increase in brick crushing strength is associated with decrease in permeability. Again, rate of this change remains almost identical for concrete of different strength. For example, if crushing strength of brick increases from 12 to 18 MPa, permeability is reduced from $6.5X10^{-11}$ m/s to $4.5X10^{-11}$ m/s.

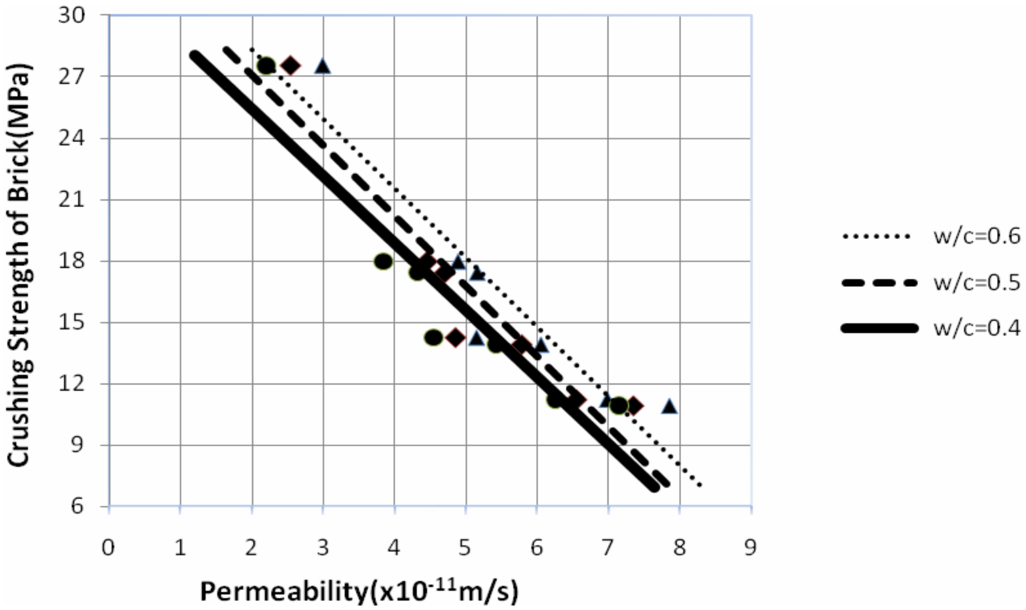

Fig.4.5: Relationship between crushing strength of bricks and permeability

4.4 LA Abrasion and Permeability

LA Abrasion test is an indicator of hardness of aggregate. Higher the LA abrasion value lower is the hardness. Before making concrete, Los Angeles abrasion for both stone and brick aggregate was measured. As shown in Table 3.4 and table 3.5, los ageless value for brick aggregates from 39 to 54 where that of stone aggregate varies from 25 to 31. These values were correlated with permeability of concrete made from them which is shown in Fig. 4.5. As may be predicted, increase in LA value of aggregate is associated with increase in permeability and vice versa. For brick aggregate concrete, the rate of increase associate with increase in LA abrasion value is flatter than what we get in stone aggregate concrete. For brick aggregate with identical LA abrasion value, increase in strength of concrete made from them does not appreciably changes the permeability characteristics of concrete. However, for stone aggregate concrete, increase in strength of concrete made from aggregate having identical LA abrasion value appreciably reduces permeability.

Since, LA abrasion value is far more than what we got in stone aggregate, effective comparison with regard to this parameter could not be made.

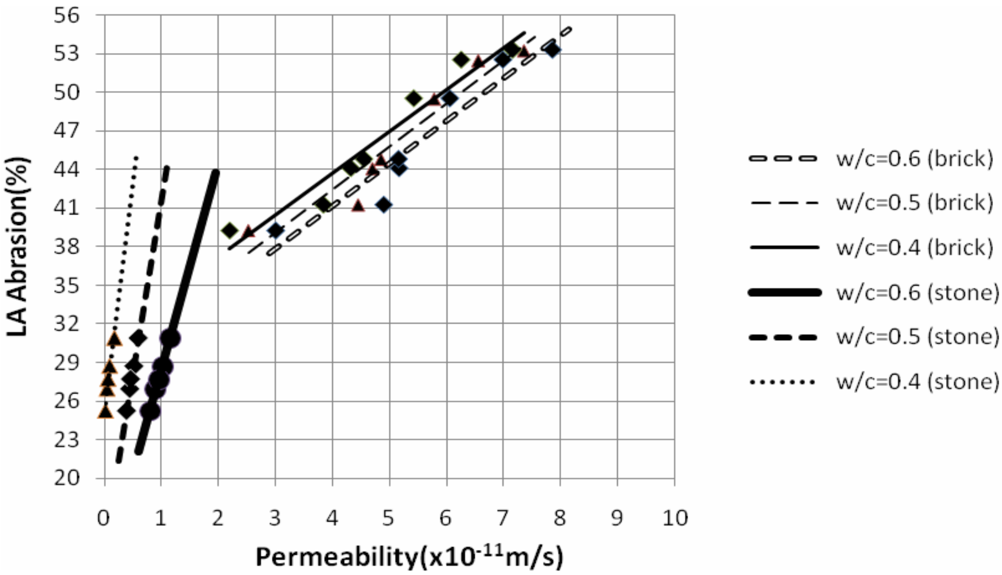

Fig.4.6: Relationship between Loss Angel and permeability

4.5 Unit Weight of Concrete and Permeability

Unit weight of concrete having different strength and made from both brick and stone aggregate were measured and shown in table 4.1 and table 4.2. These are correlated with their respective permeability and presented in Fig. 4.4. As expected, co-efficient of permeability decreases with the increase in unit weight of concrete. Since increase in unit weight is associated with increase in density, concrete becomes less porous and, consequently, less permeable. Interestingly, decrease in permeability of due to increase in unit weight of concrete made from stone aggregate is more pronounced than that of concrete made from brick aggregate which evident from the steep slope for stone aggregate concrete. This may be due to the fact that even though density increases in brick aggregate concrete, the highly porous brick aggregate facilitates in creating flow path inside concrete.

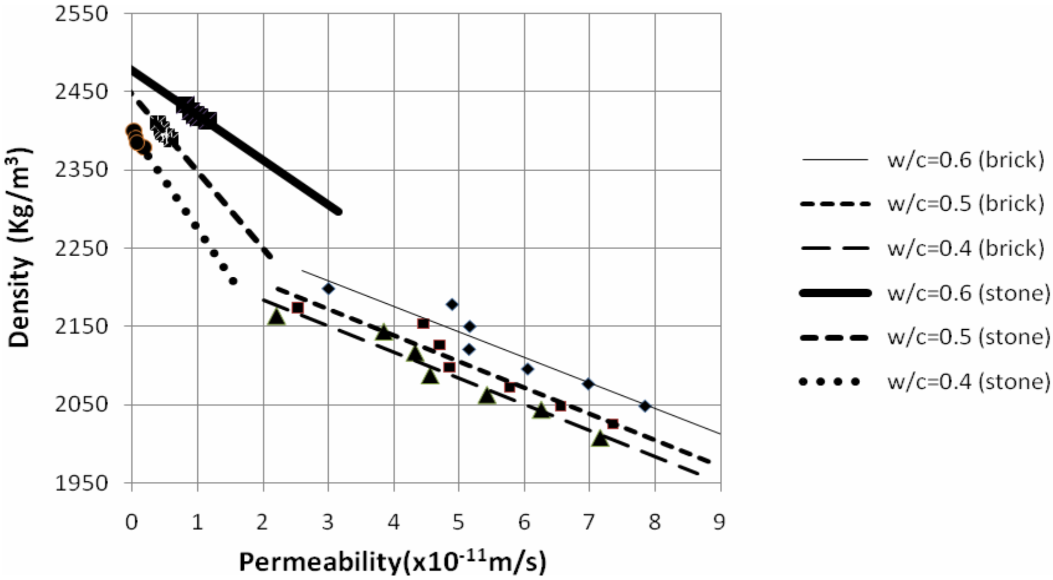

Fig.4.7: Relationship between unit weight of concrete and permeability

4.6 Absorption and Permeability

Absorption of aggregate is, in effect, depends on void spaces i.e. porosity inside aggregate. Therefore, it is understandable that increase in absorption in aggregate is associated with increase permeability of concrete made from them. This is what is found from test results which are shown in Fig. 4.5 and 4.6. Stone has less absorption capacity than brick chips consequently, coefficient of permeability is less in concrete where stone is used as aggregate than where brick chips is used. Similarly, "S" class brick has less absorption capacity than "Inferior" class brick, so coefficient of permeability is less in concrete where "S" class brick is used as coarse aggregate other than where "Inferior" class brick is used. This increase in permeability associated with increase in absorption is found to follow a linear releationship. In case of brick aggregate concrete, 10% decrease in absorption is associated with decrease in permeability value of about $2X10^{-11}$m/s. However, this variation is less pronounced in stone aggregate concrete.

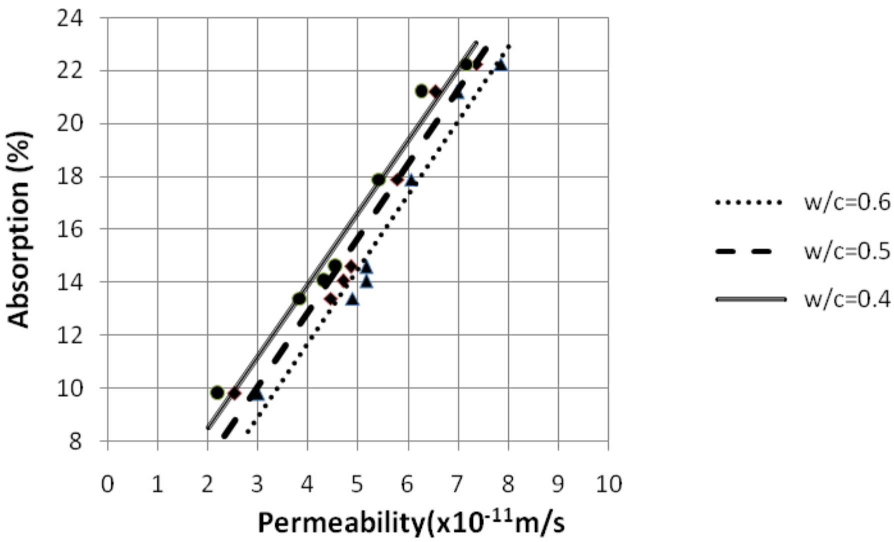

Fig.4.8: Relationship between absorption and permeability of brick chips concrete

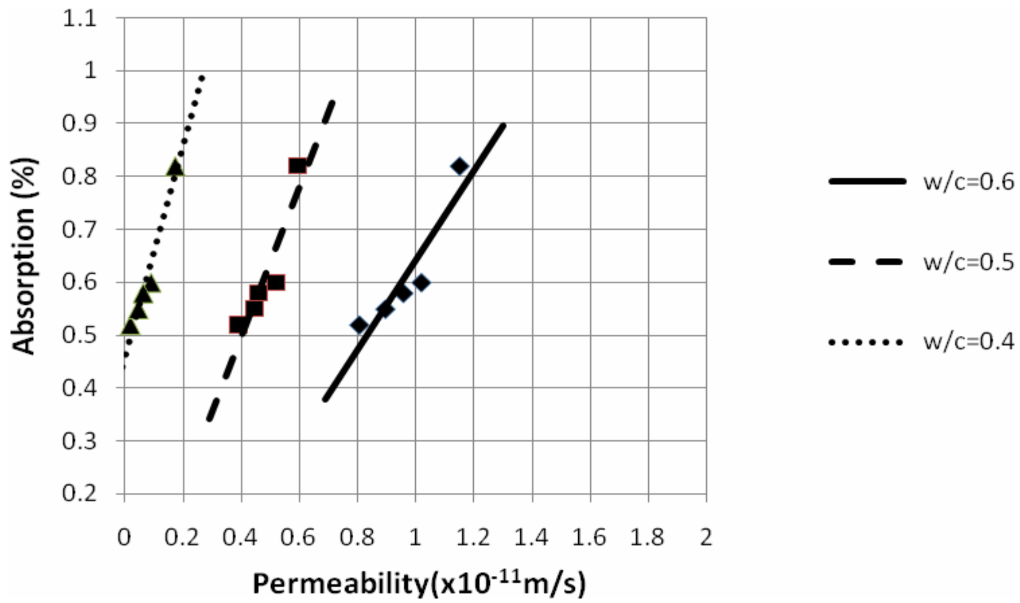

Fig.4.9: Relationship between absorption and permeability of stone chips concrete

4.7 Volume of Coarse Aggregate and Permeability

Flow of water inside concrete mass occurs mainly in the cement- fine aggregate paste that is adhered on the surface of coarse aggregate. For brick aggregate concrete, porosity inside brick aggregate itself helps to create more flow paths thereby increase the resultant permeability of concrete. For this, it was of interest to see how percent volume of brick aggregate in the total concrete mass affects the permeability characteristic of concrete. Consequently, Fig. 4.9 is prepared which shows relationship between permeability of concrete and the share of brick aggregate in the total concrete mass. Again, a linear relationship is observed between these two parameters. However, with respect to absorption of brick aggregate, the sensitivity is far less. Similar relationship is plotted for stone aggregate concrete which is shown in Fig. 4.10. However, here, the sensitivity is found to be even more flat.

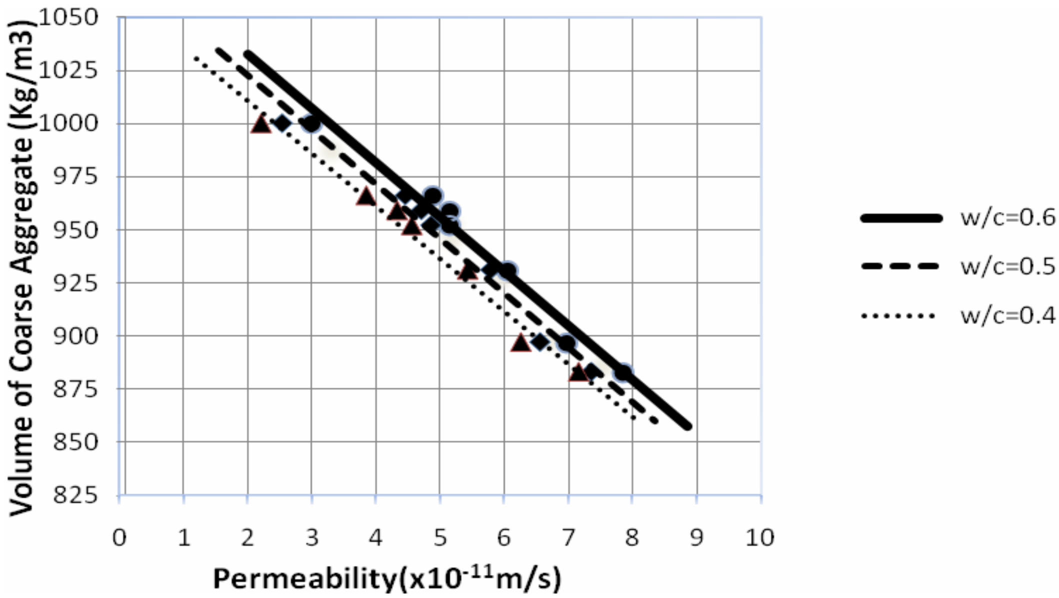

Fig.4.10: Relationship between volume of coarse aggregate (bricks chips) and permeability

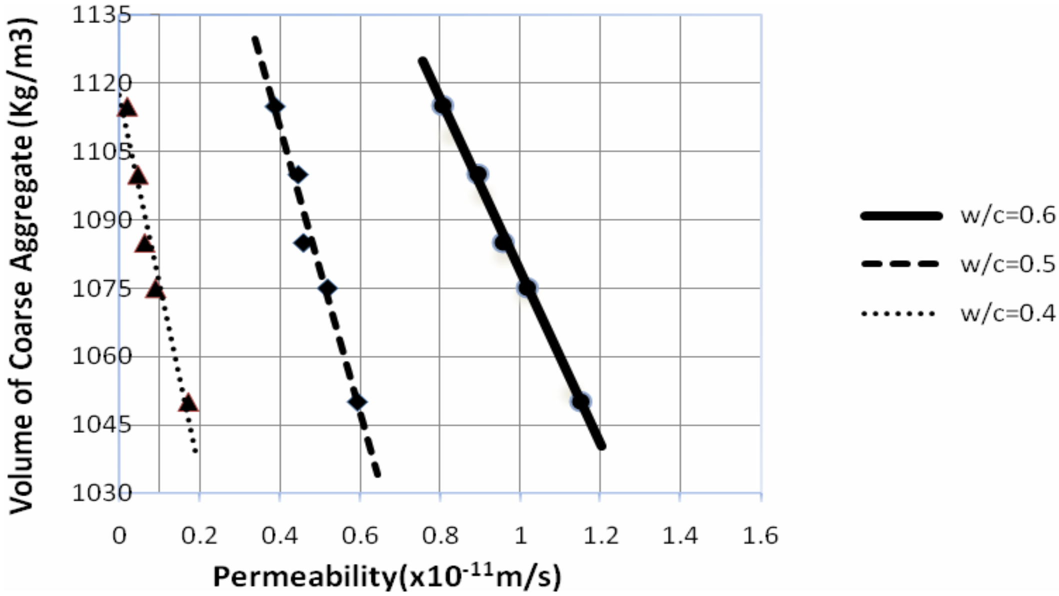

Fig.4.11: Relationship between volume of coarse aggregate (stone chips) and permeability

4.8 Conclusion

From the testing program, it is found that brick aggregate concrete is far more permeable than concrete made from stone aggregate of identical strength. This increase in permeability may range from 200 to 550 percent. Most important parameter of brick aggregate which was found to influence permeability most were its absorption capacity. Further, linear relationship was found between permeability and strength of concrete and permeability and between crushing strength of brick and permeability.

Chapter – 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions:

In this work, permeability characteristic of concrete made from brick aggregate concrete is evaluated and compared with concrete made from stone aggregate. Four different classes of brick according to Bangladesh standard are used in the testing scheme. Before bricks were crushed into aggregate, several tests were conducted to evaluate its different properties. Tests including LA abrasion and density were conducted on aggregate produced from these bricks as well. From these aggregates concrete samples were prepared using ACI mix design methods. Strength of concrete that could be achieved using brick aggregate varied between 14 to 28 MPa. Simultaneously, concrete samples were prepared from stone aggregate. Like brick, representative tests are conducted on stone aggregate. Strength of concrete achieved using stone aggregate concrete varied between 24 to 46 MPa. Relationship between permeability of concrete with several parameters was studied. These parameters include compressive strength of concrete, crushing strength of brick, LA abrasion and unit weight of concrete, absorption and volume of coarse aggregate.

Test results indicate that permeability of concrete made from brick aggregate is far greater than that of concrete made from stone aggregate of identical strength. This increase in permeability depends on classes of bricks used. For example, concrete prepared from S class brick is about 200% more permeable than concrete of identical strength but made from stone aggregate. Further, it was found that permeability of concrete made from brick aggregate is directly influenced by crushing strength of brick, absorption and LA abrasion value of brick aggregate. All of these parameters showed linear variation with permeability of concrete prepared from them. From the test results, following equations are developed so that permeability of brick aggregate concrete may be evaluated when its strength and water cement ratio is known:

$y = (-2.45xa^{1.75} + 39.50a) x10^{-11}$ for brick aggregate concrete

$y = (-0.52xa^{4} + 15.90a^{3.5}) x10^{-11}$ for stone aggregate concrete

Where,

'y' is the permeability in m/s; 'x' is the compressive strength in MPa and 'a' is the water cement ratio

5.2 Recommendations:

1. In the study only seven type bricks and five type stone chips were used. More samples may be used so that better representation of results may be found.

2. Test may be conducted varying water pressure to see its effects on water penetration and permeability.

3. Effect of including admixture on reducing permeability of brick aggregate concrete may be studied in a detail form.

4. Variation in mix design may also be examined in future studies.

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APPENDIX A

Picture of water penetration

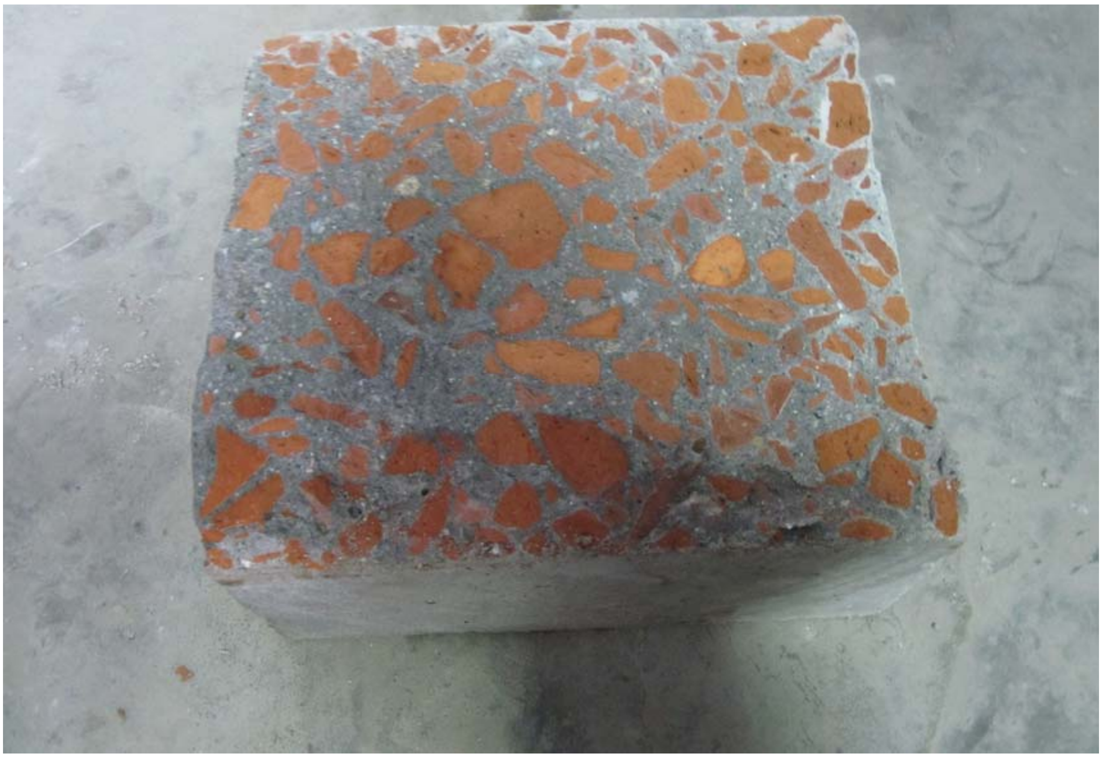

Fig-A1: Wet surface (brick aggregate concrete)

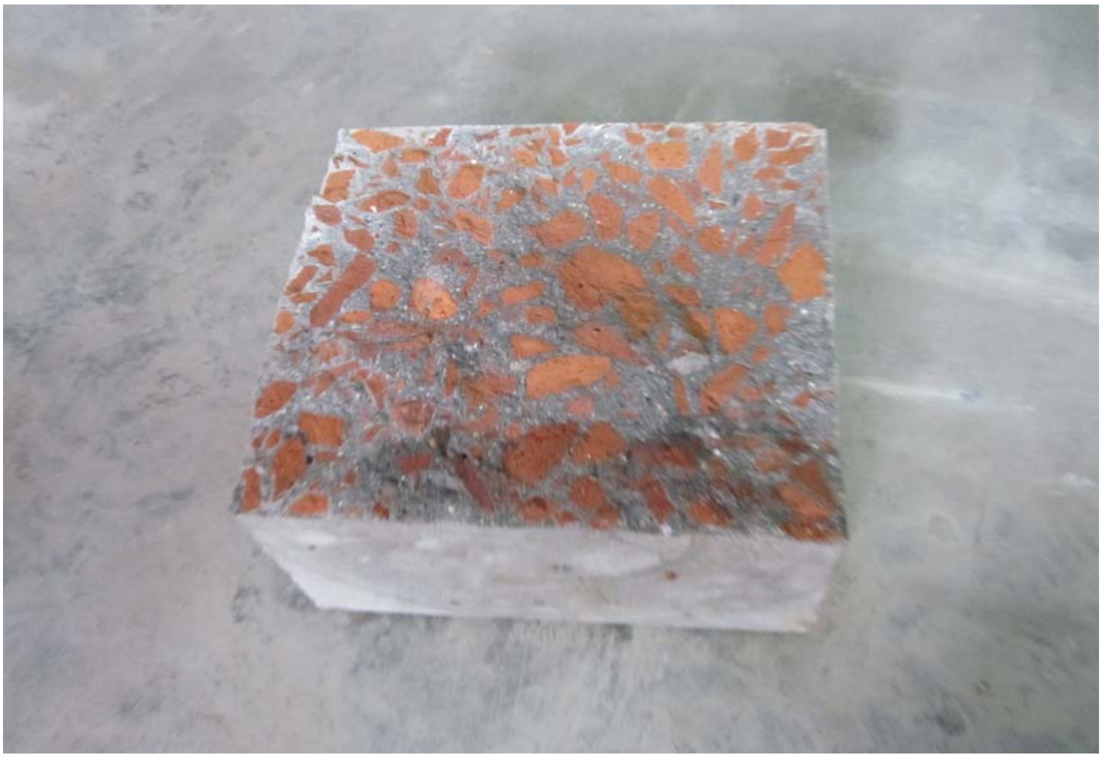

Fig-A2: Wet surface (brick aggregate concrete)

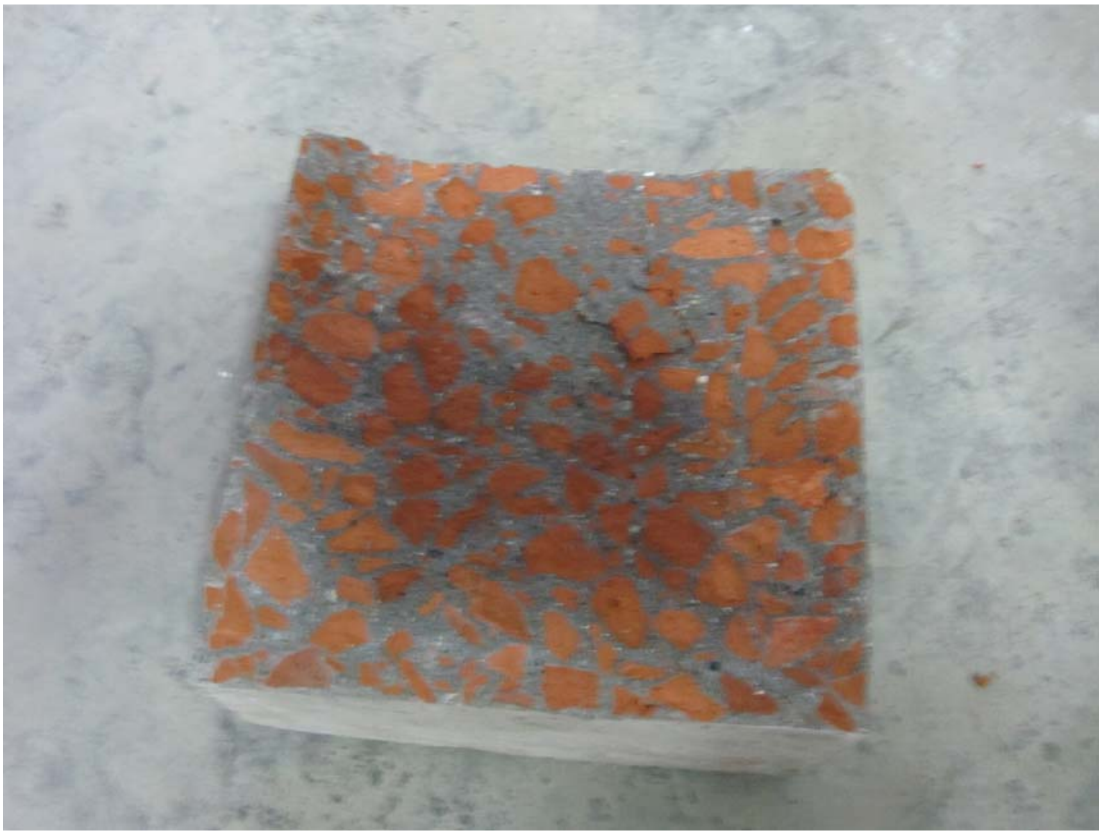

Fig-A3: Wet surface (brick aggregate concrete)

Fig-A4: Wet surface (brick aggregate concrete)

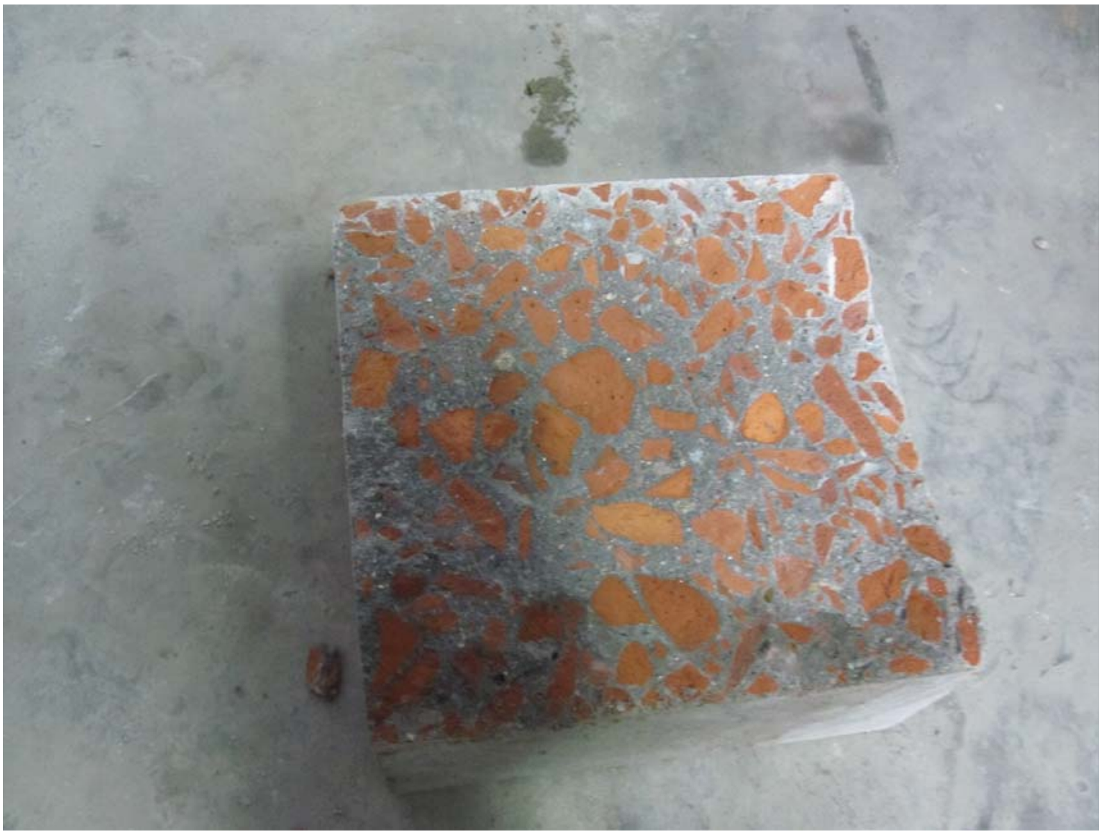

Fig-A5: Wet surface (brick aggregate concrete)

Fig-A6: Wet surface (brick aggregate concrete)

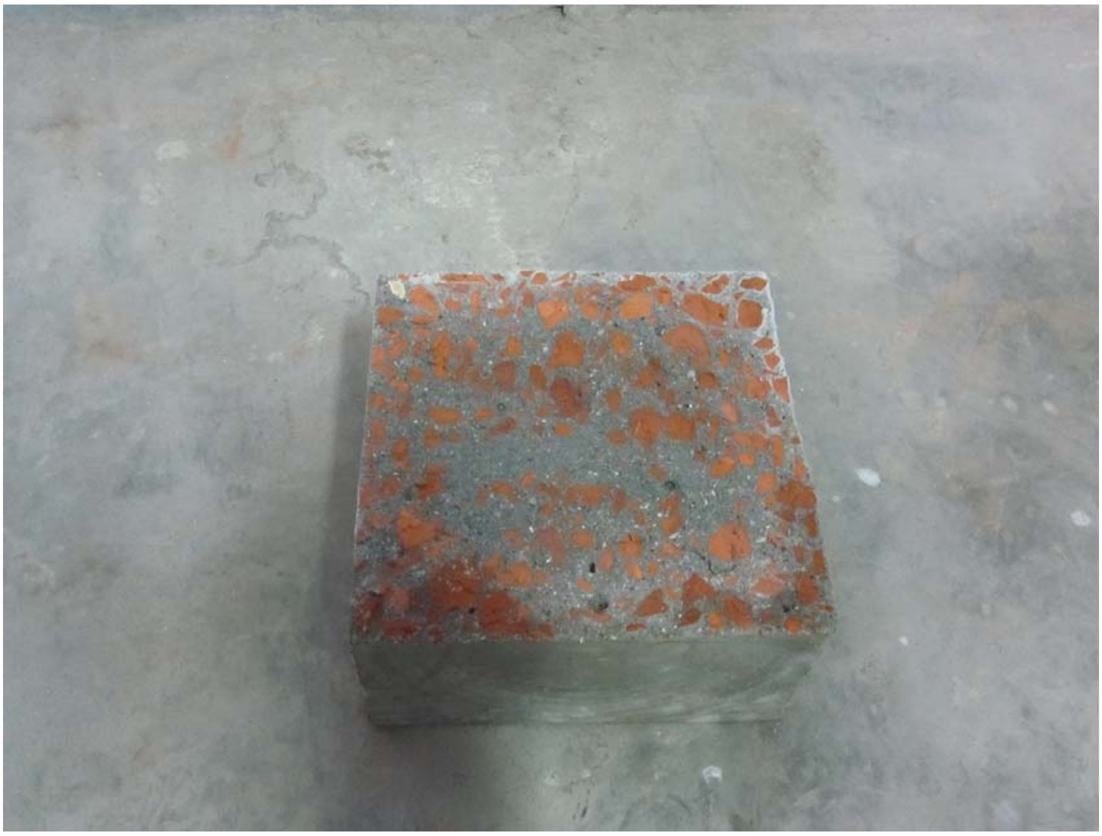

Fig-A7: Wet surface (brick aggregate concrete)

Fig-A8: Wet surface (brick aggregate concrete)

Fig-A9: Wet surface (stone aggregate concrete)

APPENDIX B

Permeability Calculation

a) **Brick aggregate concrete**

$$k = \frac{e^2 v}{2ht} \text{ m/sec.}$$

Here,

e= depth of penetration of concrete = 115 mm = 0.115 m

h= hydraulic head = 50 m

t= time under pressure = 73 h = 73*60*60 s = 262800 s

v= the fraction of the volume of concrete = 0.0658

Therefore,

k = $(0.115^2*0.0658)/(2*50*262800)$ = **3.31×10^{-11} m/s**

b) Stone aggregate concrete

$$k = \frac{e^2 v}{2ht} \text{ m/sec.}$$

Here,

e= depth of penetration of concrete = 40 mm = 0.040 m

h= hydraulic head = 50 m

t= time under pressure = 70 h = 70*60*60 s = 252000 s

v= the fraction of the volume of concrete = 0.0289

Therefore,

k = $(0.040^2*0.0289)/(2*50*252000)$ = **0.183×10^{-11} m/s**