STRENGTH AND DURABILITY PROPERTIES OF BACTERIAL RICE HUSK ASH CONCRETE

A Dissertation Submitted

In Partial Fulfillment of the Requirements

For the degree of

MASTERS OF ENGINEERING

IN

STRUCTURAL ENGINEERING

Submitted by:

KARAMBIR SINGH

(ROLL NO: 801322010)

UNDER THE SUPERVISION OF

DR. RAFAT SIDDIQUE

Senior Professor

Department of Civil Engineering

Thapar University, Patiala

DEPARTMENT OF CIVIL ENGINEERING

THAPAR UNIVERSITY,

PATIALA-147004

JULY 2015

DECLARATION

The author hereby declare that this dissertation entitled *"**STRENGTH AND DURABILITY PROPERTIES OF BACTERIAL RICE HUSK ASH CONCRETE**"*, in whole or part has not been used to obtain any degree in this, or any other, institute, except where references have been given in text, it is entirely the author own work. The author conform that the library may lend or copy this upon request for academic purposes.

(KARAMBIR SINGH)

REGD.NO. 801322010

CERTIFICATE

This is to certify that the work presented in dissertation entitled *"**STRENGTH AND DURABILITY PROPERTIES OF BACTERIAL RICE HUSK ASH CONCRETE**"* submitted by **Mr. Karambir Singh** in partial fulfillment of the requirements for the award of degree of **Master of Engineering** in Structural Engineering at **Thapar University, Patiala,** is a bonafide work carried out by the student under our supervision and guidance. The matter embodied in this report has not been submitted anywhere for award of any other degree.

Dr. RAFAT SIDDIQUE
Senior Professor
Department of Civil Engineering
Thapar University, Patiala

COUNTERSIGNED

31/7/15

Dr. NAVEEN KWATRA
Professor and Head
Department of Civil Engineering
Thapar University, Patiala

Dr. S.S. BHATIA
Dean, Academic Affairs
Thapar University, Patiala

ACKNOWLEDGEMENT

This acknowledgement is intended to be thanks giving to all those people who have been involved directly or indirectly with my thesis work.

First and foremost, I would like to express my thanks and indebtedness to my guide Dr Rafat Siddique, Sr. Professor of Civil Engineering, Thapar University, Patiala for his deep involvement, invaluable and continuous motivation throughout this work. I am highly obliged to him for being there always whenever I needed him.

I would like to thank Dr. Naveen Kwatra, Head, Civil Engineering Department, Thapar University, Patiala who has been a constant source of inspiration for me throughout this work.

Special thanks to Dr. Kunal for his valuable suggestions and help during the thesis testing writing.I do not find enough words with which I can express my feeling of thanks to entire faculty and staff of Civil Engineering Department, Thapar University Patiala for their help, inspiration and moral support, which went a long way in successful completion of my thesis work.

Finally, I would like to dedicate this project work to my parents who have always been a great source of support and encouragement, especially in all my academic endeavours.

ABSTRACT

Concrete is most widely used construction material used all over the world and usually considered as indestructible because of their longer service life as compared with the most constructional products. However, continuous exposure of hard weathering leads to an increase of the porosity of concrete and as a result, the mechanical features decreases. The permeability of the concrete depends on the porosity and on the connectivity and /or structure of the pores. A unique way of concrete design crossbreed between biology and engineering study of concrete called microbial concrete has been introduced, which involves the utilization of bacteria to increase the strength and durability of concrete. These microorganisms are used for calcium carbonate precipitation in concrete, it is highly desirable because the calcite precipitation induced as a result of microbial activities is pollution free and natural. The Calcite precipitation occupies the voids between cement matrixes and therefore leads to denser concrete. The approach does not deplete any natural resources since the bacteria used can be easily reproduced by cultivation process. The use of biological approach in concrete is also considered as a green technology as its production does not involve greenhouse gas emission.

The significant objective of the research work further involved the use of bacteria. The bacteria present in the concrete rapidly sealed freshly formed cracks through calcite production. In concrete mix, 0, 5, 10, 15 and 20% cement weight was replaced with rice husk ash. The experiments were carried out to evaluate the effect of bacteria of concentration 10^5cfu/ml on the compressive strength, water absorption, water porosity, abrasion and rapid chloride permeability of concrete made with rice husk ash up to the age of 7, 28 and 56 days.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

LIST OF ABBREVIATIONS

BR	Bacterial rice husk ash concrete
C	Coulombs
cfu	Colony forming unit
Fig	Figure
g	Grams
h	Hours
hcp	Hydrated cement paste
MICP	Microbiologically induced carbonate precipitate
mins	Minutes
ml	Millilitre
mm	Millimetre
MPa	Mega Pascal
R	Control rice husk ash concrete
RHA	Rice hush ash
OPC	Ordinary Portland cement
sec	Seconds

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Concrete is a composite material consisting of relatively inert aggregate particles, with a wide size distribution and variable mineralogical composition, embedded in a matrix of hydrated cement paste (hcp). The hardened matrix itself is derived from hydration reactions between Portland**,** cement and water. Producing cement is an energy intensive process and harmful to the environment. Globally, 1.5 billion tons of cement are used each year. Cement production releases approximately one ton of CO_2 for every ton of cement produced, which makes up 7% of all CO_2 emissions produced globally (Mehta and Monteiro, 2014).

So, in addition to portland cement, water, and aggregates, modern concretes generally contain at least some of the following additional ingredients:

- Chemical admixtures.
- Pozzolanic materials, such as fly ash, silica fumes, or blast furnace slag.
- Discontinuous fibers, made of steel, glass, or natural, synthetic, or organic materials, which are used in fiber reinforced concrete.

1.2 DURABILITY OF CONCRETE

According to the American Concrete Institute in ACI 116 R durability of concrete is defined as its ability to resist weathering action, chemical attack, abrasion, and other conditions of service. Also durability of concrete is defined as the capability of concrete by itself of keeping the original properties for a certain period.

1.2.1 Methods to Improve Durability

i. **Chemical Methods**: By applying epoxy coating which thereby reduces steel contact with water and oxygen. Also penetrating sealer siloxane can be used, as these materials combine with siliceous portions of cement and aggregates.

`

ii. **Development of Self-Healing Bacterial Concrete (Biological Method):** A novel technique for the remediation of damaged structural formations has been developed by employing a selective bacterial plugging process, in which metabolic activities promote precipitation of calcium carbonate in the form of calcite. Biomineralisation of calcium carbonate is one of the strategies to remediate cracks in building materials.

iii. **Physical methods**: Use of pozzolans like silica fume, fly ash can improve the concrete durability by enhancing impermeability and chemical durability. Sulfate resistance in concrete can be improved by incorporating supplementary cementing materials.

1.3 SUPPLEMENTARY CEMENTITIOUS MATERIALS

In its most basic form, concrete is a mixture of portland cement, sand, coarse aggregate and water. The principal cementitious material in concrete is portland cement. Today, most concrete mixtures contain supplementary cementitious materials that make up a portion of the cementitious component in concrete. These materials are generally byproducts from other processes or natural materials. They may or may not be further processed for use in concrete. Some of these materials are called pozzolans, which by themselves do not have any cementitious properties, but when used with portland cement, react to form cementitious compounds (ACI 116, 2000)

1.3.1 Need for Supplementary Materials

Supplementary cementitious materials can be used for improved concrete performance in its fresh and hardened state. They are primarily used for improved workability, durability and strength. These materials allow the concrete producer to design and modify the concrete mixture to suit the desired application. Concrete mixtures with high portland cement contents are susceptible to cracking and increased heat generation. These effects can be controlled to a certain degree by using supplementary cementitious materials. Supplementary cementitious materials such as fly ash, slag and silica fume, metakaolin and rice husk ash enable the concrete industry to use hundreds of millions of tons of by product materials that would otherwise be landfilled as waste. Furthermore, their use reduces the consumption of portland cement per unit volume of concrete. Portland cement has a high energy consumption and

`

emissions associated with its manufacture, which is conserved or reduced when the amount used in concrete is reduced.

1.4 RICE HUSK ASH

1.4.1 Scenario of Rice Production

More than half of the world's population depends on rice as a staple food and therefore, it ranks second to wheat in terms of cultivation area and production. According to Food and Agriculture Organization of the United Nations (F.A.O), world production of rice has risen steadily increased from about 150 million tonnes of paddy rice in 1960 to over 740 million tonnes in 2013. The global production of paddy in the continents is shown in Table 2.1**.** The maximum paddy is grown in Asia accounting for over 90% of the world production of paddy.

Table 1.1: Global rice paddy production in 2013 (F.A.O., 2013)

Continents	Paddy Production(million tonnes)
Asia	671
North America	8.6
South America	24.5
Europe	3.89
Africa	28.7
Oceania	11.7

Paddy, on an average, consists of about 72 % of rice, 5-8 % of bran, and 20-22 % of husk. Of all the plant residues, the ash of rice husk contains the highest proportion of silica. It is estimated that every tonne of paddy produces about 0.20 tonnes of husk and every tonne of husk produces about 0.18 to 0.20 tonnes of ash, depending on the variety, climatic conditions and geographical location (Bouzoubaa and Fournier, 2001).

1.4.2 Production of Rice Husk Ash

Rice husk ash is produced by incinerating the husks of rice paddy. Rice milling generates a by product know as husk. This surrounds the paddy grain. So during milling of paddy, about 78 % of weight is received as rice, broken rice and bran .Rest 22 % of the weight of paddy is received as husk. This husk is used as fuel in the rice mills to generate steam for the

`

parboiling process. This husk contains about 75 % organic volatile matter and the balance 25 % of the weight of this husk is converted into ash by controlled incrination, is known as rice husk ash (RHA).

1.4.3 Forms of Silica In RHA

Rice husk ash contains about 87-97 % of silica with small amount of alkalis and other trace elements. Based on temperature range and duration of burning of the husk, crystalline and amorphous forms of silica are obtained. The crystalline and amorphous forms of silica have different properties and it is important to produce ash with correct specifications for specific end use. Generally, the amorphous forms of silica are composed of silica tetrahedral arranged in a random three-dimensional network without regular lattice structures. Due to disordered arrangement, structure is open with holes in the network where electrical neutrality is not satisfied and the specific surface area is also large. This helps to increase the reactivity, since large area is available for reaction to take place.

1.4.4 Physical Properties of Rice Husk Ash

The physical properties of RHA largely depend on burning conditions. Particularly, the period and temperature of burning affect the microstructure and characteristics of RHA, (Nagataki, 1994). The partial burning of rice husks produces black RHA whereas the complete burning results in either white or grey RHA (Ismail and Waliuddin, 1996). In addition, the uncontrolled burning at high temperature produces crystalline RHA, which possesses poor pozzolanic property. Conversely, the controlled burning at about 500 to 800ºC results in non crystalline or amorphous silica, which shows very high pozzolanic activity (Nagataki, 1994). The burning condition also affects relative density of RHA. The relative density of grey RHA obtained from complete burning ranges between 2.05 to 2.11. (Ismail and Waliuddin, 1996)

Table 1.2 Physical Properties of RHA by some authors

Property		Value		
	Khani et al. (2009)	Habeeb et al. (2010)	Van et al.(2014)	Kishore et. al.(2011)
Specific Gravity	2.15	2.11	2.19	2.27
Colour	Grey	Black	Black	Black

`

1.4.5 Chemical Properties

The chemical composition of rice husk ash is almost similar to that of many organic fibres and contains cellulose (a polymer of glucose), lignin-a polymer of phenol, hemicelulose- a polymer of xylose and silicon dioxide which is the primary component of ash (Hwang and Wu, 1989). After burning, most evaporable components are slowly lost and the silicates are left. The characteristics of the ash are dependent on the components, temperature and time of burning (Mehta, 1992). In order to obtain an ash with high pozzolanic activity, the silica should be held in a non-crystalline state and in a highly microporous structure. Hence, the burning process should be controlled to remove the cellulose and lignin portion while preserving the original cellular structure of rice husk. The chemical composition of some authors are listed below

Table 1.3 Chemical composition of RHA by some of the authors

Constituents (%)	Khani et al. (2009)	Van et al. (2014)	Bui et al. (2005)	Ganesan et al. (2008)
Silica (SiO_2)	89.61	87.4	86.98	87.32
Alumina(Al_2O_3)	0.04	0.4	0.84	0.22
Iron Oxide(Fe_2O_3)	0.22	0.3	0.73	0.28
Calcium Oxide(CaO)	0.91	0.9	1.4	0.48
Magnesium Oxide(MgO)	0.42	0.6	0.57	0.28
Sodium Oxide(Na_2O)	0.07	0.04	0.11	1.02
Potassium Oxide(K_2O)	1.58	3.39	2.46	3.14
Sulpher Trioxide(SO_3)	–	0.4	–	–
Loss of ignition	5.91	4.6	5.14	2.10

1.4.6 RHA in Concrete

In concrete, the RHA mainly serves as a microfiller, pozzolan, and viscosity modifier. The RHA particles can fill the voids between the larger cement grains because of their smaller size. However, the microfilling ability of RHA is not as effective as silica fume. This is because the RHA particles are much larger than the silica fume particles. The typical median particle size of RHA is about 7 µm, while particle size of the cement and silica fume is 13 µm

`

and 0.1 μm, respectively (Zhang and Malhotra, 1996). Although RHA is not very fine in particle size, it behaves as a very reactive pozzolanic material because of its extreme surface fineness and high silica content (Mehta, 1992). In the presence of water, the RHA actively reacts with $Ca(OH)_2$ liberated during cement hydration (pozzolanic reaction) and produces additional calcium silicate hydrate (CSH),

Hydration reaction:

$$C_2S \text{ or } C_3S + H_2O \rightarrow \text{primary CSH} + Ca(OH)_2 \qquad \text{(Equation 1)}$$

Pozzolanic reaction:

$$Ca(OH)_2 + \text{RHA } (SiO_2) + H_2O \rightarrow \text{secondary CSH} \qquad \text{(Equation 2)}$$

The pozzolanic reaction product fills the pores existing between cement grains and results in dense calcium silicate hydrate. Both microfilling and pozzolanic effects of RHA play an important role to refine the pore structure in bulk paste matrix and interfacial transition zone of concrete. The pore refinement occurring due to the secondary reaction between RHA and $Ca(OH)_2$ makes the microstructure of concrete denser and improves the interfacial bond between aggregates and binder paste. As a result, the strength, transport properties and durability of concrete are improved.

1.4.7 Advantages of Using Rice Husk Ash

Use of rice husk ash in concrete gives following advantages:

(i) high compressive strength;
(ii) high tensile, flexural strength, and modulus of elasticity;
(iii) very low permeability to chloride and water intrusion
(iv) enhanced durability
(v) increased toughness
(vi) increased abrasion resistance on decks, floors, overlays and marine structures
(vii) superior resistance to chemical attack from chlorides, acids, nitrates and sulfates and life-cycle cost efficiencies;
(viii) higher bond strength
(ix) high electrical resistivity and low permeability

`

1.5 BACTERIAL CONCRETE

There is a technique that remediates cracks and fissures in concrete with Microbiologically Induced Calcium carbonate Precipitation (MICP) a process by which living organisms form inorganic solids (Stocks et al., 1999). By this process a new additional calcite layer on the surface of the already existing highly insoluble concrete layer is formed. Thus, it resists the penetration of harmful solutions like alkalis, sulphates etc into the concrete thereby decreasing the deleterious effects they may cause and increasing durability (Ramakrishnan et al., 2001).

1.5.1 Bacteria

Bacteria can be defined as a very large group of micro organisms comprising one of the three domains of living organisms. They are prokaryotic, unicellular and either free living in soil or water or parasites of plants or animals. Bacteria help in recycling nutrients by process of fixation of nitrogen from the atmosphere. Recently, it has been found that bacteria are used in concrete as a self healing agent.

1.5.2 Morphology of Bacteria

i. Size

Cells are the fundamental units of living things from the smallest bacterium to the largest of the plants and animals. Bacteria, the smallest cells are only visible with the aid of a microscope. The smallest bacteria can be only 0.1 to 0.2 µm in diameter whereas larger bacteria may be many microns in length. A newly described species is hundred times more larger than the average bacterial cell and is visible to the naked eye. Most species, however, are approximately 1 µm in diameter and are therefore visible using the light microscope which has a revolution of 0.2 µm. In comparison animal and plant cells are much larger ranging from 7 µm to several feet.

ii. Shape

a. The first shape is called coccus, plural cocci. Cells that have a cocci shape are spherical, resembling tiny balls. The 'strep' in strep throat actually refers to the bacterium Streptococcus, which exists in tiny, spherical cells.

`

b. The second shape is bacillus, plural bacilli. These bacteria are shaped like small rods, longer than they are wide. A bacillus cell looks a lot like a pill. . Some bacilli bacteria have round ends, while others are square. It is important to note that the term 'bacillus' can describe the cell shape as well as bacteria in the genus bacillus.

c. The third bacterial shape is spiral. These bacterial cells are twisted in helices and resemble little corkscrews.

1.5.3 Processes involved in $CaCO_3$ Precipitation

Ureolytic bacteria are able to precipitate $CaCO_3$ in their micro-environment by conversion of urea into ammonium and carbonate. The bacterial degradation of urea locally increases the pH and promotes the microbial deposition of carbonate as calcium carbonate in a calcium rich environment. These precipitated crystals can thus fill the cracks (Tittelboom et al, 2010) The microbial precipitation of $CaCO_3$ is determined by several factors including: the concentration of dissolved inorganic carbon, the pH, the concentration of calcium ions and the presence of nucleation sites (Hammes et al, 2003a). The bacteria produces urease which catalyzes the hydrolysis of urea ($CO(NH_2)_2$) into ammonium (NH_4^+) and carbonate (CO_3^{2-}). First, 1mol of urea is hydrolysed intracellular to 1mol of carbamate and 1mol of ammonia as shown in (Eq. 3)

$$CO(NH_2)_2 + H_2O \longrightarrow NH_3 + NH_2COOH \quad (3)$$

Carbamate spontaneously hydrolyses to form additionally 1mol of ammonia and carbonic acid (Eq. 4).

$$NH_2COOH + H_2O \longrightarrow NH_3 + H_2CO_3 \quad (4)$$

These products subsequently form 1mol of bicarbonate and 2mol of ammonium and hydroxide ions (Eqs.5 and 6).

$$H_2CO_3 \longleftarrow \text{equilibrate in water} \longrightarrow H^+ + HCO_3 \quad (5)$$
$$2NH_3 + 2H_2O \longleftarrow \text{equilibrate in water} \longrightarrow 2NH_4^+ + 2OH^- \quad (6)$$

`

The last 2 reactions give rise to a pH increase, which in turn shifts the bicarbonate equilibrium, resulting in the formation of carbonate ions (Eq. 7) (Dick et al, 2006)

$$HCO_3^- + H^+ + 2NH_4^+ + 2OH^- \longleftrightarrow CO_3^- + 2NH_4^+ + 2H_2O \qquad (7)$$

Since the cell wall of the bacteria is negatively charged, the bacteria draw cations from the environment, including Ca^{2+}, to deposit on their cell surface. The Ca^{2+}-ions subsequently react with the CO_3^{2-}-ions, leading to the precipitation of $CaCO_3$ at the cell surface that serves as a nucleation site (Eqs. 8 and 9).

$$Ca^{2+} + Cell \longrightarrow Cell.\ Ca^{2+} \qquad (8)$$

$$Cell.\ Ca^{2+} + CO_3^{2-} \longrightarrow Cell.\ CaCO_3 \downarrow \qquad (9)$$

1.5.4 Applications

i. Bioremediation of Cracks

BCP is a good sealant as it forms a new layer above the surface of the old concrete layer. This further enhances the strength and durability of the structure as this crack sealing results in decrease in water permeability. This method has been used to conserve natural stone monuments. Cracks filled with a mixture of *B.pasteurii* and sand showed a significant increase in compressive strength and stiffness, compared to cracks without cells (Ramachandran et al, 2001) whereas *B. sphaericus* was used for bioremediation of cracks (De Muynck et al, 2009)

ii. Biodeposition on Cementitious Materials

Cementitious materials (stone, concrete, mortar) are prone to ingress of water and other deleterious substances that lead to their deterioration. Therefore surface treatments play an important role in protection of such materials. The deposition of a layer of $CaCO_3$ on the surface of the material results in a decrease in the permeation properties of the material thus improving their durability (De Muynck et al., 2006)

iii. Concrete and steel are arguably the most widely used construction materials in the world today. Steel bars are embedded in concrete to produce stronger building structures and the concrete provides the added benefit of protecting the steel bars from the elements. Bacteria which have been used to create excellent water purification effect comprises:

`

- *Bacillus subtilis,*
- *Bacillus thuringiensis,*
- *Bacillus sphaericus.*

These bacterial cells have sufficient resistance against strong alkalinity even after they are mixed in the cement paste and against high temperature during production process

iv. Biomanufactured bricks

At American University of Sharjah, investigation in biomanufacturing of bricks by MICP process as a substitute to clay-fired bricks was done and results were found to be positive. (Sarda et al., 2010)

v. Improve durability of bricks

Most of the deterioration of brick structures takes place because of the presence of moisture. Sarda et al., 2009 were able to increase brick strength by reducing water absorption up to 45%. In this method deposition of calcite on the surface and in voids of the bricks reduced the water absorption

`

CHAPTER 2

LITERATURE REVIEW

2.1 EFFECT OF RICE HUSK ASH ON CONCRETE PROPERTIES

2.1.1 Workability

Using grade 30 and 40 of ordinary portland cement, Bui et al (2005) investigated the influence of rice husk ash on slump of concrete mixtures. Cement was replaced with 10, 20 and 30% of cement. The water binder ratio was kept constant at 0.34. It was seen that the slump decreased with increase in rice husk ash for same level of superplastisizer.

Ismail and Waliuddin (1996) reported the effect of rice husk ash passing through #200 and #325 sieves as 10-30% partial replacement of cement on workability of high strength concrete. Mix proportion ratio was set as 1:1.07:1.90 with cement content of 571 kg/m^3.It was seen that with minor variations slump values and density decreased with increase in RHA content.

Khassaf et al. (2014) studied the effect of rice husk ash on slump of the concrete. Water cement ratio was kept constant at 0.58 while cement was replaced by 10, 20 and 30 % of mass. Values of slump were 70, 55, 45 and 15 mm for 0, 10, 20 and 30% replacement of cement by mass respectively. This showed that the value of slump decreased with the increasing amount of rice husk ash.

2.1.2 Compressive Strength

The property of a material to withstand axially directed pushing force is called compressive strength. This property and durability depend on the microstructure of the concrete.
Sensale (2006) studied the development of compressive strength up to 91 days of concretes with RHA, in which residual RHA from a rice paddy milling industry in Uruguay (UY-RHA) and RHA produced by controlled incineration from the USA (USA-RHA) were used for comparison. Two different replacement percentages of cement by RHA, 10% and 20%, and three different water/cement ratios (0.50, 0.40 and 0.32), were used. It was seen that

`

i. At 7 days, concretes with UY-RHA exhibited higher compressive strength than concretes with US RHA,
ii. At later stage of 91 days, RHA concrete had higher compressive strength than concrete without RHA,
iii. Long term compressive strength of the concretes with UY RHA was not as high one obtained with US RHA,
iv. At higher age in w/c ratios of 0.32 and 0.40, concretes with 10% replacement showed maximum strength in UY RHA while concretes with 20% showed maximum strength for USA RHA while for w/c ratio of 0.50 maximum strength was obtained by 10% replacement by both UY and USA RHA.

Givi et al (2010) studied the development of the compressive strength of concrete by partial replacement of cement with agro-waste rice husk ash. Two types of rice husk ash with average particle size of 5 µm (ultra fine particles) and 95 µm and with four different contents of 5%, 10%, 15% and 20% by weight were used. Replacement of cement up to maximum of 15% and 20% respectively by 95 and 5 um rice husk ash, produced concrete with improved strength .The results of the compression test are shown in the Table 2.1

.

Table 2.1 Compressive strength results (Givi et al, 2010)

Sample designation	RHA %	Compression strength (MPa)		
		7 day	28 day	90 day
C (control)	0	27.3	36.8	42.3
M1	5	25.7	38.7	43.5
M2	10	25.1	40.6	46.1
M3	15	23.7	37.9	42.7
M4	20	21.5	36.7	41.3
U1	5	27.4	39.9	45.8
U2	10	28.3	43.8	51.2
U3	15	25.9	39.1	44.4
U4	20	24.6	38.3	42.8

*M1, M2, M3, M4-RHA with 95 um size used as 5, 10, 15 and 20% replacement of cement

*U1,U2, U3, U4- RHA with 5 um size used as 5, 10, 15 and 20% replacement of cement

`

<u>For M series</u>

- Comparison of the results from the 28 and 90 days samples showed that the compressive strength increased by replacing the cement with RHA up to 10% replacement and then it decreased, although specimens with 15% replacement were still giving higher compressive strength than those of the control concrete
- Replacing the cement by 20% rice husk ash decreased the compressive strength to a value which was lower than that of control concrete.
- The compressive strength declined for the samples at 7 days in the presence of RHA compared to the control concrete. This decline in early age strength is as a result of low pozzolanic activity of RHA due to its coarser particles. Additionally, the reduction in volume of hydration products due to less favourable hydration rate is expected to result in a decrease in the early age strengths

<u>For U series</u>

- Concrete samples made with the ultra fine RHA particles showed considerably higher strength than those made with the coarser RHA for all cement replacement ratios.
- The compressive strengths of the U series mixtures are higher than that of the control concrete at all ages apart from the U3 and U4 series at 7 days which are slightly lower than C series at the same age.
- The highest enhancement in compressive strength of the U series was obtained similar to M series for RHA content of 10% at 90 days age.
- The compressive strength of U4 at 90 days age becomes approximately equivalent with C at the same age.

Habeeb and Mahmud (2010) studied compression properties of 0 to 20 % RHA replacement of cement. It was found RHA concrete gave excellent improvement in strength for 10% replacement (30.8% increment compared to the control mix), and up to 20% of cement could be valuably replaced with RHA without adversely affecting the strength. The results showed that at early ages the strength was comparable, while at the age of 28 days, finer RHA concrete exhibited higher strength than the concrete with coarser RHA. At replacement level of 10%, the percentage of increment for RHA concretes compared to the control OPC mix were 22.2, 26.7 and 30.8% for 5, 10 and 15 % replacement, respectively.

`

Saraswathy and Song (2007) investigated the effect of rice husk ash as partial replacement of fine aggregate on the compressive strength with cement replacement of 0 to 30% and 28 days of curing. Compressive strength test was carried out in concrete cubes of size 100 mm using 1:1.5:3.0 mix with W/C ratio of 0.53. It was concluded that the compressive strength for all replacement levels increased with blending percentage and with age. The maximum strength at 7 days was found to be at 30% cement replacement of rice husk ash while at 28 days it was found to be at 25 % cement replacement.

2.1.3 Rapid Chloride Permeability Test

Saraswathy and Song (2007) investigated the effect of partial replacement of cement with rice husk ash on chloride permeability of concrete. Mix proportion was fixed as 1:1.5:3 with w/c ratio 0.53. RHA was replaced with 0 to 30 % cement. Test was conducted according to ASTM C 1202-94 test method. Concrete specimens with and without rice husk ash were casted and allowed to cure for 28 days. Rapid chloride permeability charge passing through concretes made with 0%, 5%, 10%, 15%, 20%, 25% and 30% cement replacement were 1161, 1108, 653, 309, 265, 213 and 273 C respectively. So it can be seen that the replacement of cement with rice husk ash drastically reduced the coulomb values. As the replacement increased, the chloride penetration decreased. The maximum drop in charge was seen from 5 to 10% of replacement when the charge decreased by 52.6 %.

At 100 days, Coutinho (2003) determined the rapid chloride permeability of concrete with partial replacement of cement with RHA at 10, 15, 20%. From the results it was seen that 2349.3, 435, 322, 260 C of charged passed at 0, 10, 15, 20 % replacement of cement by rice husk ash. It is evident from the result that the inclusion of RHA significantly reduced the charge passed. The maximum decrease in charge came between 0 and 10% when there was a decrement of 81.4%.

Zhang and Malhotra (1996) investigated the chloride ion penetration resistance of concretes made with 10% RHA. Water cement ratio was kept constant at 0.40 and the testing was done after 28 and 90 days of curing. The values of chloride ion resistance control concrete after 28 and 90 days were 3175 and 1875 C respectively whereas the values for 10% replacement after 28 and 90 days were 875 and 525 coulombs respectively. So after replacement of 10% cement by rice husk ash, chloride ion penetration decreased by 72.4% after 28 days and by 72% after 90 days. All these values are less than 1000 C. As per ASTM C1202 when charge

`

passing through concrete is less than 1000 C than the concrete has very high resistance to chloride ion penetration.

Ganesan et al (2008) determined the optimum level of replacement for permeability properties of concrete. In this, eight different proportions of concrete mixes (RHA ranging from 5% to 35% by weight of cement) including the control mix were prepared with a water to binder W/(C + RHA) ratio of 0.53. Cylindrical specimens of 100 mm diameter and 50 mm height were cast from each mix for chloride penetration tests and were tested at 28 and 90 days of curing. It can be seen that the total coulombs charge passing through RHA blended concrete specimens continuously decreases with increase in RHA content up to 30%. At 35% RHA there is an increase in total charge passed value and this value is also lower than that of control concrete. This observation is true for both 28 and 90 days cured specimens. Chloride permeability is considerably reduced by partial replacement of OPC with RHA up to 30%. Particularly the total charge passed for 30% RHA blended concrete is considerably reduced (more than 70% reduction) both at 28 and 90 days cured concretes.

2.1.4 Water Absorption

Percentage of water absorption is an evaluation of the pore volume or porosity of concrete after hardening which is occupied by water in saturated state

Givi et al (2010) studied the percentage of water absorption of concrete by partial replacement of cement with agro-waste rice husk ash. Two types of rice husk ash series with average particle size of 5 µm (ultra fine particles) designated as U series and average size of 95 µm designated as M series and with four different contents of 5%, 10%, 15% and 20% by weight were used..M series was used to denote RHA-blended concrete with average particle size of 95 lm while U series was used to denote ultra fine RHA-blended concrete. Water absorption values of RHA-blended concrete samples with both average particle sizes were measured as per ASTM C 642 after 7, 28 and 90 days of moisture curing. In both series it was seen that the percentage of water absorption of concrete samples immersed in water decreases with increasing the age of moist curing from 7 to 90 days for all three series during the hardening process of the concrete. At the 7 and 28 days curing the percentage of water absorption increased in M series compared to C0 series. By increasing the age of curing to 90 days, the percentage of water absorption values decreases significantly with the increase in RHA content up to 10% for both M and U series. Even at 20% RHA in both M and U series, the values were lower compared to C0 series.

`

It was seen by Ganesan et al. (2008) that at 28 days curing, the percentage of water absorption increased with RHA content up to 35% while replacing RHA with 0 to 35% weight of cement. The test was done according to ASTM C 642 after 28 and 90 days of curing. When the curing time was increased to 90 days the percentage of water absorption values decreased considerably with increase in RHA content up to 25%. Even at 30% RHA, the value was lower compared to that of control.

Sanusi et al. (2014) assessed the water absorption property of binary concrete containing 10% RHA after 28, 56 and 90 days. From the results it was seen that the binary concrete had lower water absorption than the control concrete having a water absorption of 5.76%, 4.98% and 4.2% at 28, 56 and 90 days while the control concrete has a water absorption of 5.96%, 5.26% and 4.56% at 28, 56 and 90 days respectively. So in all, replacement of RHA reduced the water absorption percentage.

2.1.5 Porosity

Chindaprasirt and Rukzon (2008) studied of the porosity of mortars made with ternary blends of ordinary Portland cement (OPC replaced with ground rice husk ash (RHA) at 10, 20 and 40 % replacement. Cylindrical specimens of 100 mm diameter and 200 mm height were prepared in accordance with ASTM C39 and were tested at the age of 7, 28 and 90 days. In the results it was seen:

- At the age of 7 days, the porosities of mortar containing 10% and 20% of pozzolans
- and blend of pozzolans are lower than that of the control at all ages
- The porosity of mortar containing pozzolan reduces with the low replacement level of up to 20% of pozzolan, but increases with the 40% replacement level.
- At high replacement level of 40%, the porosities of the mortars containing RHA increase in comparison with that of the control. At the age of 7 days, the porosity of 40% RHA is 21.8% which are significantly larger than 17.8% of the OPC mortar.
- At the later age of 90 days, the porosity of the RHA containing pozzolans reduced to similar values to that of OPC mortar. The porosities of 40% RHA mix at 90 days are was 12.8% same as that of OPC mortar at the same age.

`

With a constant mix proportion was fixed as 1:1.5:3 with w/c ratio 0.53, Saraswathy and Song (2007) investigated the porosity property by partial replacement of cement with rice husk ash. Cement was replaced with 0 to 30 % RHA. Test was conducted according to ASTM C C642-97 test method after 28 days .The effective porosity percentage of 0, 5, 10, 15, 20, 25 and 30% replacement came out to be 18.06, 18.18, 13.82, 13.80, 13.54, 13.04 and 11.89 % respectively. So it can be concluded that the porosity values decreases as the percentage of replacement increases. Also, it was seen that at early ages of curing (7 and 28 days) supplementary cementitious materials are more porous than the plain cement paste.

2.1.6 Abrasion

Deterioration of concrete surfaces occurs due to various forms of wear such as erosion, cavitation, and abrasion due to various exposures. Abrasion wear occurs due to rubbing,
Scraping, skidding, or sliding of objects on the concrete surface. This form of wear is observed in pavements, floors, or other surfaces on which friction forces are applied due to relative motion between the surfaces and moving objects. Concrete abrasion resistance is markedly influenced by a number of factors including concrete strength, aggregate properties, surface finishing, and type of hardeners or toppings (Naik et al, 1997)

Not work has been reported on abrasion resistance of concrete containing rice husk ash. However, Naik et al. (1997) carried out experiments on non air entrained concrete and air entrained concrete. The abrasion resistance of non air entrained concrete containing fly ash and used foundry sand exhibited less than 2.0 mm depth of wear at 60 minutes of abrasion per ASTM C 944 is considered to have adequate resistance to abrasion. In general, inclusion of used foundry sand and fly ash caused a reduction in the concrete resistance to abrasion. However, the maximum depth of abrasion for the 45% used foundry sand and 34% fly ash mixture was only 1.9 mm, while other mixtures exhibited less than 1.4 mm, for the 60-minute abrasion cycle, thus all mixtures with and without foundry sand/fly ash exhibited excellent resistance to abrasion. At the age of 182 days all concrete mixtures containing fly ash and used foundry sand showed an increase in resistance to abrasion compared with the 28-day age results. The maximum depth of abrasion was 1.4 mm, occurred in the 45% used foundry sand and 34% fly ash concrete mixture

Ghafoori and Diawara (1999) investigated the abrasion resistance of concrete incorporating four percentages of fine aggregate replacement (5%, 10%, 15%, and 20% replacement) with silica fume. They concluded that the resistance to wear of concrete containing silica fume as a

`

fine aggregate replacement was consistently better and increased with increasing amounts of silica fume up to 10%.

Siddique (2004) investigated the abrasion resistance property of concrete proportioned to have four levels of fine aggregate replacement (10%, 20%, 30%, and 40%) with Class F fly ash. A control mixture with ordinary Portland cement was designed to have 28 days compressive strength of 26 MPa. Specimens were subjected to abrasion testing in accordance with IS: 1237-12. It was observed that depth of wear increased with increase in abrasion time for all concrete mixtures at all ages. Also with the increase in percentage of fine aggregate replacement with fly ash, depth of wear decreased, which indicated that the abrasion resistance of concrete increased with the increase in fly ash content.

2.2 EFFECT OF BACTERIA ON CONCRETE

2.2.1 Bacterial Calcium Carbonate Precipitation

Bacterially induced calcium carbonate precipitation is an environmentally friendly method to protect decayed stones and concrete Microbial involvement in the process of carbonate precipitation has led to the exploration of this technique in a variety of fields.

Calcium carbonate precipitation occurs as a by-product of common microbial metabolic process which increases the alkalinity and produce microbial calcite precipitation (Knorre and Krumbein, 2000).

An alternative technique for the improvement of the durability of concrete is reported by De Myunck et al. (2008). They reported the effects of bacterial carbonate precipitation on the durability of mortar specimens with different porosity. The surface deposition of calcium carbonate crystals decreased the water absorption by 65 to 90% depending on the porosity of the specimens. An increased resistance towards freezing and thawing was also noticed. The results obtained with the biodeposition treatment were similar as those obtained with conventional surface treatments. They concluded that surface treatments play an important role in the protection of construction materials from the ingress of water and other deleterious substances. They reported the effects of bacterial calcite precipitation on parameters affecting the durability of concrete and mortar.

`

Microbial mineral precipitation using ureolytic bacteria is able to influence the precipitaton of calcium carbonate by the production of urease enzyme. An increase of the pH and carbonate concentration in the bacterial environment catalyzes the hydrolysis of urea to CO_2 and ammonia (Stocks et al., 1999). .

Calcium carbonate precipitation can be induced extracellularly by some bacteria through a variety of processes that include ammonification, photosynthesis, denitrification, sulfate reduction and even through anaerobic sulphide oxidation. (Castanier et al. 2000; Riding, 2000). Under appropriate conditions calcium carbonate precipitation is a general process performed by bacteria (Boquet et al., 1973).

2.3.1 Compressive Strength

Ramachandran et al., (2001) studied the effect of the buffer solution, type and amount of microorganisms on compressive strength of portland cement mortar cubes. To determine this, both living and dead cells of *S. pasteurii* and *P. aeruginosa* were investigated. After demolding, the mortar specimens were stored in a solution containing urea and calcium chloride for 7 days. At lower concentrations, the presence of *S. pasteurii* was shown to increase the compressive strength of mortar cubes while the in case of *P. aeruginosa* the strength was found to be insignificant.

B pasteurii was used by Bang et al. (2014) to study the compressive properties of concrete at 7 and 28 days.The highest concentration was observed for cubes that were treated with concentration of $5x10^9$ cell concentration for 7 days. With longer incubation period of 28 days, the increase of all remediated cubes was found to be marginal compared to 7 days.

De Muynck et al. (2008a) reported that the durability of mortar specimens increased due to bacterial carbonate precipitation. De Belie et al., (2005) concluded that when weathered concrete samples were treated with *Thiobacillus* bacteria a dense layer of calcite and vaterite crystals were observed by SEM and XRD analysis.

Chahal et al. (2012) carried out experiments to evaluate the Influence of *Sporoscarcina pasteurii* bacteria on the compressive strength and rapid chloride permeability of concrete made without and with fly ash. Cement was replaced with three percentages (10, 20 and 30)

`

with fly ash by weight. Three different cell concentration (0, 10^3,10^5, 107 cells/ml) of bacteria were used in making the concrete mixes. Their results indicated that inclusion of *S. pasteuri*i in fly ash concrete enhanced the compressive strength, reduced the porosity and permeability of fly ash concrete. Maximum increase (22%) in compressive strength and four-time reduction in water absorption was observed with 10^5 cells/ml concentration of bacteria

2.2.2 Water Absorption and Permeability

Bacterial deposition of a layer of calcite on the surface of the specimens resulted in a decrease of capillary water uptake and gas permeability (De Muynck et al., 2008a). The surface deposition of calcium carbonate crystals decreased the water absorption with 65 to 90% depending on the porosity of the specimens. As a consequence, the carbonation rate and chloride migration decreased by about 25–30% and 10–40% respectively.

Chahal et al (2012) studied the water absorption and permeability properties with bacteria *Sporosarcina pasteurii* with concentration of 10^3,10^5 and 10^7 cells/ml . It was seen that, with the inclusion of bacteria there was a decrease in water porosity and absorption of fly ash concrete upto cell concentration of 10^5 cells/ml, whereas reduction was seen at cell concentration of 10^7 cells/ml. Maximum decrease in water porosity was achieved at 10^5 cells/ml for all fly ash concrete; 10^3 cells/ml showed maximum water porosity.

Nemati et al., (2005) reported that due to calcium carbonate forming reactants, the decrease in permeability was observed. Nolan et al. (1995) concluded that application of bacteria on top of concrete helps in lowering the permeation properties making the concrete more durable. The calcite crystals when precipitated helps in reducing the water permeability moreover reduction in other harmful substances was observed. The calcite deposition on the surface of specimens by bacteria helps in decreasing the capillary water uptake (Tittelboom et al., 2010).

Achal et al., (2010) concluded that bacteria played an important role in reducing the chloride permeability of concrete. The effects of *Sporosarcina pasteurii* on the permeability of concrete was determined by the average charge passed through the specimens. For the concrete samples treated with bacteria, the permeability class type was ‘‘low’’ whereas for control concrete specimens the class changed to ‘‘moderate’’. The average charge passed was 3177 coulombs for the control samples treated with bacteria, whereas for samples prepared

`

with bacterial cells in Nutrient Broth and Corn Steep Liquor media it was 1019 and 1185 coulombs, respectively.

`

CHAPTER 3

EXPERIMENTAL STUDY

This chapter describes the details of the experimental programs for the isolation, identification and the urease activity of bacteria , physical and chemical properties of coarse aggregates, fine aggregates, cement and rice husk ash, mix design, strength property of compressive strength and durability properties such as abrasion resistance, water absorption, porosity, rapid chloride permeability along with X-Ray Diffraction (XRD) and Standard Electron Microscopy (SEM) tests of concrete mixes made with varying percentages of rice husk ash as partial replacement of cement .

3.1 EXPERIMENTAL PROGRAM OF BACTERIA

3.1.1 Isolation of Bacteria

Alkaliphilic and/or alkalitolerant bacteria (that tolerate high pH) was isolated from rhizospheric (near to root of plant) soil and from marble sludge. The samples were suspended in sterile saline solution (0.85% NaCl), diluted properly and plated on enrichment medium containing glucose (10 g/l), peptone (10 g/l), yeast extract (5 g/l), KH_2PO_4 (1 g/l), agar (15 g/l) and pH was adjusted to 10.5 with 1 N.

3.1.2 Urease Test

For preparation of urea agar medium, following ingredients were used peptone 1.0 g/l , sodium chloride 5.0g/l , potassium di hydrogen phosphate 2.0 g/l, agar 20.0 g/l, 0.2% phenol red and distilled water 1000 ml. All the above ingredients were dissolved and the pH was adjusted to 6.8 and autoclaved at 121°C for 15 mins and cooled. Later 1 g of glucose and steamed for one hour. Finally 20% aqueous 100 ml of urea was added and sterilized by filtration and poured into the test tube and slants were prepared. The organisms isolated were streaked on the surface of the media and incubated at 37°C and observed for the change of the color of the media from yellow to pink.

`

3.1.2 Hydrolysis of Media

Presence of urea in the media (composition of media: urea (20 g/l), $NaHCO_3$ (2.12 g/l), H_4Cl (10 g/l), Nutrient broth (3 g/l), calcium acetate (25 g/l) hydrolyzes the media (due to the occurrence of the urease enzyme) which in turn increases the pH, as it (bacteria) utilizes urea as a nitrogen source and also as a source of energy. The addition of urea and calcium chloride in the medium supports the microbial growth. In this study, out of 3 strains AKKR5 were found to be best on the basis of calcite formation.

3.2 EXPERIMENTAL PROGRAM OF CONCRETE.

3.2.1 Cement

Ordinary Portland cement of 43 grade was used in this study .The physical properties of cement are mentioned in Table 3.1 whereas the chemical properties which were obtained by X-ray fluorescence (XRF) test are mentioned in Table 3.2.

Table 3.1: Physical properties of Ordinary Portland Cement (OPC)

Physical Properties	Obtained value	Standard value
Consistency of standard cement paste (%)	28	
Initial setting time(min)	123	Not be less than 30 mins
Final setting time(min)	270	Not be greater than 600 mins
Specific gravity	3.1	

`

Table 3.2: Chemical properties of Ordinary Portland Cement (OPC)

Constituent	Constituent %
Cao	63.49
SiO_2	21.25
Fe_2O_3	4.30
Al_2O_3	4.74
MgO	1.02
K_2O	0.78
Na_2O	0.30
SO_3	2.93
TiO_2	0.36

3.2.2 Fine Aggregates

Natural sand with 4.75 mm maximum size was used as fine aggregate. It was tested as per Indian Standard Specifications BIS: 383-1970. Its physical properties and sieve analysis are given in Tables 3.3 and Table 3.4, respectively.

Table 3.3: Physical properties of fine aggregates

Properties	Observed values
Specific gravity	2.68
Net water absorption	0.86
Fineness modulus	2.58

`

Table 3.4 Sieve analysis of fine aggregates

Sieve No	Retained (g)	Retained %	Passing %	% Retained Cumulative
4.75	10	1	99	1
2.36	60	6	93	7
1.18	200	20	73	27
600	190	19	54	46
300	350	35	19	81
150	40	4	0	100
				∑% retained=258

Fineness modulus = 258 / 100 = 2.58

3.2.3 Coarse Aggregates

Crushed stone with maximum of 12.5 mm graded aggregates (nominal size) were used in this study. Physical properties and the sieve analysis results are mentioned in Tables 3.5 and Table 3.6, respectively.

Table 3.5: Physical Properties of Coarse Aggregates

Properties	Observed Value
Maximum Size(mm)	12.5
Bulk Density (kg/m3)	1650
Specific gravity	2.7
Water Absorption (in %)	1.14
Moisure Content (in %)	Nil

`

Table 3.6: Sieve Analysis of Coarse Aggregates

IS Sieve	Weight (gm)	% Weight (gm)	Cumulative% weight	% Passing
20 mm	0.0	00	0.0	100
12.5 mm	0.97	4.8	4.8	95.2
10 mm	642	32.1	36.9	63.1
4.75 mm	1184	59.2	96.1	3.9
Pan	77	3.85	100	0.0
		Cumulative % retained=237.8		

Weight of the sample taken = 2.0 kg.

Fineness modulus = (237.8+500)/100 = 7.3

3.2.4 Properties of Rice Husk Ash

Rice husk ash was collected from KGR Agro Fusions Private Limited, Ludhiana, Punjab. Physical and chemical properties of RHA were analysed. Rice husk ash has a very high content of amorphous silicon dioxide and consists of fine spherical particles along with small amounts of iron, magnesium, and alkali oxides. Sieve analysis and physical properties results are given in Table 3.7

Plate 3.1: Rice husk ash used in the study

`

Table 3.7: Chemical properties of rice husk ash

Constituent	Constituent %
SiO_2	90.38
K_2O	2.86
Al_2O_3	1.74
Fe_2O_3	1.58
CaO	1.38
MgO	0.69
Na_2O	0.34
SO_3	0.10

3.2.5 Design of Concrete Mix

The compressive strength of concrete is considered as the strength and index of its quality. Therefore the mix design is generally carried out for a particular compressive strength of concrete with adequate workability so that the fresh concrete can be properly mixed, placed and compacted. The proportions for the mix were calculated adopting the requirements of water as specified in BIS: 10262-1982. The proportioning of concrete mixes consists of three interrelated steps.

(i) Selection of suitable materials and ingredients-cement, supplementary cementing materials, water, coarse and fine aggregates.

(ii) Determination of the relative quantities of these materials in order to produce a concrete that has desired strength and durability.

(iii) Careful quality control of every phase of the concrete making process.

M20 design mix Data

Characteristic strength at 28 days = 20 N/mm^2

Maximum size of aggregate = 12.5mm

Type of exposure = Mild, no sulfate attack

Concrete use = Concrete structure.

`

Table 3.8: Mix Proportion M20

Unit of Batch	Water (l)	Cement (kg)	Fine Aggregate	Coarse Aggregate
Cubic meter content	195	390	568.7	1164.12
Ratio of ingredients	0.5	1	1.45	2.98

Mix composition

The concrete mixes were designed with constant cement, fine aggregate, coarse aggregate. Control concrete mixture was designed as per IS 10262-1982 to have 28-day compressive strength of 28 MPa. Then cement was partially replaced with 0, 5, 10, 15 and 20% rice husk ash by weight of cement with 10^5 cfu/ml; of bacteria concentration. The detailed description of all mixes is given in Table 3.8.

Table 3.9: Concrete mix proportions

Mixture number	Cement (kg/m^3)	RHA (%)	RHA (kg/m^3)	Natural sand (kg/m$^{3)}$	Coarse aggregate (kg/m^3)	W/C ratio	Water (kg/m3)	Bacteria Content (cfu/ml)	Slump (mm)
R0	390	0	0	568.7	1164.12	0.5	195	0	90
R5	370.5	5	19.5	568.7	1164.12	0.5	195	0	83
R10	351	10	39	568.7	1164.12	0.5	195	0	77
R15	331.5	15	58.5	568.7	1164.12	0.5	195	0	72
R20	312	20	78	568.7	1164.12	0.5	195	0	66
BR0	390	0	0	568.7	1164.12	0.5	195	10^5	90
BR5	370.5	5	19.5	568.7	1164.12	0.5	195	10^5	83
B10	351	10	39	568.7	1164.12	0.5	195	10^5	77
BR15	331.5	15	58.5	568.7	1164.12	0.5	195	10^5	72
BR20	312	20	78	568.7	1164.12	0.5	195	10^5	66

*R0/5/10/15/20: Rice Husk Ash 0/5/10/15/20% replacement:

BR0/5/10/15/20: Bacteria + Rice Husk Ash 0/5/10/15/20% replacement

`

For these mix proportions, required quantities of materials were weighed. The mixing procedure adopted was as follows:

i). The cement and rice husk ash were dry mixed in a tray for 15 minutes to get uniform colour.

ii). Weighed quantities of coarse aggregates and sand were then mixed in dry state.

iii) The mix of cement and rice husk ash was added to the mix of coarse aggregates and sand and these were mixed thoroughly for a homogeneous mix.

iv) Water and bacterial culture was then added.

All the moulds were properly oiled before casting the specimens. The casting immediately followed mixing, after carrying out the tests for fresh properties. The top surface of the specimens was scraped to remove excess material and achieve smooth finish. The specimens were removed from moulds after 24 hours and cured in water till testing or as per requirement of the test. After required period of curing i.e 7, 28 and 56 days, the specimens were taken out of the curing tank and their surfaces were wiped off.

3.3 TESTING PROCEDURE FOR CONCRETE

The tests as shown in table were performed in this study

Table 3.10: Tests and Codes

TEST	Code
Compressive strength	BIS 516-1959
Water Absorption and Porosity	ASTM C642-2006
Rapid Chloride Permeability Test	ASTM C1202-2010
Abrasion	BIS 1237-2012
X-Ray Diffraction (XRD)	
Scanning Electron Microscopy (SEM)	

The specimen properties were determined at the age of 7, 28 and 56 days

3.3.1 Compressive Strength

Compressive strength is the capacity of a material or structure to withstand axially directed pushing forces. When the limit of compressive strength is reached, materials are crushed.

`

Concrete can be made to have high compressive strength. Rice husk ash was added by replacing the amount of cement at the concentrations of 0%, 5%, 10%, 15% and 20% . To study the compressive strength test of cement concrete cubes as per specifications of compressive strength cubes were casted. Sand and cement were thoroughly mixed, adding along with grown culture of bacteria. Cubes were cast and compacted in a vibration machine. After de-molding, all specimens were cured compression testing at 7, 28 and 56 days. Control specimens were also prepared in similar way where water and medium (described above) replaced bacterial culture.

Compressive strength is often measured on a universal testing machine. Measurements of compressive strength are affected by the specific test method and conditions of measurement. Compressive strengths are usually reported in relationship to a specific technical standard. When a specimen of material is loaded in such a way that it extends it is said to be in tension. On the other hand if the material compresses and shortens it is said to be in compression. Cube specimens of size 150 mm were cast for compressive strength as per Indian standard specifications IS: 516-1959. After casting, all tests specimens were finished with steel trowel. Specimens were demoulded after 24-h and then cured in water at approximately room temperature till testing. Compressive strength tests for cubes were carried out at 7, 28 and 56 days. The compressive strength was then calculated according to the formula:

$$\sigma = P / A$$

where σ = Compressive Strength (MPa)

P = Maximum load (N)

A = Cross section area of cube (mm^2)

3.3.2 Rapid Chloride Permeability Test

A durable concrete is the one that performs satisfactorily under anticipated exposure condition during its service life span. One of the main characteristics influencing the durability of concrete is its permeability to the ingress of chloride. The chloride ion present in the concrete can have harmful affect on concrete as well as on the reinforcement. Swelling of concrete due to chloride ion penetration is 2 to 2.5 times larger than that observed with water penetration. So this test covers the experimental evaluation of electrical conductance of concrete to provide rapid indication of concrete resistance against chloride ion penetration.

The test method covered the determination of the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions. According to

`

Table 3.11 the chloride ion penetrability was decided on the basis of charge passed. The test method consisted of monitoring the amount of electrical current passed through 2-in. (51m) thick slices of 4-in. (102 mm) nominal diameter cores or cylinders for a 6-h period. A potential difference of 60 V Dc was maintained across the ends of the specimen, one of which was immersed in a sodium chloride solution, the other in a sodium hydroxide solution. The total charge passed, in coulombs, was related to the resistance of the specimen to chloride ion penetration.

Table 3.11 Chloride ion penetrability based on charge passed (ASTM 1202)

Charge passed (Coulomb)	Chloride Ion Penetrability
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very Low
<100	Negligible

Preparation of Samples

Cylindrical concrete disc of thickness (100×200 mm) with and without bacterial culture were casted and cured in water for 7, 28 and 56 days. Concrete mixture was designed using M-20 grade. . Then cement was partially replaced with 0, 5, 10, 15, and 20 % rice husk ash .

Conditioning and Testing of Concrete Specimen

Specimens were placed in the vacuum desiccator's bowl .The vacuum was maintained in the desiccators bowl for 3 hours. The de-aerated water was allowed to flow into the desiccator, so that it completely covers the specimens and no air was allowed to enter. Again the vacuum was maintained for another one hour. Then the specimens were left to soak in the container water for another 18 h. The specimens were removed from the dessicator, dried and placed in gasket. The liquids (3% NaCl and 0.3 N NaOH solutions) were filled in the two cells. Power supply was set to 60V, and initial current reading was recorded. Temperatures of the specimen, applied voltage cell and solutions were 20 to 25°C at the time the test was initiated (when the power supply was turned on). The values for the current were recorded after 6h experiment.

`

3.3.3 Water Absorption and Porosity

The water absorption test was conducted as per ASTM C 642 in order to determine the increase in resistance towards water penetration in concrete. The cube moulds of 150 mm for concrete were prepared both with and without bacteria and rice husk ash. The concrete specimens were cured for 7, 28 days and 56 days. After curing, the specimens were oven dried at 110˚C in oven. Then the specimens were immersed in water at approximately 21˚C for 48 h and saturated mass after immersion was calculated. Then the specimens were placed in suitable receptacle, covered with tap water and were boiled for 5 h, further the saturated mass after boiling was calculated. The specimens were suspended by a wire and the apparent mass in water was calculated as per the formula :

$$\text{Volume of permeable voids \%} = \frac{(C-A)}{(C-D)} * 100$$

Where in ; A = mass of the oven dried sample in air, in grams

C = mass of sample after immersion and boiling, grams

D = apparent mass of sample in water after immersion and boiling, grams.

The total porosity (P) measurements are based on Archimedes Principle. The total porosity can be calculated from water saturated surface dry mass (W_{sat}), mass susupended in water (W_{water}) and oven dry mass (W_{sat})

$$(W_{dry}): P(\%) = (W_{sat} - W_{dry} / W_{sat} - W_{water}) * 100$$

3.3.4 Abrasion Test

This test was conducted according to IS 1237(2012) according to which test specimens square in shape of size 70·6 mm x 70·6 mm with and without bacterial culture were casted and cured in water for 7, 28 and 56 days. Concrete mixture was designed using M-20 grade with w/c ratio of 0.5.

Procedure of test

The specimens were dried at 110 ^{o}C for 24 h and then weighed. After initial drying and weighing of the specimen, the thickness of the specimen was noted. The grinding path of the disc of the abrasion testing machine was evenly strewn with 20 g of the Al_2O_3 which was used as an abrasive abrasive powder. The specimen was then be fixed in the holding device

`

with the surface to be ground facing the disc, and loaded at the centre with 300 N. The grinding disc was then put in motion at a speed of 30 rev/min and the abrasive powder is continuously fed back on to the grinding path 80 that it remains uniformly distributed in a track corresponding to the width of the test piece. After every 22 revolutions, the disc was stopped. The abraded tile powder and the remainder of the abrasive powder was .removed from the disc, and fresh abrasive powder in quantities of 20 g applied each time. After every 22 revolution the specimen was turned about the vertical axis through an angle of 90° in the clockwise direction and repeated 9 times thereby giving total number of revolutions of 220. After the abrasion is over, the specimen shall be reweighed. The value was checked up with the average loss in thickness of the specimen obtained by the following formula :

$$T = \frac{(W1-W2)\,V1}{W1.A}$$

Where T = average loss in thickness in mm,

W_1 =- initial mass of the specimen in g.

W_2 = final mass of the abraded specimen in g,

V_1 = initial volume of the specimen in mm^2, and

A = surface area of the specimen in mm

Plate 2: Abrasion testing machine used for study

`

3.3.6 SEM of Concrete Samples

Scanning Electron Microscope (SEM) is essentially a high magnification microscope, which uses a focussed scanned electron beam to produce images of the sample, both top-down and, with the necessary sample preparation, cross-sections. The morphology and chemical constituents of the concrete samples were analyzed with SEM. SEM is a powerful instrument which permits the characterization of heterogeneous materials and surfaces. Samples were completely dried at room temperature, then examined at accelerating voltages of 20 kV SEM .In the present investigation, the SEM was used in its most common mode, the emissive mode. Samples were gold coated prior to examination. Primary electrons generate low energy secondary electrons, which tend to emphasise the topographic nature of the specimen.

3.3.7 XRD

X-ray diffraction is a non-destructive technique used to determine the elements present in any particular substance. X-ray powder diffraction technique is the most prominent technique used for unraveling the structure of the materials in bulk and thin film forms. XRD spectra were with a Cu anode (40 kV and 30 mA) and scanning from 3° to 60°. Each sample was crushed and ground before mounting onto a glass fibre filter using a tubular aerosol suspension chamber (TASC). The components of the sample were identified by comparing them with standards established by the International Center for Diffraction Data. All experiments were performed in triplicate. X-ray diffraction is based on the fact that, in a mixture, the measured intensity of a diffraction peak is directly proportional to the content of the substance producing it. The samples for X-Ray diffraction analysis were taken from the inner core and were then prepared in powdered form for the test.

`

CHAPTER 4

RESULTS AND DISCUSSIONS

This chapter presents the results and discussions related to urease activity of bacteria and effect of bacteria and RHA on concrete properties such as compressive strength of cubes, micro structure analysis using XRD and SEM . The durability properties like water absorption, water porosity, abrasion and rapid chloride permeability of the mixes are also studied and analysed.

4.1) RESULTS AND DISCUSSION RELATED TO BACTERIA

XRD test

To confirm the presence of bacterial calcite precipitation the bacteria were examined under XRD. The maximum number of calcite peaks was observed in AKKR5. So, from the above results it was concluded that AKKR5 was more efficient than other isolated strains

.

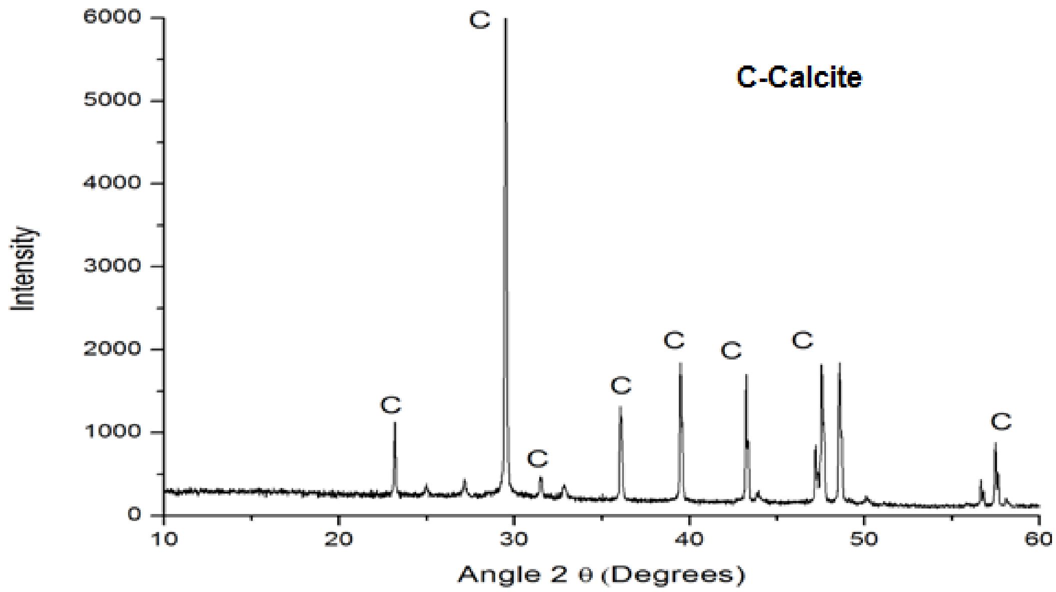


Fig 4.1: XRD analysis of bacteria precipitate

`

4.2) EFFECT OF RHA AND BACTERIA ON CONCRETE PROPERTIES

4.2.1 Compressive Strength

The compressive strength of control and bacterial concrete was studied and it was seen that the compressive strength increased with increase in curing period in both control concrete and bacterial concrete mixes as shown in Table 4.1.

Table 4.1: Compressive strength values (MPa) of RHA concrete with and without bacteria

RHA %	7 day		28 day		56 day	
	Control	Bacterial	Control	Bacterial	Control	Bacterial
0	22.3	23.4	32.8	35.8	36.4	40.7
5	23.2	24.4	34.1	37.8	38.9	42.8
10	24.3	25.8	36.1	40	41.3	46.7
15	22.5	23.8	35.3	38.4	39.8	43.8
20	20.8	21.3	33.1	36.2	37.8	42.3

From Fig 4.2, it is seen that 56 day strength of all the mixes is higher than corresponding 7 day and 28 day strength. In control concrete mix, maximum strength was seen in R10. The strength increased till R10 and after that at R15 and R20 strength starts to decrease. R10 increased by 8.7%, 10% and 13.4% with respect to R0 at 7, 28 and 56 day.

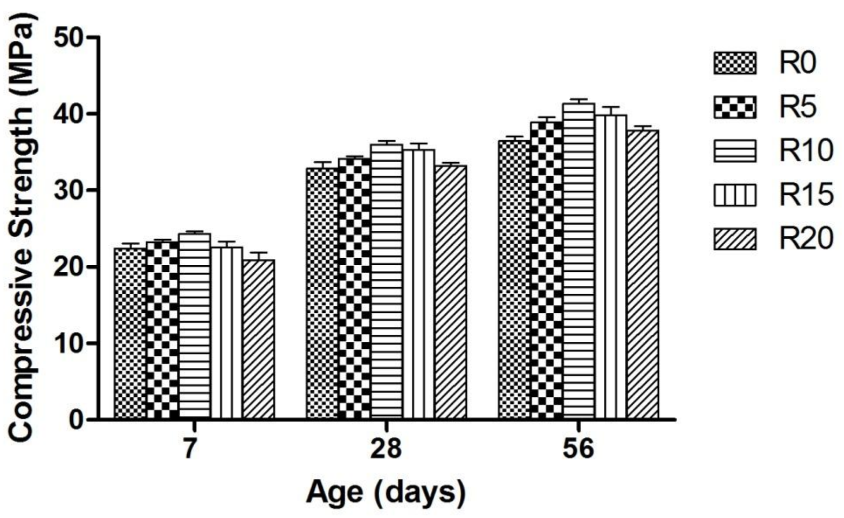


Fig 4.2: Compressive strength of control concrete mix at 7, 28 and 56 day

`

Similarly, in bacterial concrete mix, strength increased with age. As shown in Fig 4.3, the maximum strength was seen at BR10 . The strength of BR10 increased by 10.2, 11.8 and 14.7% at 7, 28 and 56 day respectively. The results obtained are supported by Habeeb and Mahmud (2010) where the strength of RHA increased with age upto 10% due to increase in RHA fineness and decreases after that due to excess silica content. Active silica reacts with hydration product of cement and produce secondary CSH gel and thus the strength is increased (Khassaf et al., 2014).

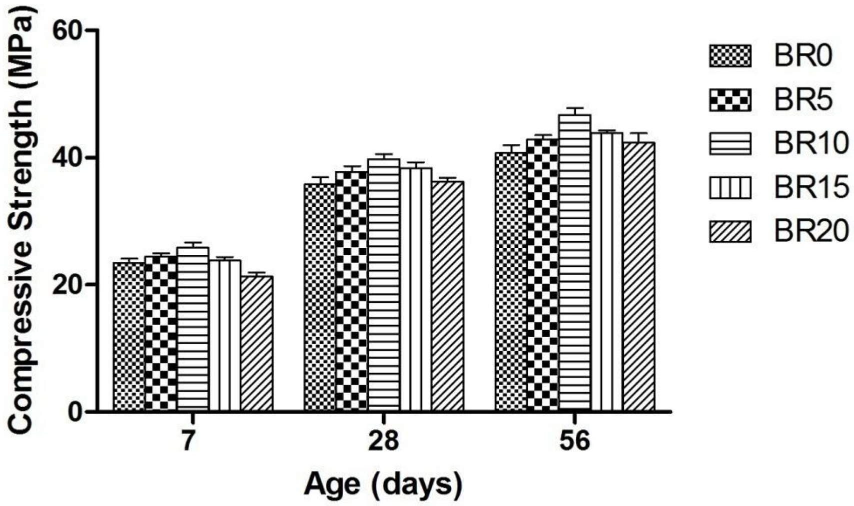


Fig 4.3: Compressive strength of bacterial concrete at 7, 28 and 56 day

On inclusion of bacteria, it was seen that compression strength of bacterial concrete was more than control concrete at all days as shown in Fig 4.4 (a), (b) and (c). Increase in strength of R10 by 6.2%, 10.7% and 13% with respect to BR10 was seen at the age of 7, 28 and 56 days, respectively. Increase in strength in bacterial concrete was also observed by Ghosh et al. (2005) with concentration of 10^5 cell/ ml which was due to the formation of calcite layer within the pores of the cement sand matrix. On the contrary, Jonkers et al. (2010) observed reduction in strength (upto 10%) due to incorporation of a high number of bacterial spores (6×10^8 cm^{-3}) after the age of 3, 7 and 28 days cured specimens. Bang et al. (2014) found increase in compressive strength at later curing ages (28 days) compared to 7 days.

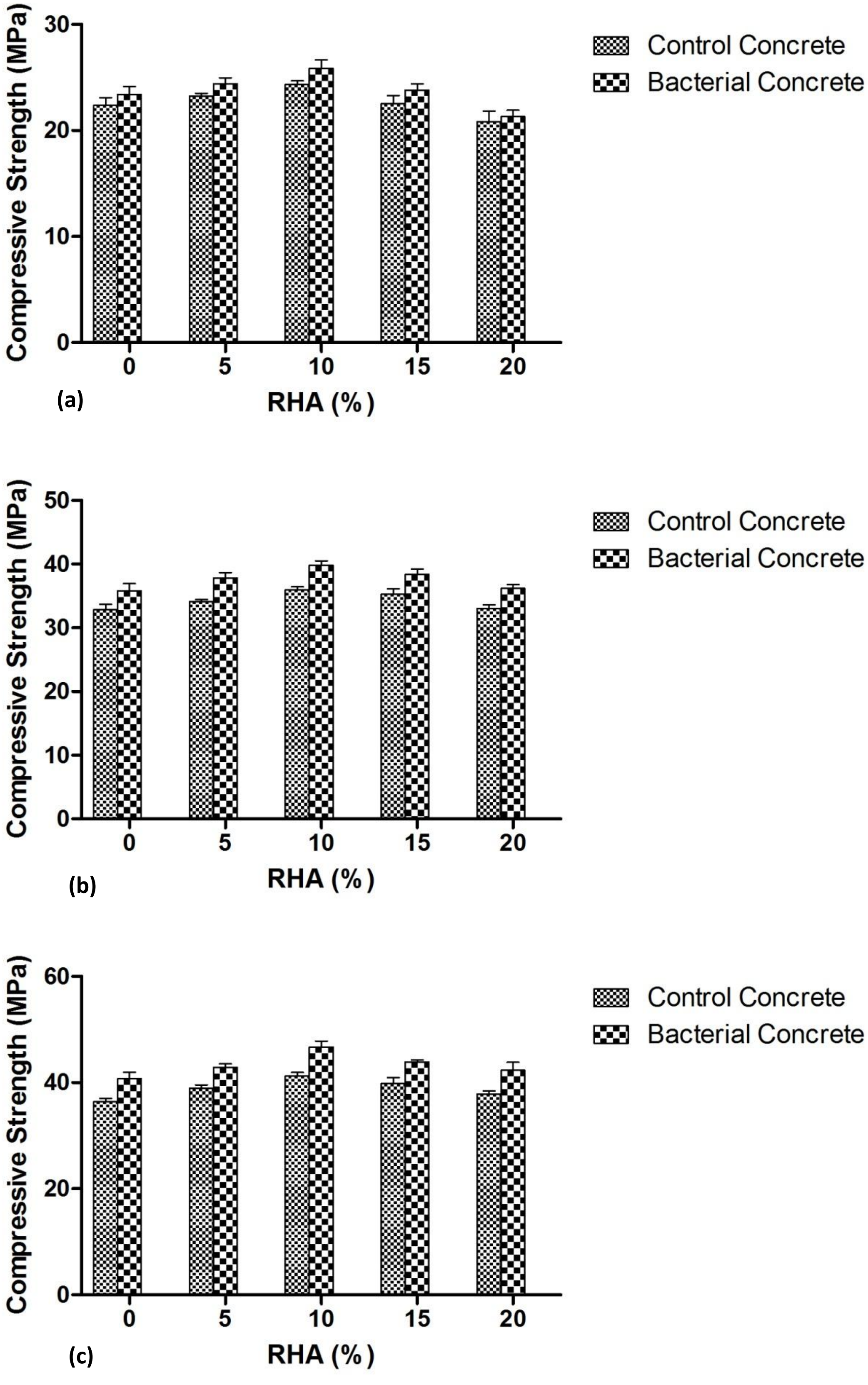


Fig 4.4: Compressive strength of control and bacterial mix at (a) 7, (b) 28, (c) 56 day

`

4.2.2) Rapid Chloride Permeability Test

The ability of concrete to resist the penetration of chloride ions is a critical parameter in determining the durability of concrete structures**.** The results of bacterial and control concrete mixes are shown in Table 4.2.

Table 4.2: RCPT values (coulombs) of RHA concrete with and without bacteria

RHA %	7 day		28 day		56 day	
	Control	Bacterial	Control	Bacterial	Control	Bacterial
0	3305	3032	2366	2075	1947	1650
5	2502	2400	1714	1471	1431	1137
10	1998	1693	1285	1036	1024	799
15	2263	1967	1478	1250	1201	943
20	2705	2559	1867	1633	1395	1216

From Fig 4.5, it can be noted that in case of concrete mix, as the replacement of RHA increased up to R10, the charge passed decreased whereas in case of R15 and R20, charge passed starts to increase. Charge passed in R10 decreased by 64.2 %, 84% and 90.1% with respect to R0 at the age of 7, 28 and 56 days respectively.

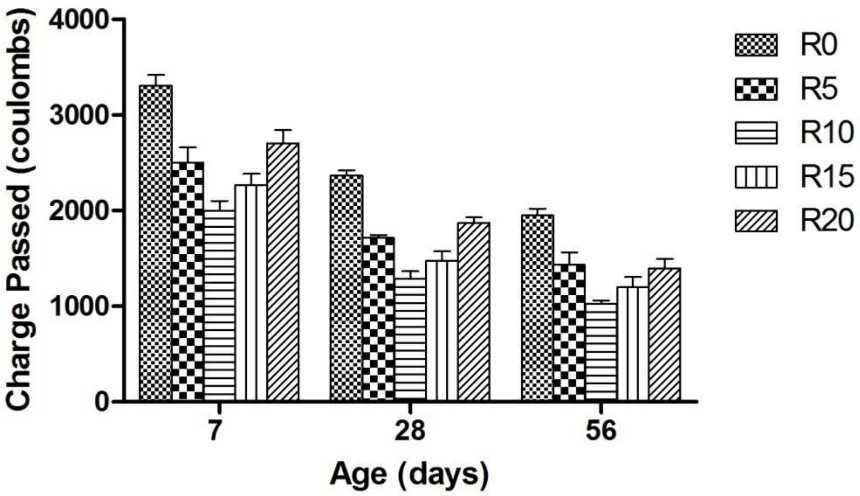


Fig 4.5: Charge passed by control concrete at 7, 28 and 56 day

`

Similarly, in case of bacterial concrete mix, the minimum charge passed was at BR10, as shown in Fig 4.6. Charge passed in BR10 decreased by 79.2 %, 100.6% and 106.8% with respect to BR0 at the age of 7, 28 and 56 days respectively. Replacement of rice husk ash reduced the coulomb values remarkably. As the replacement level increases, the chloride penetration decreased (Saraswathy and Song, 2007). Since the total charge passed through the concrete depends on the electrical conductance, the lower unburnt carbon content present in RHA might have contributed to the significant reduction in the electrical charge passed. (Ganesan et al., 2008).

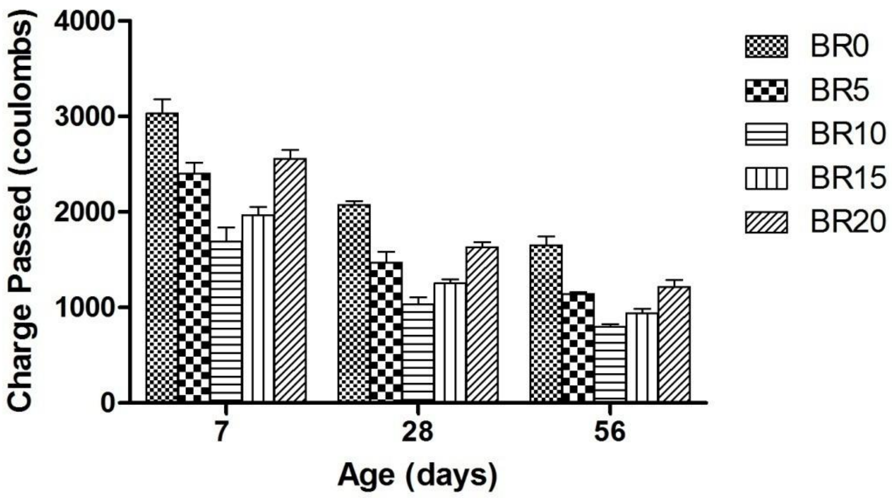


Fig 4.6: Charge passed by bacterial concrete at 7, 28 and 56 day

Inclusion of bacteria showed the decrease in the passing of charge of the samples compared to control mixes as shown in Fig 4.7 (a), (b) and (c). Decrease of 18.2, 24.3 and 28.5 % was seen in R10 with respect to BR10 at 7, 28 and 56 day respectively. The permeability range for the samples remained between low to moderate for control concrete mix and between very low to moderate for bacteria mixes. There was decrease in permeation properties of mortar and concrete due to calcite precipitation by bacteria (De Muynck et al., 2008). Chloride ion penetrability can thereby reduce the durability of concrete structures. The bacterial pore blockage by calcite deposition resulted in resistance towards the chloride permeation (Chahal et al, 2012).

`

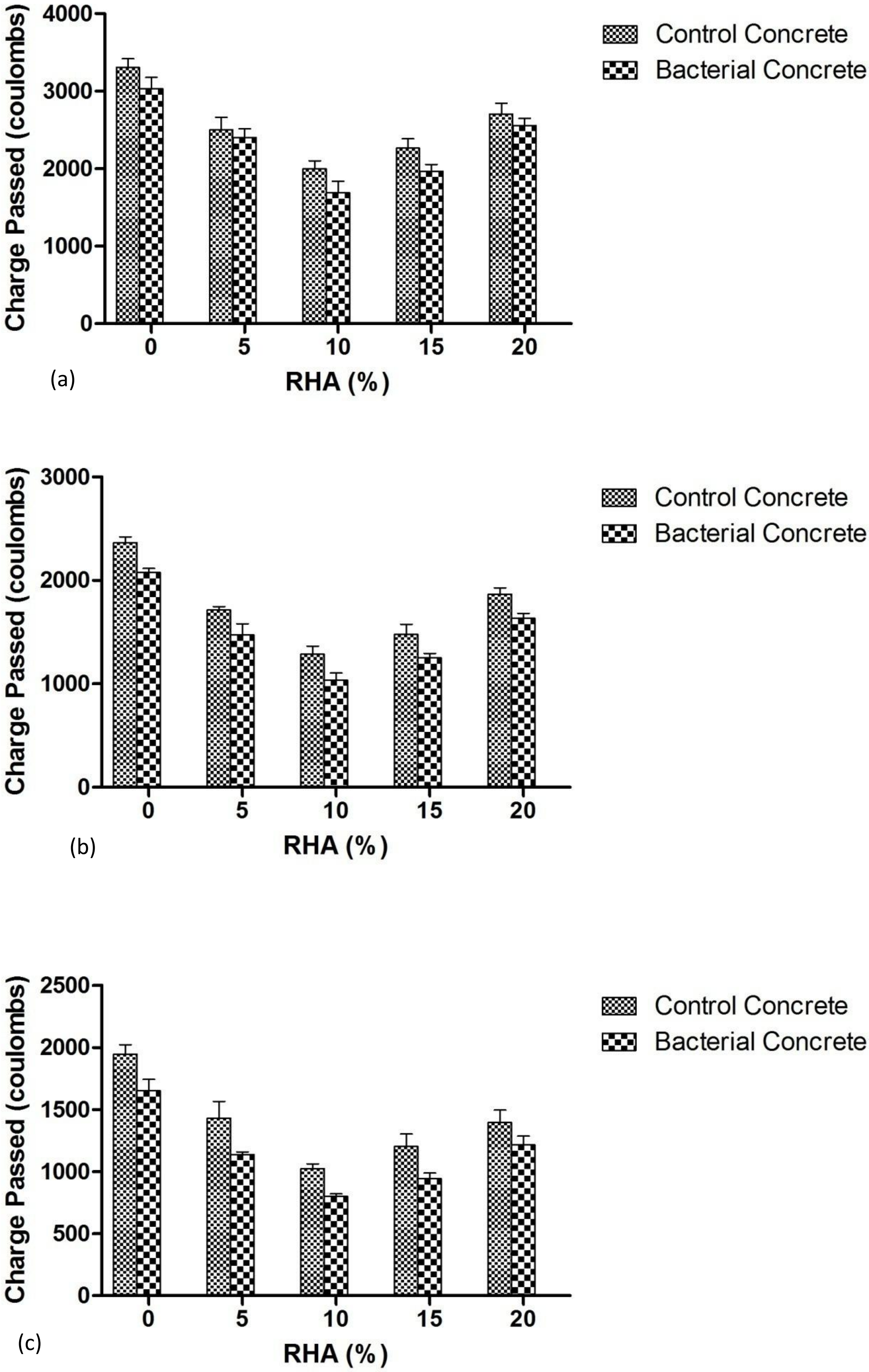


Fig 4.7: Charge passed by control and bacterial concrete at (a) 7, (b) 28, (c) 56 day

`

4.2.3 Abrasion

Abrasion of the concrete occurs due to scraping, rubbing, skidding or sliding of objects on its surface**.** The abrasion resistance of concrete is influenced by a number of factors such as mechanical properties of concrete (compressive strength), surface finish, aggregate properties, types of hardeners and curing. Abrasion resistance is measured in terms of depth of wear. Reduction in depth of wear indicated enhanced abrasion resistance and vice-versa. Thickness loss due to abrasion on control concrete and bacterial concrete mixes is given in Table 4.3.

Table 4.3: Average depth resistance values (mm) of RHA concrete with and without bacteria

RHA %	7 day		28 day		56 day	
	Control	Bacterial	Control	Bacterial	Control	Bacterial
0	0.980	0.931	0.720	0.640	0.615	0.533
5	0.895	0.845	0.622	0.556	0.537	0.447
10	0.831	0.752	0.585	0.501	0.491	0.400
15	0.886	0.811	0.633	0.542	0.523	0.415
20	0.950	0.877	0.678	0.599	0.556	0.480

Maximum abrasion resistance in control and bacterial concrete was shown by R10 and BR10 respectively as shown in Figs 4.8 and 4.9. R10 showed abrasion loss of 0.831 mm at 7 days, 0.585 mm at 28 days and 0.491 mm at 56 whereas BR10 showed abrasion loss of 0.752 mm, 0.501 mm and 0.400 mm at 7, 28 and 56 day, respectively. Abrasion is proportional to compression strength and directly depends on it (Li et al., 2006). No work of abrasion has been done on RHA. However at the age of 90 days, all concrete mixtures containing fly ash and used foundry sand showed an increase in resistance to abrasion compared with the 28-day age results (Singh and Siddique, 2012).

`

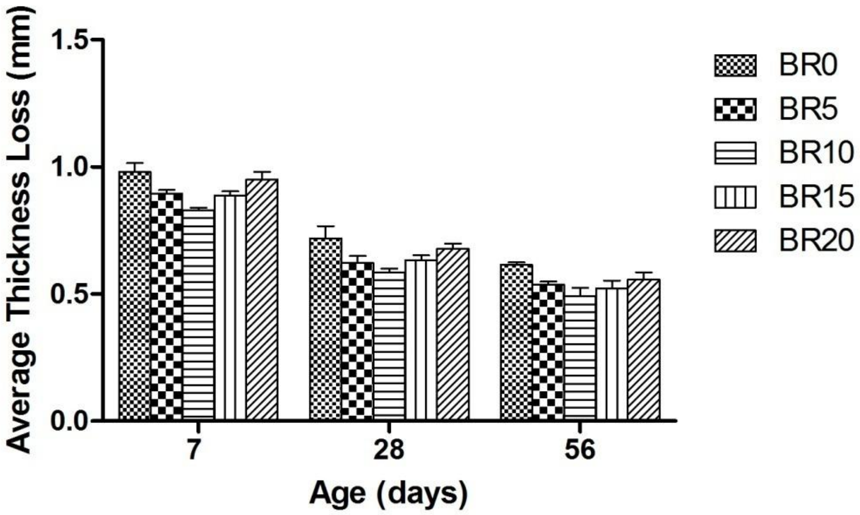


Fig 4.8: Average thickness loss of control concrete at 7, 28 and 56 day

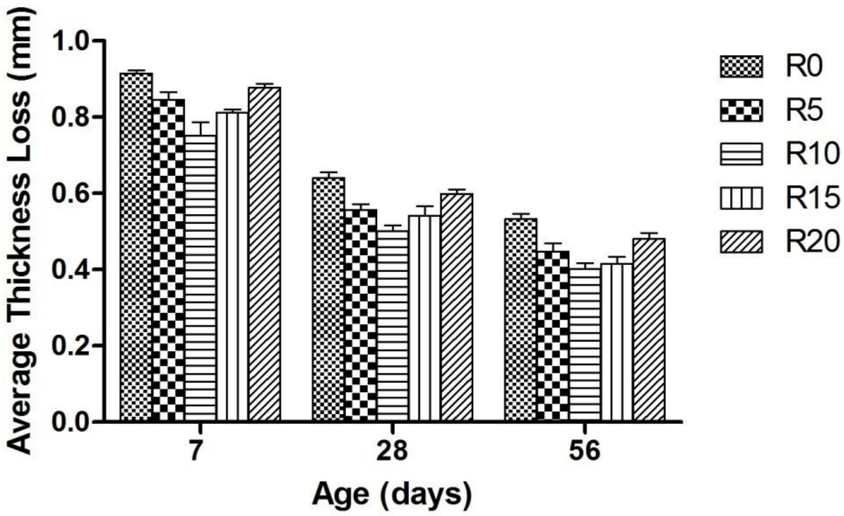


Fig 4.9: Average thickness loss of bacterial concrete at 7, 28 and 56 day

Inclusion of bacteria increased the abrasion resistance in all samples. This can be seen in Fig 4.10 (a), (b) and (c). The value of R10 decreased by 10.5, 16.7 and 22.7% on inclusion of bacteria at 7, 28 and 56 days respectively. No work has yet been done on influence of bacteria on abrasion properties. The increase in abrasion resistance in bacterial concrete mix was probably due to deposition of $CaCO_3$ on the microorganism cell surfaces and within the pores.

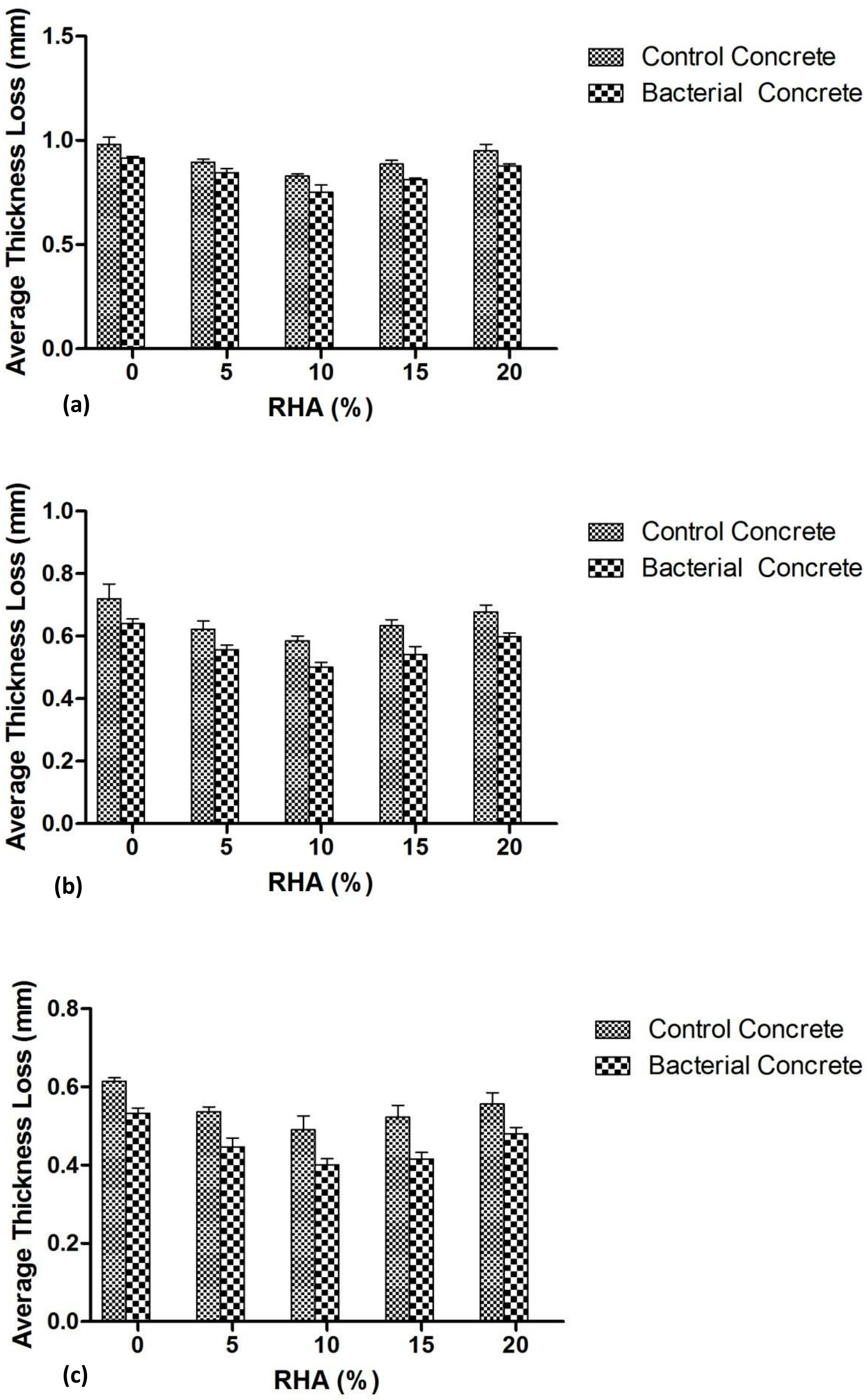


Fig 4.10 : Average thickness loss of control and bacterial concrete at (a) 7, (b) 28, (c) 56 day

`

4.2.4 Water Absorption and Porosity

(i) Water Absorption

The influence of control and bacteria concrete on the water absorption of RHA concrete is given in Table 4.4.

Table 4.4: Water absorption values (%) of RHA concrete with and without bacteria

RHA %	7 days		28 days		56 days	
	Control	Bacterial	Control	Bacterial	Control	Bacterial
0	2.90	2.21	2.08	1.31	1.89	1.06
5	2.63	2.01	1.8	1.19	1.65	0.91
10	2.51	1.86	1.66	1.03	1.47	0.80
15	2.58	1.99	1.76	1.12	1.55	0.85
20	2.75	2.13	1.94	1.25	1.75	0.95

It can be observed from the Table 4.4 that water absorption capacity decreases with age. As shown in Figs 4.11 and 4.12, the minimum percentage of absorption was observed in R10 and BR10, respectively. The water absorption in R10 was 2.51, 1.66 and 1.47% at the age of 7, 28 and 56 days while in BR 10 water absorption was 1.86, 1.03 and 0.80% respectively.

The results were supported by Givi et al. (2010) where decrease in percentage of water absorption in 10% RHA was observed with increasing the age of moist curing from 7 to 56 days during the hardening process of the concrete. Formation of CSH gel as a product of pozzolanic reaction between calcium hydroxide and silica filled the voids and increased the density of concrete resulting in decreased porosity (Chopra et al., 2015).

`

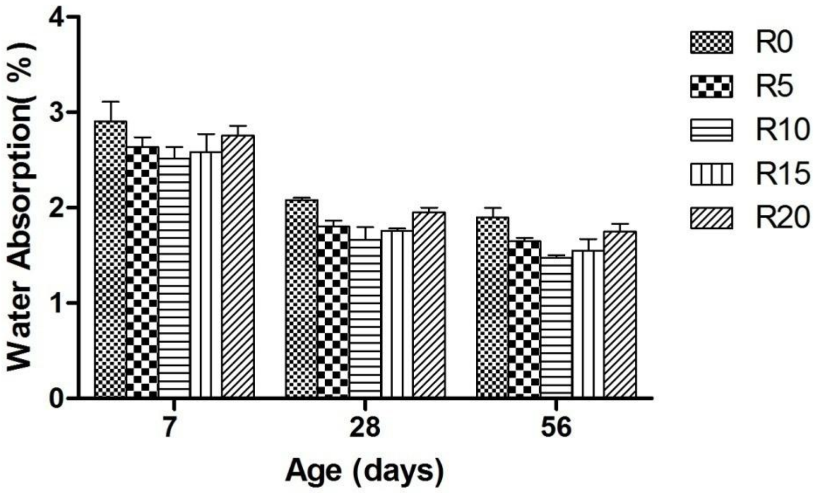


Fig 4.11: Water absorption percentage of control concrete at 7, 28 and 56 day

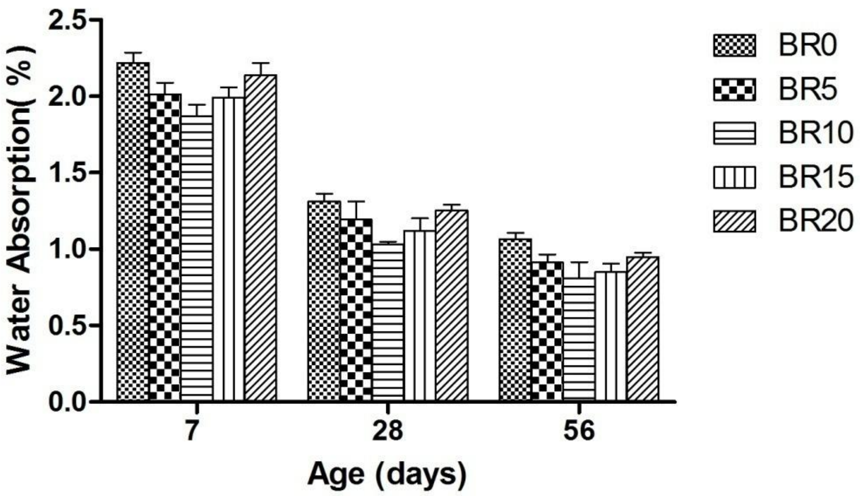


Fig 4.12: Water absorption percentage of bacterial concrete at 7, 28 and 56 day

On inclusion of bacteria it can be seen in Figs 4.13 (a), (b) and (c) that the water absorption percentage of control concrete decreases remarkably. Water absorption of bacteria treated concrete reduced due to the filling of pores effectively by calcite (Zhang et al., 2015).

`

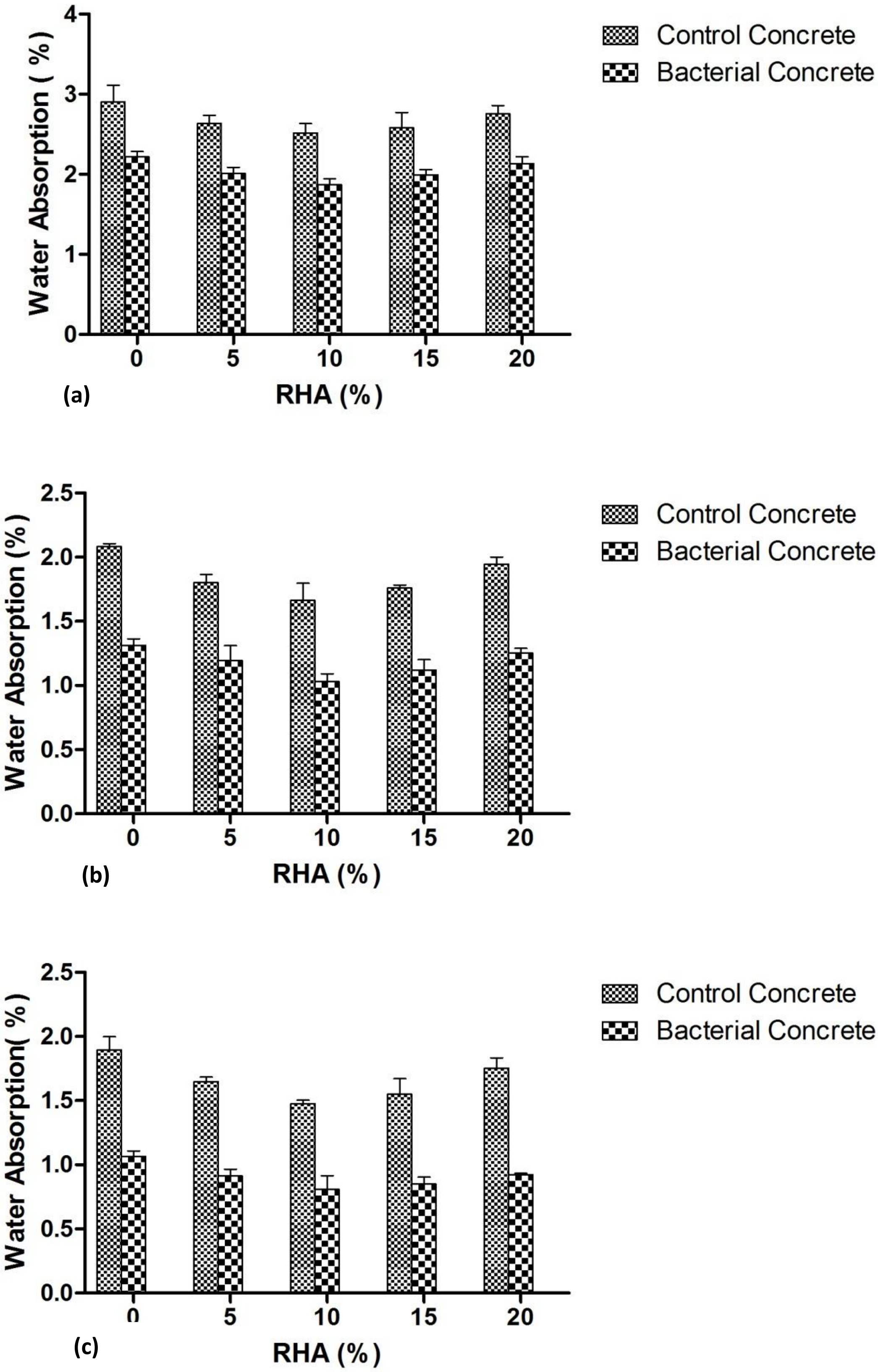


Table 4.13: Water absorption percentage of control and bacterial concrete at (a) 7, (b) 28, (c) 56 day.

`

(b) Porosity

The values of porosity percentages of control and bacteria mixes are given in Table 4.5

Table 4.5 Porosity percentage values (%) of RHA concrete with and without bacteria

RHA %	7 day		28 day		56 day	
	Control	Bacterial	Control	Bacterial	Control	Bacterial
0	6.42	4.01	4.86	2.59	4.1	2.05
5	5.65	3.59	4.12	2.31	3.48	1.72
10	5.46	3.32	3.90	2.00	3.12	1.52
15	5.61	3.49	4.11	2.12	3.29	1.62
20	5.96	3.72	4.45	2.39	3.67	1.80

It is shown that porosity percentage decreased with age for both control and bacterial concrete mixes. Lowest porosity value was observed in 10% RHA whereas after 10% replacement, decreasing trend was observed in 0 and 15% RHA replacement levels. Addition of fine particles of RHA causes segmentation of large pores and increases nucleation sites for precipitation of hydration products in cement paste. This results in pore refinement and a reduction of calcium hydroxide in paste (Chindaprasirt and Rukzon, 2008).

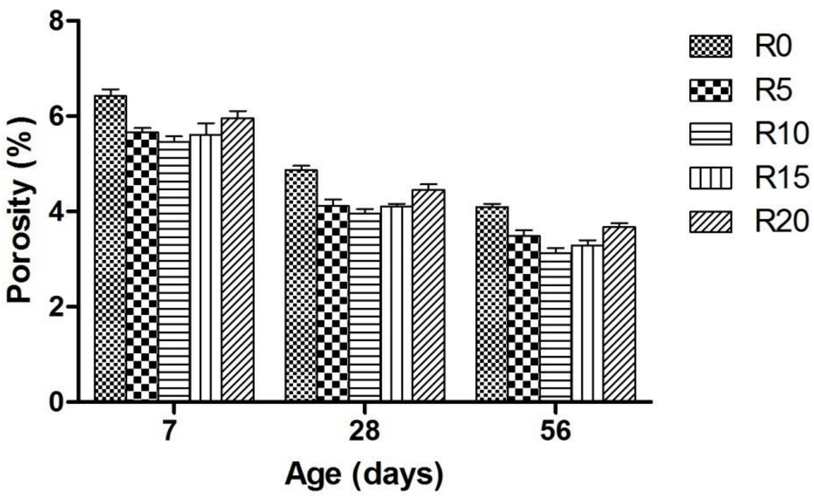


Fig 4.14: Porosity percentage of control concrete at 7, 28 and 56 day

`

Similarly in case of bacterial concrete, the results indicated that the porosity decreased with increase in curing time. Least value of porosity was seen in BR10 at all ages while the maximum value was seen in BR0. The value of BR10 at 7, 28 and 56 day was 3.32%, 2% and 1.52%, respectively.

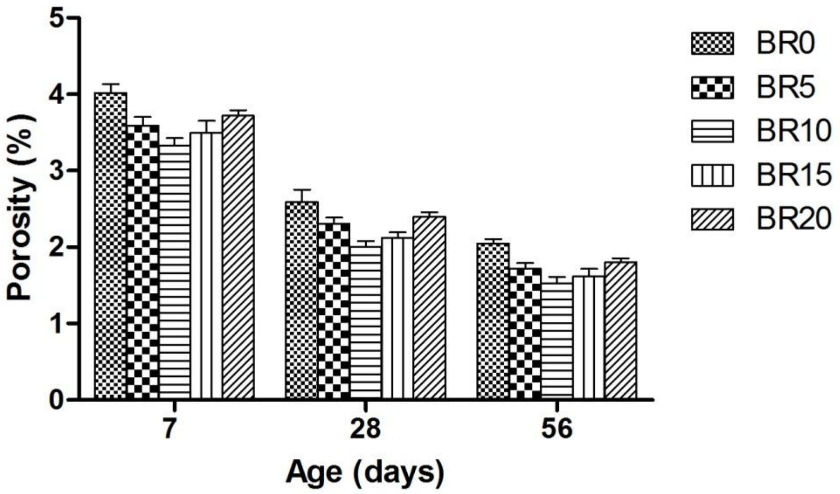
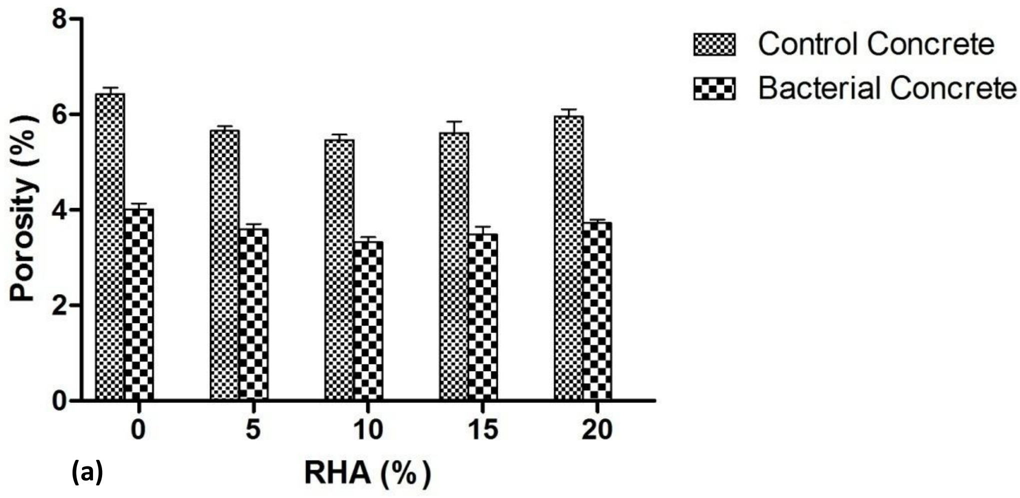
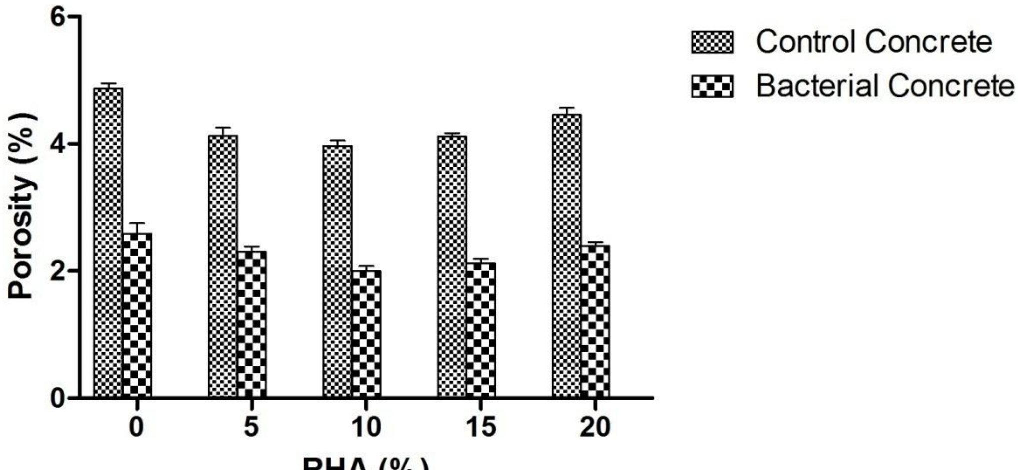


Fig 4.15: Porosity percentage of bacterial concrete at 7, 28 and 56 day

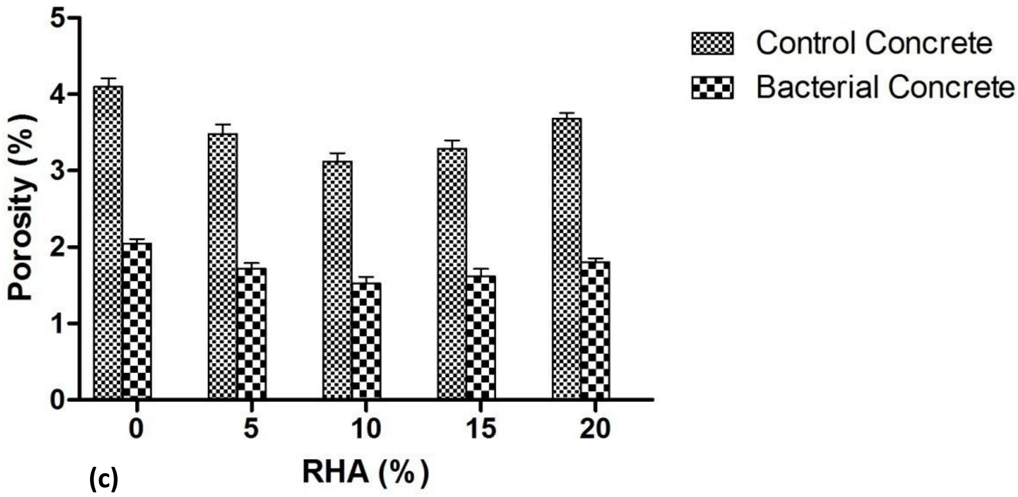
Inclusion of bacteria reduced the porosity percentage. The value of control concrete reduced significantly at 7, 28 and 56 day as shown in Figs 4.16 (a), (b) and (c). The value of R10 decreased from 5.46 to 3.32 % at 7 days, 3.9% to 2% at 28 days and, 3.12 % to 1.52 % at 56 days with respect to BR0. When the pores are blocked by inert material like calcium carbonate, the passage for water, air and pollutants is sealed which reduces the permeation of water and chloride in concrete (Wang et al., 2014)



(a)



(b)



(c)

Fig 4.16: Porosity percentage of control and bacterial concrete at (a) 7, (b) 28, (c) 56 day

4.2.5 XRD Analysis

This technique was used to observe concrete for CSH gel and calcite formation for concrete and bacterial concrete. XRD analysis of concrete samples with or without bacterial rice husk ash showed peaks of quartz (Q), calcium silicate hydrate (CSH), calcite (C), larnite (L) and ettringite (E) phases.It was observed that in BR0, BR5, BR10, BR15 and BR20, the increased formation of CSH gel and calcite resulted in increased strength compared to R0, R5, R10 and R15. Formation of CSH was high in R10 and BR10 resulting in more strength as compared to other control concrete and bacterial concrete samples. In control concrete, the maximum CSH peaks were seen in R10 in Fig 4.21 signifying more CSH and therefore more strength among the control concrete samples. X-ray analysis of the samples with and without bacteria shows that there were some extra peaks in the XRD spectra of the bacteria treated samples, which

`

are absent in the control samples. (Dick et al., 2006). Calcite peaks as confirmed by XRD analysis are responsible for lowering the permeability of the specimens (Ramakrishnan et al., 2001). XRD analyses revealed that majority of carbonate deposits were present as calcite crystals along with other components such as quartz (Dhami et al., 2012)

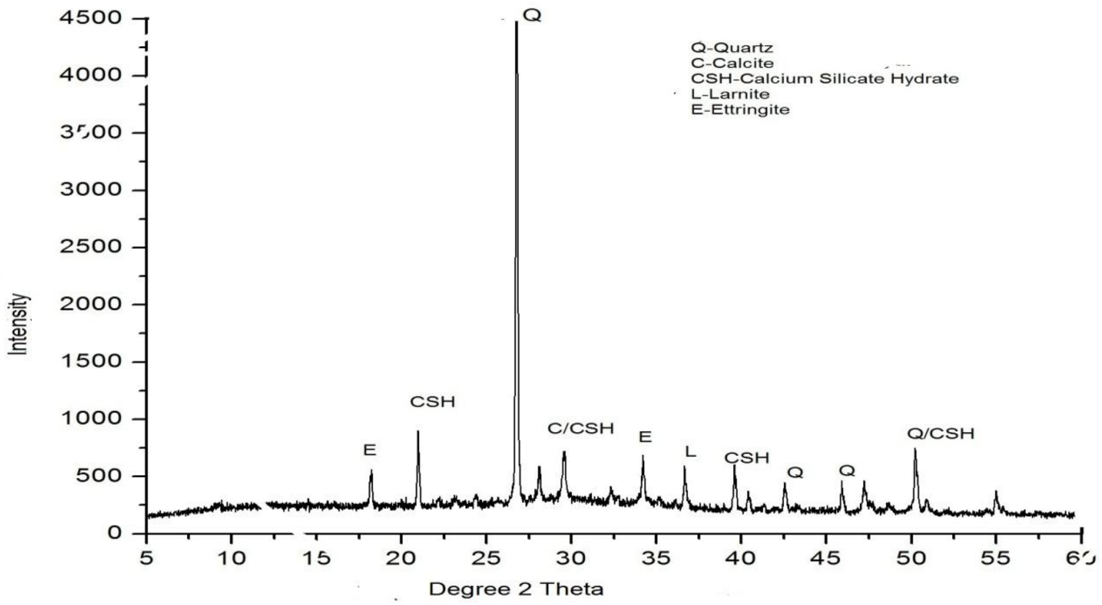


Fig 4.17: X-ray diffraction of control concrete (R0) at 28 day

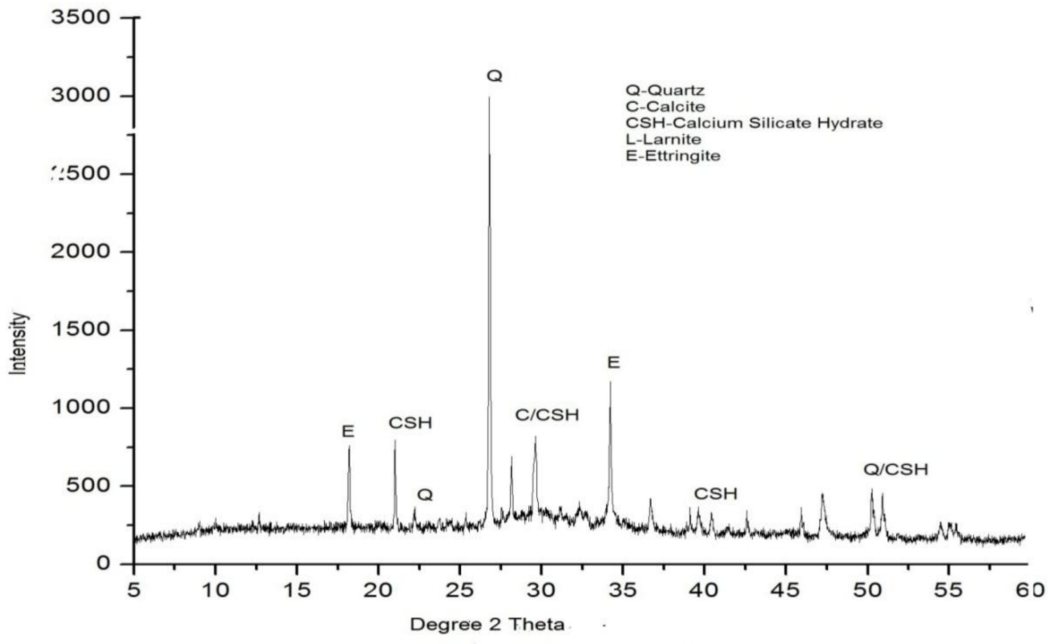


Fig 4.18: X-ray diffraction of bacterial concrete (BR0) at 28 day

`

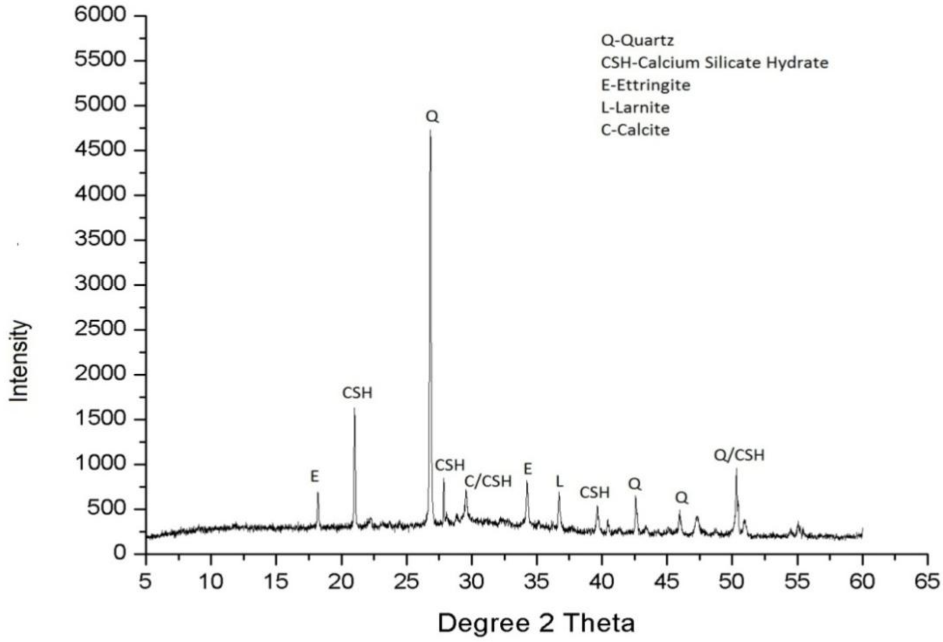


Fig 4.19: X-ray diffraction of control concrete (R5) at 28 day

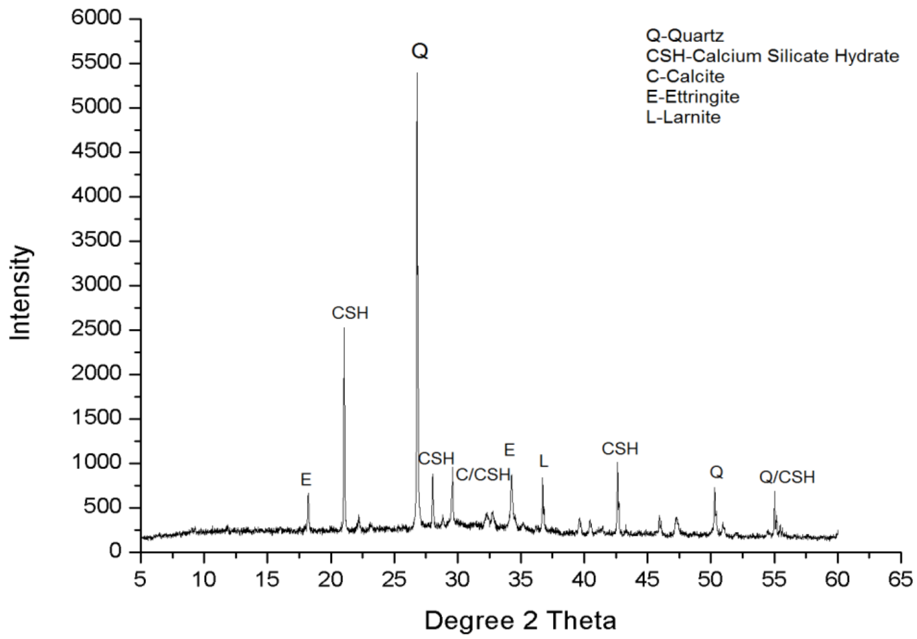


Fig 4.20: X-ray diffraction of bacterial concrete (BR5) at 28 day

`

c

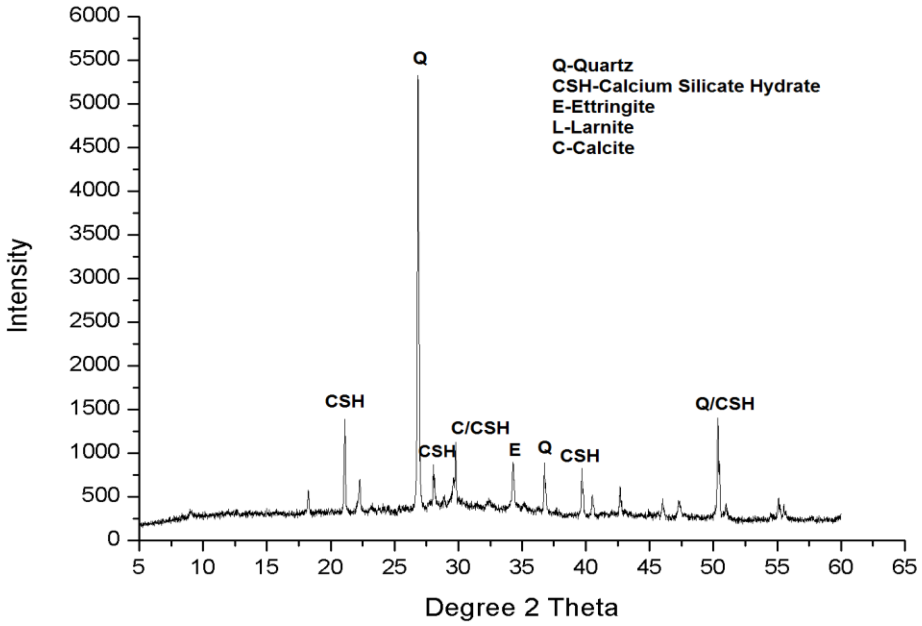


Fig 4.21: X-ray diffraction of control concrete (R10) at 28 day

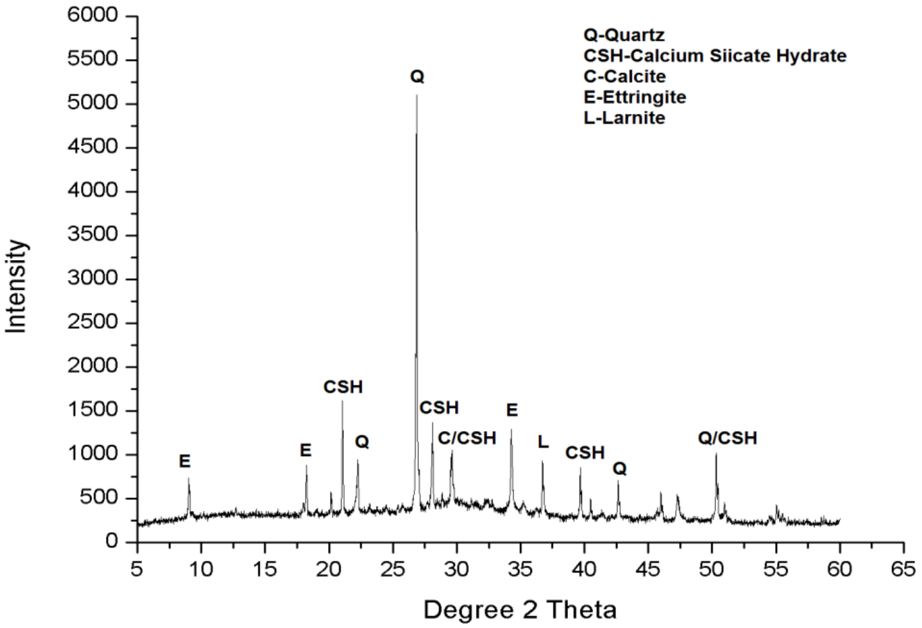


Fig 4.22: X-ray diffraction of bacterial concrete (BR10) at 28 day

`

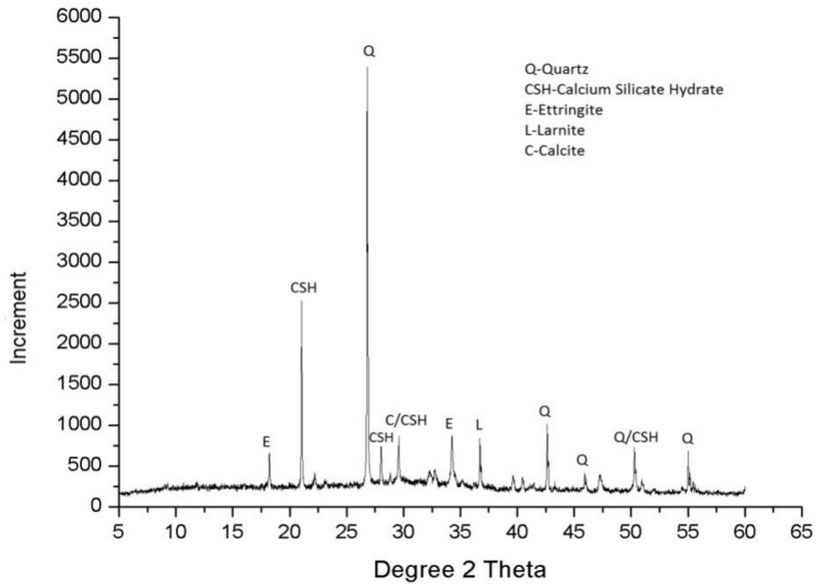


Fig 4.23: X-ray diffraction of control concrete (R15) at 28 day

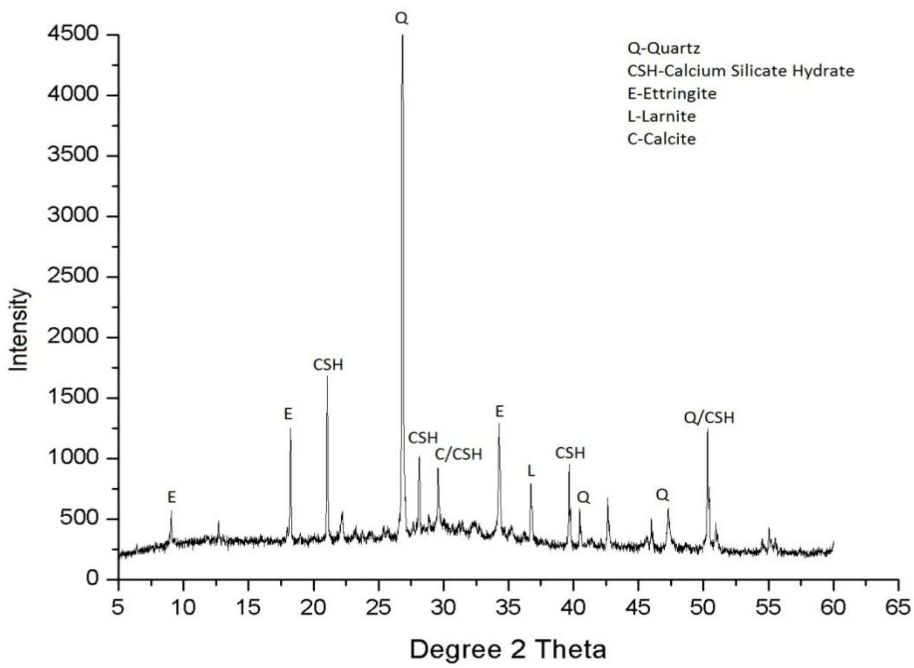


Fig 4.24: X-ray diffraction of bacterial concrete (BR15) at 28 day

`

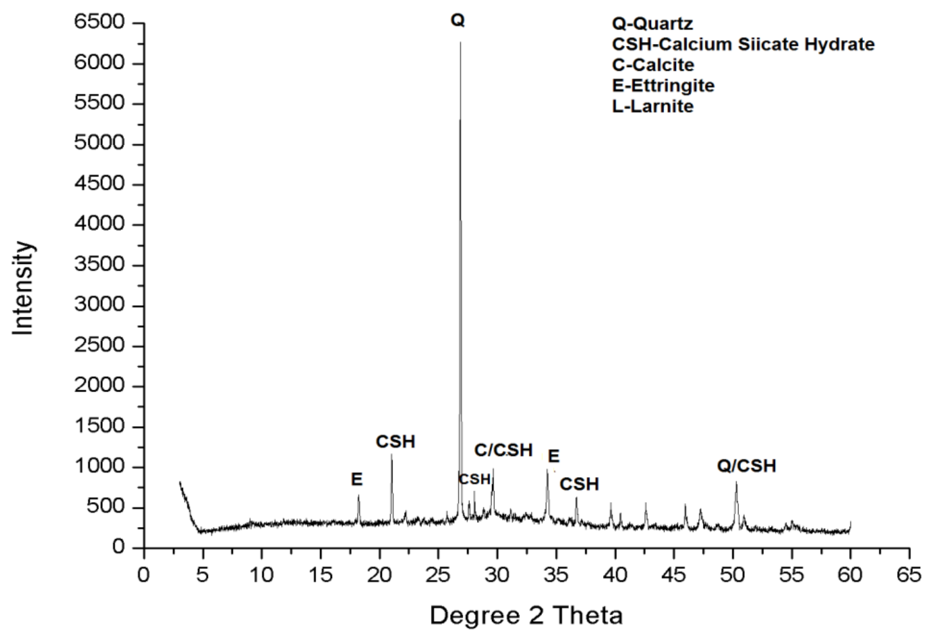


Fig 4.25: X-ray diffraction of control concrete (R20) at 28 day

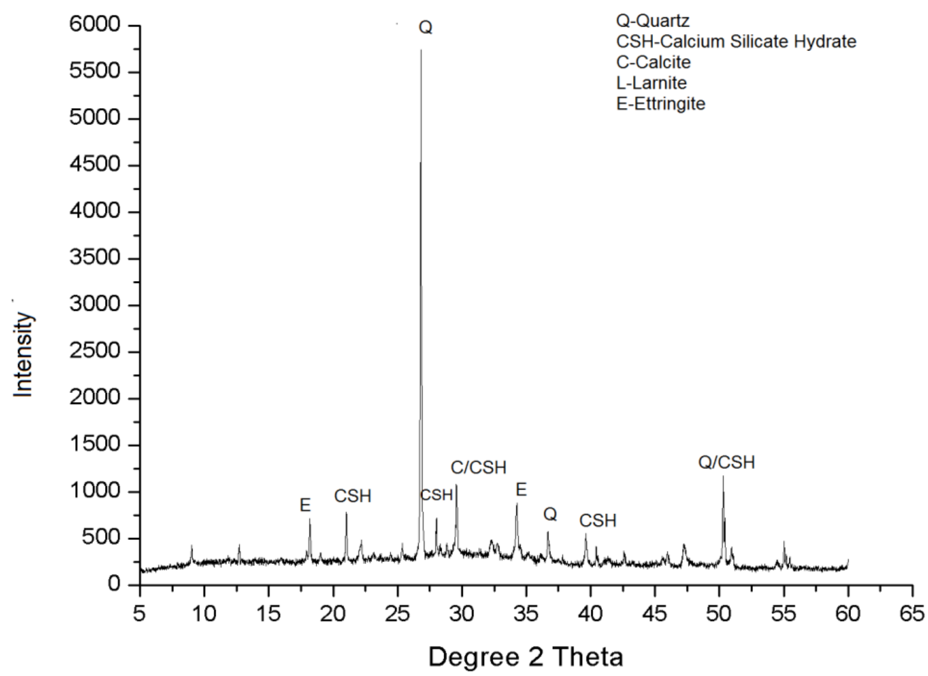


Fig 4.26: X-ray diffraction of bacterial concrete (BR20) at 28 day

`

4.2.6) SEM Analysis

Figs. 4.27- 4.31 show the scanning electron microscope (SEM) analysis of control and bacterial concrete containing 0%, 5%, 10%, 15% and 20% RHA. SEM images show the formation of calcium silicate hydrate (CSH) and dense structure in R10 due to the hydration reaction in the concrete specimen. In control concrete specimen for R10 (Fig 4.29 a) , more CSH and dense structure was observed after 28 days of curing whereas in R0 (4.27 a) , R5 (4.28 a), R15 (Fig 4.30 a) and R20 (Fig 4.31 a) concrete samples, a significant amount of unreacted calcium hydroxide or portlandite (CH) was observed. Jumate and Manea (2011) observed that after 28 days, CSH forms a mass that exhibits more density, more compactness and more continuity leading to increase in strength.

Similar observations were made for bacterial concrete BR10 (Fig 4.29 b) that showed CSH gel formation. Calcite(C) can be observed in all bacterial concrete samples responsible for improvement in strength in bacterial concrete. More voids were found in BR0 (Fig 4.27 b), BR5 (Fig 4.28 b) , BR15 (Fig 4.30 b) and BR20 (Fig 4.31 b) compared to BR10 which had a dense structure. The dense matrix in control and bacterial (10% RHA) showed higher compressive strength and lower water absorption and porosity due to the growth of calcite crystals within the pores of the cement–sand matrix (Enein et al., 2013)

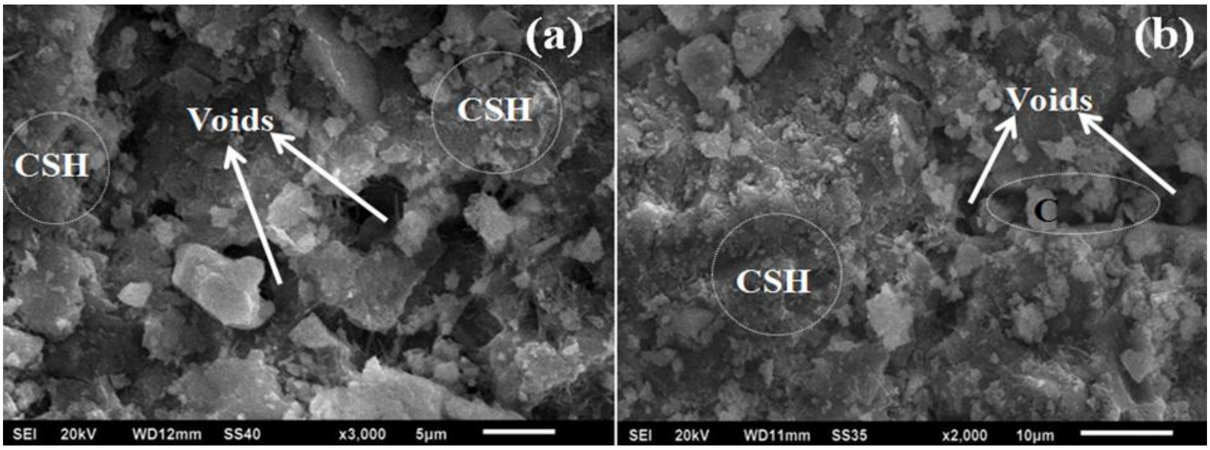


Fig 4.27: SEM analysis of (a) R0 and (b) BR0 at 28 day

`

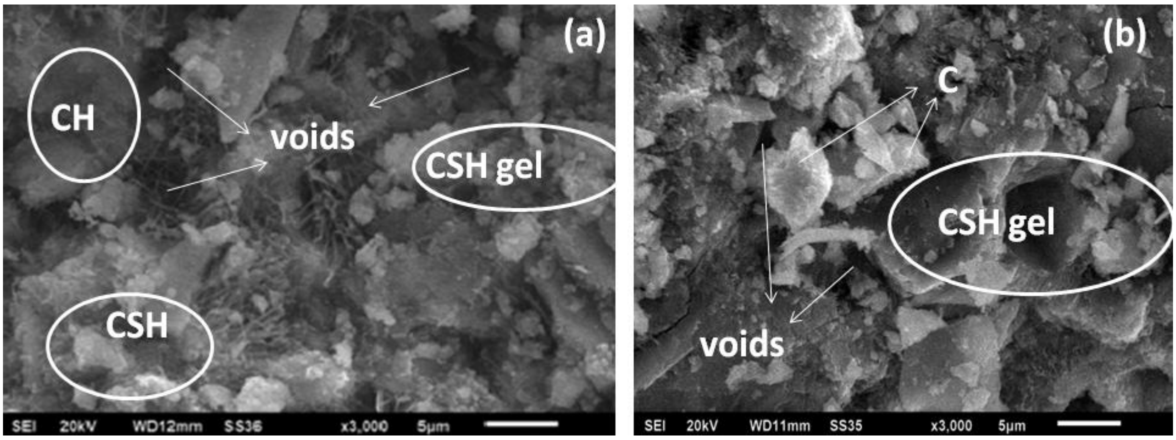


Fig 4.28: SEM analysis of (a) R5 and (b) BR5 at 28 day

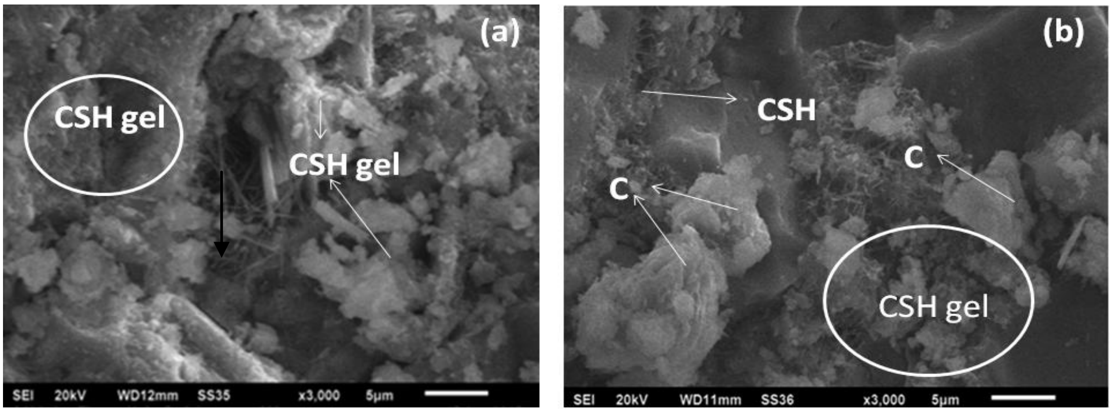


Fig 4.29: SEM analysis of (a) R10 and (b) BR10 at 28 day

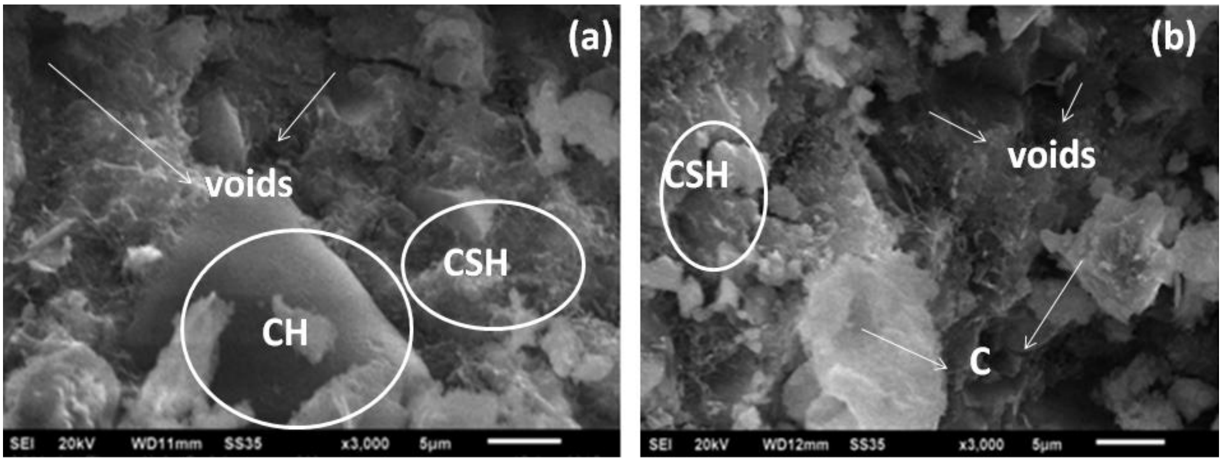


Fig 4.30: SEM analysis of (a) R15 and (b) BR15 at 28 day

`

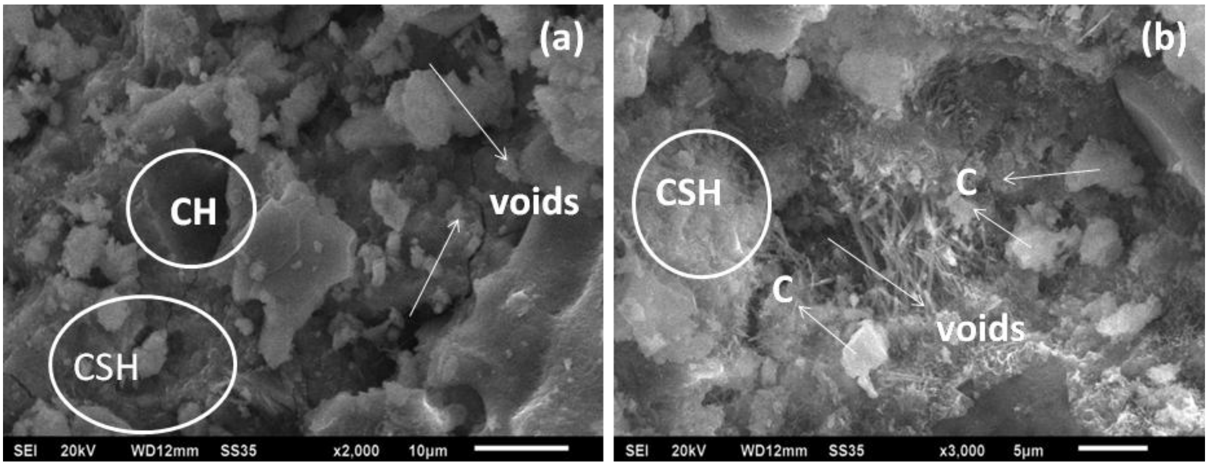


Fig 4.31: SEM analysis of (a) R20 and (b) BR20 at 28 day

`

CHAPTER 5

CONCLUSIONS

The present work investigated the influence of bacteria on partial replacement of fine aggregate cement by RHA concrete. On the basis of the results from the present study, following conclusions are drawn

5.1) COMPRESSION STRENGTH

i. Compressive strengths for all concrete mixtures increased with age. The maximum value of all mixes was seen at 56 days.

ii. The maximum compressive strength was seen in 10% RHA replacement in both control and bacterial concrete at all days. The compressive strength of control series at 28 days was 32.8, 34.1, 36.1, 35.3 and 33.1 MPa for 0, 5, 10, 15 and 20% replacement of RHA. In case of bacterial concrete, the compressive strength was 35.8, 37.8, 40, 38.4 and 36.2 MPa for 0, 5, 10, 15 and 20% RHA replacement respectively. Similar trend in strength was observed at 7 and 56 days of curing for all the percentages.

iii. Bacterial concrete (BR10) had highest compressive strength of 25.8, 40 and 46.7 MPa at the age of 7, 28 and 56 days curing while compressive strength of R10 was 24.3, 36.1 and 41.3 MPa at 7, 28 and 56 day curing respectively.

iv. The maximum increment was seen in 10 % RHA replacement on addition of bacteria.

v. Compressive strength in all cases increased with increase in age for all mixtures with or without bacteria. However, the rate of compressive strength increase was higher in case of mixtures with bacteria than mixtures without bacteria.

5.2) RAPID CHLORIDE PERMEABILITY TEST

i. The chloride permeability of control and bacterial concrete specimen showed reduction in chloride permeability with increasing curing period from 7 to 56 days.

ii. At 7 days , R10 (1998 coulombs) was in low permeability range while rest of the control concrete mixes were in moderate range. Similarly in bacterial concrete, R10 (1693) and R15 (1967) were in very low range while rest of the mixes were in moderate range.

`

iii. At 28 day of curing, R0 (2366 coulombs) and BR0 (2075 coulombs) both were in moderate range whereas rest of the of the mixes of both control and bacterial concrete were in low range.

iv. At 56 days of curing, all the control concrete mixes were characterized in “low” range whereas bacterial concrete with 10% RHA (799 coulombs) and 15% RHA (943 coulombs) were in very low range .

v. Permeability was reduced in bacterial concrete with all percentages as compared to control concrete, which leads to the conclusion that calcite was formed pores in bacterial concrete.

vi. Chloride permeability resistance was observed for all concrete mixtures. It was found that chloride permeability resistance was less in mixtures where bacteria was added as compared to the mixtures without bacteria which indicates resistance to the flow through the voids of concrete as a result of reduction in their umber or blockage.

5.3) ABRASION

i. Abrasion resistance depends on compression strength .Therefore, the abrasion resistance increased upto 10% RHA replacement as the the strength increased upto 10% and then starts decreasing.

ii. In control mix, minimum average thickness loss of 0.831, 0.585 and 0.491 mm was shown by R10 at 7, 28 and 56 days respectively.

iii. In bacterial control mix, minimum average loss of 0.752, 0.501 and 0.4 mm was shown by BR10 at the age of 7, 28 and 56 days respectively.

iv. At the age of 56 days, all concrete mixtures of control and bacterial concrete showed an increase in resistance to abrasion compared with the 7 and 28 day age results.

v. The abrasion loss was less in bacterial concrete mixes compared to control concrete mixes at all ages.

5.4) WATER ABSORPTION AND POROSITY

i. Increased water absorption and pore size decreased the compressive strength and vice-versa. The water absorption of R0 at the age of 28 days was 2.08%, whereas 5, 10, 15 and 20% control RHA concrete showed water absorption of 1.8, 1.66, 1.76 and 1.94%, respectively. At

`

28 days, minimum water absorption of 1.66% and 1.03% was observed in 10% RHA replaced control and bacterial concrete.

ii. At 7 days of curing bacterial concrete had minimum water absorption of 1.86% for 10% RHA compared to control concrete which showed water absorption of 2.51%. Similarly at 56 days bacterial concrete at 10% RHA replacement had water absorption value of 0.80% compared to 1.47% of control concrete.

iii. Similarly for porosity, the minimum values of 5.46, 3.90 and 3.12% were observed by 10 % replacement of control concrete at 7, 28 and 56 days compared to porosity values of 3.32, 2 and 1.52 % of bacterial concrete at 7, 28 and 56 days.

iv. Increased percentage of RHA upto 10% lead to decrease in water absorption and pororsity and made concrete structure more dense.

v. Water porosity and absorption was less in mixtures where bacteria was added as compared to the mixtures without bacteria. This indicates that the pores of the concrete may have been reduced in number or may have been blocked, which was the result of calcite precipitation by bacteria.

5.5) SCANNING ELECTRON MICROSCOPE (SEM)

i. SEM analysis reveal increased formation of CSH gel for mixes which supports the increased compressive strength upto 10% RHA in control and bacterial concrete.

ii. Pores were observed maximum for 0% replacement of RHA. Most dense structure was observed in case of R10 and BR10 that results in highest compressive strength for 10% RHA replacement.

5.6) X-RAY DIFFRACTION

i. XRD analysis revealed the increase formation of CSH gel which supports increase in compressive strength for mix containing RHA.

ii. XRD analysis confirmed the formation of higher calcite peaks in bacterial concrete compared to control concrete which causes an improvement in the strength of material.

`

REFERENCES

Achal, V., Mukherjee, M. and Reddy, M.S. (2010), Effect of calcifying bacteria on permeation properties of concrete structures, Journal of Industrial Microbiology and Biotechnology, 38: 1229-1234.

ACI 116 (2000), Cement and Concrete Terminology, American Concrete Institute, Farmington Hills, Michigan, USA.

ASTM C191-13 (2013), Standard test methods for time of setting of hydraulic cement by vicat needle, ASTM, West Conshohocken, PA.

ASTM C642 (2006), Standard test for method for density, absorption and void in hardened concrete , ASTM, West Conshohcken, PA.

ASTM C1202 (2010), Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration, ASTM, West Conshohocken, PA.

BIS 383 (1970), Specification for coarse and fine aggregates from natural sources for concrete, Bureau of Indian Standards, New Delhi, India.

BIS 456 (2000), Plain and reinforced concrete Code of Practice , Bureau of Indian Standards, New Delhi, India.

BIS 4031 (1996), Methods for physical test for hydraulic cement (1-6), Bureau of Indian Standards, New Delhi, India.

BIS: 10262 (1982), Recommended guidelines for concrete mix design. Bureau of Indian standards. New Delhi, India.

BIS 516 (1959), Indian standard Code for Practice – methods of test for strength of concrete. Bureau of Indian Standards, New Delhi,.

BIS: 1237(2012), Method for testing abrasion resistance of concrete. Bureau of Indian Standards. New Delhi, India.

`

BIS: 1489(1991), Portland pozzolan Cement Specification, Bureau of Indian Standards. New Delhi, India

BIS 8112 (1989), Specification for 43-grade Portland cement, Bureau of Indian Standards, New Delhi, India.

Bang, S.S. , Lippert, J.J. ,Yerra, U., Mulukutla S., Ramakrishnan V. (2014), Microbial calcite, a bio-based smart nanomaterial in concrete remediation. International Journal of Smart and Nano Material, 1:28-39

Boquet, E., Boronat, A., Ramos, C.A. (1973). Production of calcite (calcium carbonate) crystals by soil bacteria is a general phenomenon. Nature, 246: 527-529.

Bouzoubaa, N. And Fournier B. (2001), Concrete Incorporating Rice-Husk Ash: Compressive Strength and Chloride-ion penetrability. Materials Technology Laboratory., 121:81-92.

Bui, D.D., Hu, J., Stroeven, P. (2005), Particle size effect on the strength of rice husk ash blended gap-graded portland cement concrete, Cement Concrete Composites, 27: 35-366.

Castainer, S., Le, M.G., Perthuisot, J.P. (2000), Ca-carbonates precipitation and limestone genesis -the microbiogeologist point of view. Sediment Geology 126 : 9–23.

Chahal, N., Siddique, R., Rajor, A. (2012), Influence of bacteria on the compressive strength, water absorption and rapid chloride permeability of concrete incorporating silica fume, Construction and Building Materials, 37: 645-651.

Chahal, N. (2013), Influence of bacteria on the permeation characteristics of concrete made with supplementary cementing materials, PhD. thesis.

Chandramouli, K., Rao, S.P., Pannirselvam, N., Sekhar, S.T., Sravana, P. (2010), Durability and comparative study on concrete using RCPT for different grades of concrete. International Journal of Civil Engineering and Research, 1:19-27.

`

Chaturvedi, S., Chandra, R., Rai, V. (2006), Isolation and characterization of *Phragmites australis* (L.) rhizosphere bacteria from contaminated site for bioremediation of colored distillery effluent. Ecology Engineering, 27 :202–207.

Chatveera, B., Lertwattanaruk, P. (2011), Evaluation of sulfate resistance of cement mortars containing black rice husk ash. Journal of Environmental Management, 90:1435–1441.

Chindaprasirt, P., Rukzon, S. (2008), Strength, porosity and corrosion resistance of ternary blend Portland cement, rice husk ash and fly ash mortar. Construction and Building Materials, 22:1601–1606.

Chopra, D., Siddique, R., Kunal (2015), Strength, permeability and microstructure of self-compacting concrete containing rice husk ash. Biosystems Engineering, 130: 72-80.

Coutinho, J.S.(2003), The combined benefits of CPF and RHA in improving the durability of concrete structures. Cement Concrete Composites, 25: 51–59.

De Belie, N., De Muynck, W., Verstraete, W. (2005), Bacteria as protagonists for Concrete: bacterial cleaner and bacterial builder. fib Symposium "keep concrete attractive", Budapest, 24/1/2005.

De Muynck, W., Cox, K., De Belie, N., Verstraete W. (2008a), Bacterial carbonate precipitation as an alternative surface treatment for concrete. Construction and Building Materials, 22: 875–885.

De Muynck, W., Verbeken, K. ,De Belie N., Verstraete, W. (2009), Influence of the calcium dosage on the effectiveness of bacterially induced carbonate precipitation on limestone. Ecological Engineering, 36: 99-111.

De Muynck, W.,Belie, N. and Veratraete, W. (2010), Microbial carbonate precipitation in construction materials: A review, Ecological Engineering, 36: 118-136

Dhami, N.K.,Reddy, M.S.,Mukherjee, A.(2012), Improvement in strength properties of ash bricks by bacterial calcite. Ecological Engineering, 39: 31–35.

`

Dick, J., De Windt W., Graef, BD., Saveyn, H., Meeran, P.V., De Belie, N., Verstraete, W. (2006), Biodeposition of a calcium carbonate layer on degraded limestone by Bacillus species. Biodegradation, 17(4): 357-67.

Enein , S.A., Ali, .A.H.,Talkhan, F.N., Gawwad, H.A.(2013), Application of microbial biocementation to improve the physico-mechanical properties of cement mortar. HBRC Journal, 9 (1): 36–40.

Ganesan, K., Rajagopal, K., Thangavel, K. (2008), Rice husk ash blended cement: assessment of optimal level of replacement for strength and permeability properties of concrete. Construction And Building Materials, 22: 1675–1683.

Givi, A.N., Rashid, S.A., Aziz , F.N.A.,Salleh, M.A.M. (2010), Assessment of the effects of rice husk ash particle size on strength, water permeability and workability of binary blended concrete. Construction and Building Materials, 24: 2145-2150.

Ghafoori, N., Diawara, H (1999), Abrasion resistance of fine aggregate replaced silica fume concrete.ACI Materials Journal, 96: 559-567.

Ghosh, P.,Mandal, S.,Chattopadhyay, B.D.,Pal, S. (2005) Use of microorganism to improve the strength of cement mortar .Cement and Concrete Research, 35: 1980-1983

Habeeb, G.A. and Mahmud, H.B. (2010), Study on properties of rice husk ash and its use as cement replacement material. Materials Research, 13: 185-190.

Hammes, F. And Verstraete, W. (2002), Key roles of pH and calcium metabolism in microbial carbonate precipitation. Environment Science and Biotechnology, 1: 3–7.

Hammes, F., Boon, N., De Villiers, J., Verstraete, W., Siciliano, S.D. (2003a), Strain specific ureolytic microbial calcium carbonate precipitation. Applied and Environmental Microbiology, 69: 4901-4909.

Hammes, F., Seka, A., De Knijf, S., Verstraete, W. (2003b), A novel approach to calcium removal from calcium-rich industrial wastewater, Water Resources, 37 : 699–704.

Hwang, C.L., Wu, D.S.(1989), Properties of cement paste containing rice husk ash. American Concrete Institute, 114: 733–765.

`

Ikpong, A.A., Okpala, D.C. (1992), Strength characteristics of medium workability ordinary Portland cement-rice husk ash concrete. Building Environment, 27: 105–111 .

Ismail, M.S., Waliuddin, A.M. (1996), Effect of rice husk ash on high strength concrete. Construction and Building Materials, 10: 521–526.

Jonkers, H.M., Thijssen, A., Muyzer, G., Copuroglu, O., Schlangen, E. (2010), Application of bacteria as selfhealing agent for the development of sustainable concrete. Ecological Engineering, 36: 230-235.

Jumate, E.,Manea, D.L. (2011), X-ray diffraction study of hydration process in Portland cement. Journal Of Applied Engineering Sciences,14: 79-86.

Khani, M. M., Ramezanianpour, A. A.,Ahmadibeni, G. (2009), The effect of rice husk ash on mechanical properties and durability of sustainable concretes. International Journal of Civil Engineering, 7: 83-91.

Khassaf, S.I., Jasim, A.T., Mahdi, F.K. (2014), Investigation the properties of concrete containing Rice husk ash to reduction the seepage in canals. International Journal Of Scientific And Technology Research , 3: 43-49.

Kishore, R., Bhikshma,V.,Prakash P.J. (2011), Study on strength characteristics of high strength rice husk ash concrete. Procedia Engineering, 14: 2666-2672.

Knorre, H., Krumbein, W. (2000), Bacterial calcification of inmicrobial sediments. Springer-Verlag, 6: 25-31.

Li, H.,Zhang, M.H.,Ou, J.P.(2006), Abrasion resistance of concrete containing nano-particles for pavement. Wear, Elsevier, 260: 1262–1266.

Mehta, P.K. (1986), Concrete: structure, properties and materials, Englewood cliffs, NJ: Prentice hall.

Mehta, P.K., (1975), Rice hull ash cement high quality, acid resisting, ACI Journal Proceeding, 61: 235-236.

`

Mehta P.K. (1977), Properties of blended cement made from rice husk ash, ACI Journal Proceeding, 74: 440-442.

Mehta, P.K., (1978), Siliceous ashes and hydraulic cement preparation, Belgium Patent 802909, 1973, U.S. Patent 4105459. 63.

Mehta, P.K.,Pritz, D. (1978), Use of rice hull ash to reduce temperature in high-strength mass concrete. ACI Journal Proceeding, 75: 60-63.

Mehta, P.K.(1992), Rice husk ash—a unique supplementary cementing material. In: Proceedings of the International Symposium on Advances in Concrete Technology, Athens, Greece :407-430.

Mehta, P.K. and Monteiro, P.J.M. (2014*)*, Concrete: Microstructure, Properties, and Materials, McGraw-Hill, 4: 23-49.

Naik, T.R., Singh, S.S., Hossain, M.M. (1997), Abrasion resistance of high-strength concrete made with class C fly ash, ACI Materials Journal. 92 : 649-659.

Naik , T.R., Singh, S, Ramme, B.W. (2002), Effect of source of fly ash on abrasion resistance of concrete .American Society of Civil Engineers.

Nagataki, S. (1994), Mineral Admixtures in Concrete: State of the Art and Trends. American Concrete Institute, 144: 447-482.

Nemati, M.,Greene, E.A.,Voordouw, G. (2005), Permeability profile modification using bacterially formed calcium carbonate: comparison with enzymic option. Process Biochemistry, 40: 925–933.

Neville, A.M. (1973), Properties of concrete ,National Academics Of Sciences, Engineering And Medicine, 38: 822.

Nolan, E., Basheer, P.A.M., Long, A.E. (1995), Effects of three durability enhancing products on some physical properties of near surface concrete. Construction and Building Materials, 9: 267–272.

`

Ramachandran, S.K., Ramakrishnan, V., Bang, S.S. (2001), Remediation of concrete using micro-organisms. ACI Materials Journal, 98: 3-9.

Ramakrishnan, S.K., Panchalan, R.K., Bang S.S. (2001), Improvement of concrete durability by bacterial mineral precipitation,In: 11th international conference on fracture Turin, Italy.

Riding, R. (2000), Microbial Carbonates: the geological record of calcified bacterial mats and biofilms. Sedimentology, 47: 179-214.

Sakr, K. (2006), Effects of silica fume and rice husk ash on the properties of heavy weight concrete. International Journal of Civil Engineering, 18: 367–376.

Sanusi, G., Dahiru, D., Khalil, I.M. (2014), An assessment of the durability properties of binary concrete containing rice husk ash. Civil and Environmental Research, 6: 53-67.

Saraswathy, V.,Song, H.W. (2007), Corrosion performance of rice husk ash blended concrete. Construction and Building Materials, 21: 1779–1784.

Sarda, D., Huzaifa, C., Sarode, D.D., Lele, S. (2009), Biocalcification by *Bacillus pasteurii* urease: a novel application. Journal of Industrial Microbial Biotechnology, 36: 111-115.

Sensale, G.R.D. (2006), Strength development of concrete with rice-husk ash. Cement and Concrete Composites, 28: 158–160.

Siddique, R. (2004), Performance characteristics of high-volume Class F fly ash concrete. Cement and Concrete Research, 34: 487–493

Siddique, R.,Khatib, J.M. (2010), Abrasion resistance and mechanical properties of high volume fly ash concrete. Material and Structures, 43: 709-718.

Siddique, R. (2013), Compressive strength, water absorption, sorptivity, abrasion resistance and permeability of self-compacting concrete containing coal bottom ash. Construction and Building Materials, 47: 1444-1450.

`

Singh, G. and Siddique, R. (2011), Effect of waste foundry sand (WFS) as partial replacement of sand on the strength, ultrasonic pulse velocity and permeability of concrete. Construction and Building Materials, 26: 416–422.

Stocks, F.S., Galinat J.K., Bang, S.S., (1999). Microbiological precipitation of $CaCO_3$. Soil Biology and Biochemistry, 31: 1563-1571.

Tittelboom, K., De Belie, N., De Muynck, W., and Verstraete, W. (2010), Use of bacteria to repair cracks in concrete. Cement and Concrete Composites, 40: 157-166.

Van, V., Robler ,V., Bui, B., Ludwig, L.(2014), Rice husk ash as both pozzolanic admixture and internal curing agent in ultra-high performance concrete. Cement and Concrete Composites, 53: 270–278.

Wang, J.Y., Snoeck, D.,Vlierberghe, S.,Verstraete, W.,Belie, N.(2014), Application of hydrogel encapsulated carbonate precipitating bacteria for approaching a realistic self-healing in concrete. Construction and Building Materials, 68: 110–119.

Zhang, M. H., and Malhotra, V. M. (1996), High-performance concrete incorporating rice husk ash as a supplementary cementing material, ACI Materials Journal, , 93: 629-636.

Zhang, Y.,Guo, H.X.,Cheng, X.H. (2015), Role of calcium sources in the strength and microstructure of microbial mortar. Construction and Building Materials, 77:160–167.