SOME STUDIES ON POROUS CONCRETEWITH RECYCLED CONCRETE AGGREGATE

THESIS

Submitted by

Bibekananda Mandal

[Exam Roll No- M4 CIV 1602]

[Class Roll No – 001410402001]

[Reg No- 128858 of 2014 -15]

Under the Guidance of

Prof. (Dr.) Saroj Mandal

In the partial fulfillment for the award of the degree
Of

MASTER OF CIVIL ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING
JADAVPUR UNIVERSITY
Jadavpur, Kolkata- 700 032
2016

JADAVPUR UNIVERSITY

FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF CIVIL ENGINEERING

JADAVPUR, KOLKATA-700032

CERTIFICATE OF RECOMMENDATION

This is to certify that Bibekananda Mandal (Exam Roll No M4CIV 1602, Registration no 128858 of 2014-2015 has carried out the thesis work entitled "**SOME STUDIES ON POROUS CONCRETE WITH RECYCLED CONCRETE AGGREGATE"** under my direct supervision & guidance .He carried out this work independently .I hereby recommend that the thesis be accepted in partial fulfillment of the requirements for awarding the degree of "**MASTER OF ENGINEERING IN CIVIL ENGINEERING (STRUCTURAL ENGINEERING**)".

....

Prof. (Dr.) Saroj Mandal
Department of civil engineering
Jadavpur University
Kolkata- 700 032

Countersigned by

……………………………………….

Dean
Prof. Sivaji Bandhopadhyay
Faculty of Engineering and Technology
Jadavpur University
Kolkata- 700 032

....

(H.O.D)
Department of civil engineering
Jadavpur University
Kolkata- 700 032

JADAVPUR UNIVERSITY

FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF CIVIL ENGINEERING

JADAVPUR, KOLKATA-700032

CERTIFICATE OF APPROVAL

This foregoing thesis is hereby approved as credible study on an Engineering Subject carried out and presented in a manner satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted.

Committee of final examination

For evaluation of the thesis.

…………………………………………………………

Signature of examiner

……………………………………

Signature of examiner

DECLARATION

I, Bibekananda Mandal a student of Master of engineering in civil engineering dept. (structural engineering), Jadavpur university, Faculty of engineering & technology, hereby declare that the work being presented in the thesis work entitled, **“SOME STUDIES ON POROUS CONCRETE WITH RECYCLED CONCRETE AGGREGATE”** is authentic record of work that has been carried out at the Department of civil engineering**,** Jadavpur university, under Prof. (Dr.) Saroj Mandal Department of civil engineering**,** Jadavpur university.

The work contained in the thesis has not yet been submitted in part or full to any other university or institution or professional body for award of any degree or diploma or any fellowship.

Date: (Bibekananda Mandal)

Place: Exam Roll No- M4 CIV 1602

Reg No- 128858 of 2014 -15

ACKNOWLEDGEMENTS

First of all, I would like to express my gratitude to my supervisor, Professor Dr. Saroj Mandal, for his valuable contributions and advice through the course of my graduate studies. His guidance and support are the main reasons that made the completion of this research possible. His patience and availability for any help whenever needed with his heavy workload is appreciated.

I would also like to express my gratefulness to the laboratory technicians of Jadavpur University Mr. Samrat Sengupta and the administrative staff in the Department of Civil Engineering. Additionally, thanks are extended to Mr. Malay Chatterjee who provided the Carbonation Chamber used in this project.

My sincere appreciation goes to my post graduate co partner Mr. Sougata Das, Likhon Biswas, Subhankar Pramanik, Sourav Chanda and Falguni Shit for their support and assistance both inside and outside the laboratory.

Finally, I would like to thank my friends, new and old, for their constant encouragement during the difficult times, and my family, for their confidence in me and their endless understanding.

Date: ……………………………………….

Bibekananda Mandal

Abstract

Porous concrete is a sustainable material with several environmental advantages. It is composed of mixtures of cement, water and coarse aggregate, without any fine aggregate. Pore connectivity is the essential requirement to the porous concrete and thus compaction is generally made with some restriction, otherwise it can result in a layer of cement paste at the bottom of the concrete structure that would negatively affect the permeability. In general, the natural coarse aggregate, an important natural resource is used for porous concrete. For environmental benefit and future scarcity of natural resources, the use of recycled concrete aggregate is now widely used in normal concrete construction.

The most important features of porous concrete are its reduced density, high water permeability and adequate compressive strength. Compare to the conventional concrete, the porous concrete are being used in pavements, driveways, parking lots and water logged area. This can also be used as a sound barrier in different building construction also.

An attempt has been made to develop porous concrete with recycled concrete aggregate .A comparison has been made among the properties of porous concrete with fully natural aggregate, porous concrete with fully recycled aggregate and porous concrete with both natural and recycled (50:50) aggregate .The study is limited to mainly strength, water permeability and the carbonation effect. Recycled concrete aggregate are derived from the old crushed concrete cubes (already tested) by manual hammering and subsequent sieving. Both the natural and recycled concrete aggregate passes through 12.5 mm sieve and retained on 10 mm sieve has been only used for the present study. Recycled concrete aggregates are comparatively lighter and having higher water absorption compared to the natural aggregate due to the presence of weak attached mortar with the aggregate. The quantity of mortar attached to the recycled concrete aggregate is determined as 22.5 %.The other parameter like water cement ratio (0.35,0.33 and 0.30) and cement aggregate ratio (1:4,1:5 and 1:6) have been incorporated in the experimental study.

Based on the present experimental results, it is possible to developed more environment friendly porous concrete with recycled concrete aggregate. The compressive strength of porous concrete with recycled concrete aggregate is about (35%) less than that of porous concrete with natural aggregate of similar mix. However, the deficiency can be improved by the use of a combination of natural and recycled aggregate (50:50) or increasing the cement content.

TABLE OF CONTENTS

3.2 Ingredients

3.6 Test of porous concrete

LIST OF TABLES

LIST OF FIGURES

❖ List of abbreviations

EPA: Environmental Protection Agency
CWA: Clean Water Act
PSC: Portland Slag Cement
ITZ: Interfacial Transition Zone
PC: Porous concrete
LEED: Leadership in Energy and Environmental Design
OPC: Ordinary Portland cement
NA: Natural aggregate
RCA: Recycled aggregate
W/C: Water Cement ratio
A/C: aggregate cement ratio
SCM: Supplementary cementing material
SSD: Saturated surface dry
CPC: Conventional Porous Concrete
HPPC: High Performance Porous concrete
R.H: Relative Humidity

❖ Cement chemistry notations

C: CaO - Calcium oxide or lime
C: CO_2 - Carbon dioxide
H: H_2O - Water
S: SiO_2 - Silicon dioxide or silica
C_3S: 3 CaO · SiO_2 – Tricalcium silicate
C_2S: 2 CaO · SiO_2 – Dicalcium silicate
CSH: Calcium silicate hydrates
Ca $(OH)_2$: calcium Hydroxide
$CaCO_3$: Calcium Carbonate

CHAPTER 1.0 INTRODUCTION

1.1 GENERAL

Porous concrete (PC) is a special type of concrete with a high interconnected pore structure. Porous structure and interconnectivity of pores allow efficient drainage of water through its matrix and can offer sustainable drainage solutions. Porous concrete was developed in the mid 19 th century, especially after the Second World War, to emphasis on conservation of non-renewable mineral resources and energy [1].But it has been gaining popularity in the past decade for its economic and environmental benefit.

Porous concrete is a composite material consisting of coarse aggregate, Cement, and water. It is different from conventional concrete in that it contains no fine aggregate in the mixture. That’s why sometimes this type of porous concrete termed as no fines concrete or pervious concrete. The aggregate usually consists of a single size and is bonded together at its points of contact by a paste formed by the cement and water. The presence of high percentage of interconnected voids permits the rapid percolation of water through the concrete. Unlike conventional concrete, which has porosity anywhere from 2- 5%, porous concrete can have porosity from 15-35% depending on its application. Porous concrete characteristics differ from conventional concrete in several other ways. Compared to conventional concrete, porous concrete has a lower compressive strength, higher permeability, and a lower unit weight, approximately 70% of conventional concrete. Nowadays, PC is considered as one of the best management practices [2] and most important environmentally materials for managing storm-water runoff, recharging groundwater, and improving water quality [3].

The use of porous concrete in specific applications requiring high permeability is very attractive. There is also an increasing interest for PC in low-traffic roads, parking lots, driveways, and sidewalks to reduce the risk of flooding runoff [4, 5]. PC can also be used for sustainable constructions because of its high insulation performance and noise reduction [6, 7]. The reduction of heat transfer is another attractive property of PC [6, 8]. In terms of environmental performance, PC can be also used to filter contaminants, such as chemicals and heavy metals within the porous structure [9, 10].

PC mixtures are usually proportioned with water to cementitious materials (w/c) ratios ranging between 0.30 and 0.35. Too much water will cause paste drain down, while too little water can hinder strength development and lead to a premature surface raveling. Although the permeability of PC is of greatest concern, which is maximized with the use of single-sized aggregate, the strength and durability of PC cannot be ignored. Indeed, when it is properly designed, it is possible to develop porous concrete having both good permeability and high performance. The use of a well gap-graded aggregate and no-fine aggregates generally can achieve a continuous void network. The design approach of PC is mainly based on proper selection of aggregate varying the paste volume and water cement ratio until the targeted properties are achieved.

The use of construction and demolition waste as a source of aggregate for the production of new concrete has become more common in recent years. Due to the increasing cost of landfill, and the scarcity of natural resources for aggregate, the use of recycled aggregate is becoming more effective in concrete construction [11]. Thus, the use of waste from construction sites as a source of aggregates is an important area of research. Recycling of concrete process involves different activities like breaking, removing, and crushing the existing concrete into a material with a specified size and quality. Significant differences have been observed between the properties of the porous concrete with recycled aggregates of various particle size groups [12]. Extensive research and development on reuse of waste crushed concrete (recycled aggregate) is going on globally to prove its feasibility, economic viability and cost effectiveness [13, 14].

There are some disadvantages also. Generally, the strength and durability of porous concrete is less than that of ordinary concrete. As there are more void space present in porous concrete, there remains a high possibility of clogging of dust particles after few days later, of its use. The seepage also gets reduced considerably, in pore structure due to clogging. So, high maintenance is required. Hence, at present condition the main limitation to broaden the potential application of porous concrete is their low durability. As low durability is not sustainable friendly since we have to emphasize to increase the long term impact of the porous structure.

1.2 USES:

Porous concrete is limited to use in areas subjected to low traffic volumes and heavy loads. But presently porous concrete is utilized in various sections which are described as below in the Table 1.1.

Table1.1 Uses of Porous Concrete in various Prospective

Low-volume traffic pavements	concrete pavements	Aquatic amusement centers
Floors for greenhouses	Tennis courts	Low water crossings
Sidewalks and pathways	Hydraulic structures	Noise barriers
Fish hatcheries	Driveways	Tree grates in sidewalks
Parking areas	Swimming pool decks	Pavement edge drains
Artificial reefs	Slope stabilization	Groins and seawalls
Patios	Well linings	Foundations
Sub-base for conventional	Residential roads and alleys	Walls (including load-bearing)

.

1.3 ADVANTAGES

The advantages of porous concrete in environmental, safety and economic purposes are described as follows

- Reduce volume of runoff water.
- Recharge the ground water level.
- Reduce pollution of runoff water.
- Minimize the heat effect due to its light color.
- Increase life quality of greenery.
- Increase road traffic safety.
- Improve pavement noise performance due to its open interconnected air voids structure.
- Allow the water to flow freely through the surface which reduces pavement glare especially at night when the road is wet.
- Facilities for parking by reducing water retention areas.
- Require less costly repairs than bitumen black top.

1.4 DISADVANTAGES

Although advantageous in many regards, the porous concrete has limitations that must be considered when planning its use.

- The bond strength between particles is lower than conventional concrete and therefore provides a lower compressive strength.
- It increases surface raveling , excessive cracking and wearing which increases early deterioration
- There is a potential for clogging by organic and inorganic materials if not properly installed and maintained, thereby reducing possibly its permeability characteristics.

1.5 OBJECTIVES OF PRESENT RESEARCH:

The main objectives of the present study are as follows:

1) To study the properties of porous concrete with natural coarse aggregate and to compare with that of porous concrete with recycled concrete aggregate and with both natural and recycled concrete aggregate (50:50).

2) To determine appropriate water-cement ratio and aggregate- cement ratio that will yield the required compressive strength, water permeability and durability.

3) To observe the effects of initial carbonation on various mixes of porous concrete in a carbonation chamber for the duration of 10 days and 30 days.

4) Reducing the production costs of concrete in terms of natural resources, energy and economical costs by using recycling concrete aggregate in terms of environmental benefit.

1.6 SCOPE OF PRESENT RESEARCH

1) The main properties studied include density, workability, porosity, sorptivity, compressive strength, tensile strength, flexural strength, water permeability and carbonation test of various mixes of porous concrete.

2) Although water permeability and rate of carbonation test for durability characteristic is the most important features of the porous concrete, there is no well-established method for its quantification. Therefore, an experimental procedure to assess the water permeability and one carbonation chamber test set up has been developed.

CHAPTER 2.0 LITERATURE REVIEW

Porousconcrete was developed in the year 1950, but its popularity has increased in the past decade because of its environmental benefits. It is a known mixture of concrete with cement, coarse aggregate, and water with no fine aggregates, which allows the formation of interconnected void spaces in the hardened product. To create a Porous concrete structure with optimum permeability and durability, the amount of water, amount of cement, type and size of aggregate, and compaction, all must be considered. Many studies have been performed to determine the properties associated with Porous concrete for engineering applications throughout the past few decades by a variety of researchers .A summary of the values provided in this literature can be seen in a series of tables and graphs.

In 1976, V.M. Malhotra [16, 17]discussed Porous concrete applications and properties.He provided details on such properties as consistency, proportions of materials, unit weight, compatibility, and curing in an attempt to maximize permeability in the porous concrete. Malhotra also conducted multiple experiments on various test cylinders in an attempt to find a correlation between compressive strength and any of the material's properties. He concluded that the compressive strength of Porous concrete was dependent on the water cement ratio and the aggregate cement ratio. Table 2.1.1 and Figure 2.1.1 illustrate the relationship between compressive strength and time using various water cements ratios and aggregate cement ratios. He also concluded that even the optimum ratios still would not provide compressive strengths comparable to conventional concrete.

Malhotra went on to investigate the effects of compaction on compressive strengths. Table 2.1.2 and Figure 2.1.2 show the correlation between compressive strength and unit weight when different aggregate cement ratios along with various aggregate gradings are employed. Malhotra alsoexperimented on different types of aggregates and their effect on compressive strength.Table 2.1.3 shows the relationship between aggregate type and compressive strength.

Table 2.1.1 Relationship between Compressive Strength and W/C & A/C Ratios (Aggregate Size ¾ "Gravel)

Aggregate Cement Ratio (A/C)*	Water Cement Ratio (W/C)**	Age of Test (days)	Density (lb/ft^3)	Cement (lb/yd^3)	Compressive Strength (psi)
6	0.38	3	125.8	436	1295
		7	125.4	436	1660
		28	124.8	436	2080
8	0.41	3	120	326	850
		7	119.5	326	1055
		28	119.4	326	1365
10	0.45	3	116.7	261	625
		7	116.4	261	780
		28	116.2	261	1015

*A/C Ratios are by volume. **W/C Ratios are by weight.

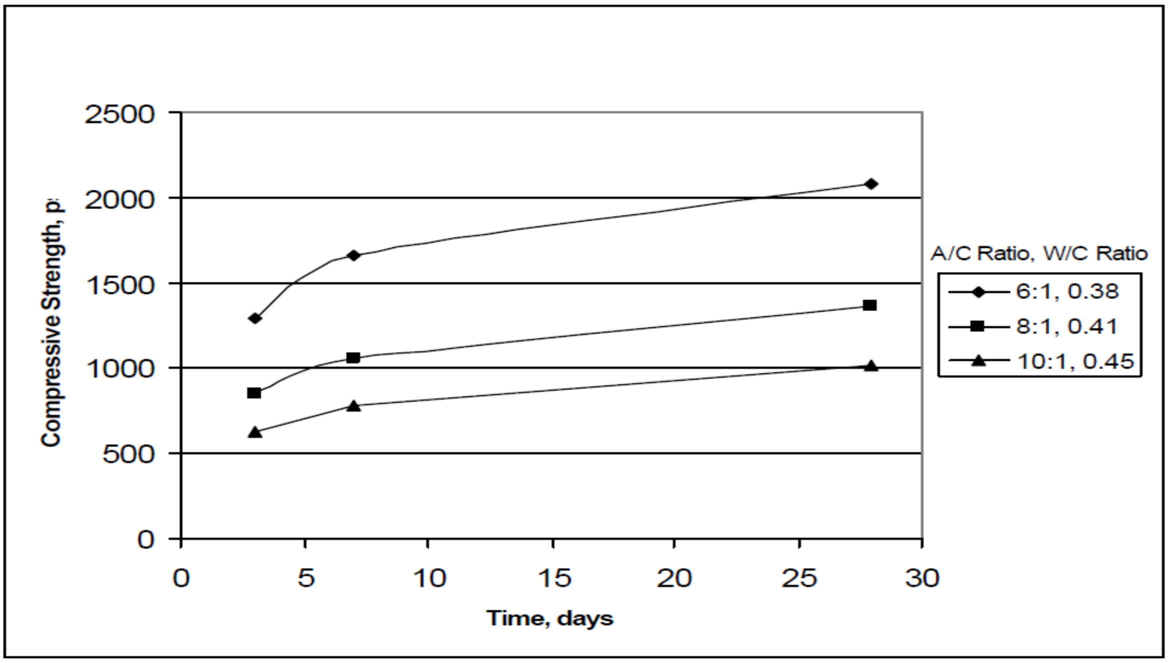
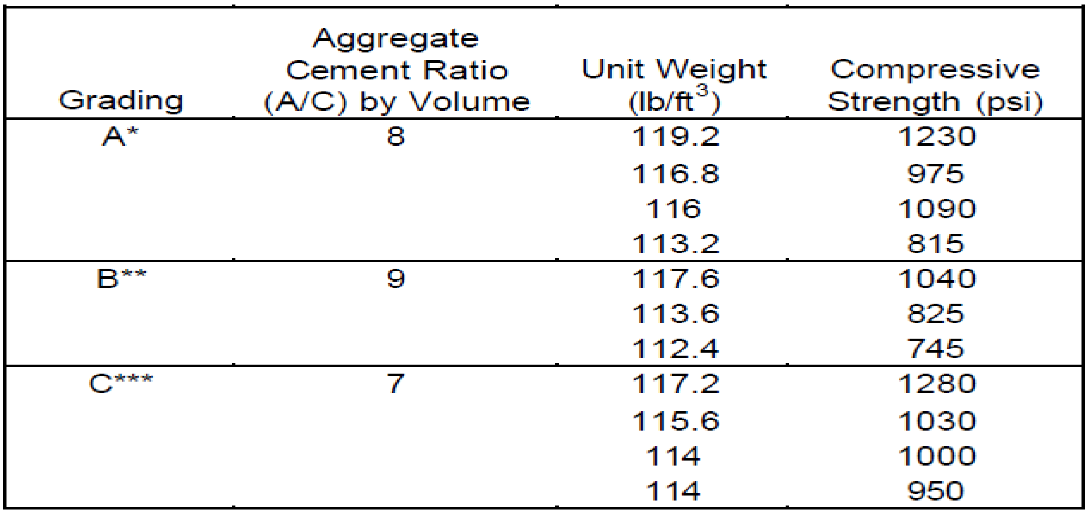


Fig 2.1.1 28 Days Compressive Strength with time

Table 2.1.2 Relationship between 28 Day Compressive Strength and Grading (W/C=0.36)



Grading	Aggregate Cement Ratio (A/C) by Volume	Unit Weight (lb/ft^3)	Compressive Strength (psi)
A*	8	119.2	1230
		116.8	975
		116	1090
		113.2	815
B**	9	117.6	1040
		113.6	825
		112.4	745
C***	7	117.2	1280
		115.6	1030
		114	1000
		114	950

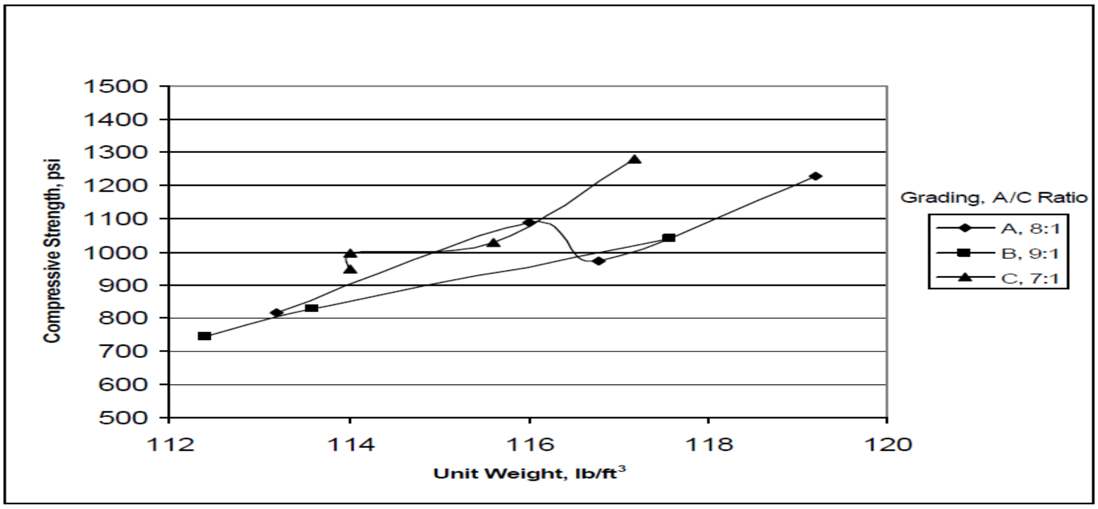


Fig2.1.2: 28 Days Compressive Strength and unit weight

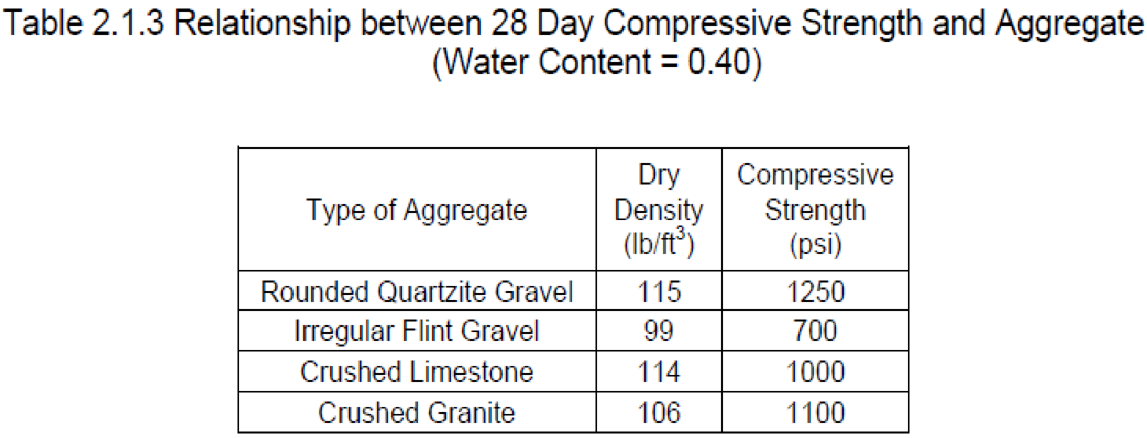


Table 2.1.3 Relationship between 28 Day Compressive Strength and Aggregate (Water Content = 0.40)

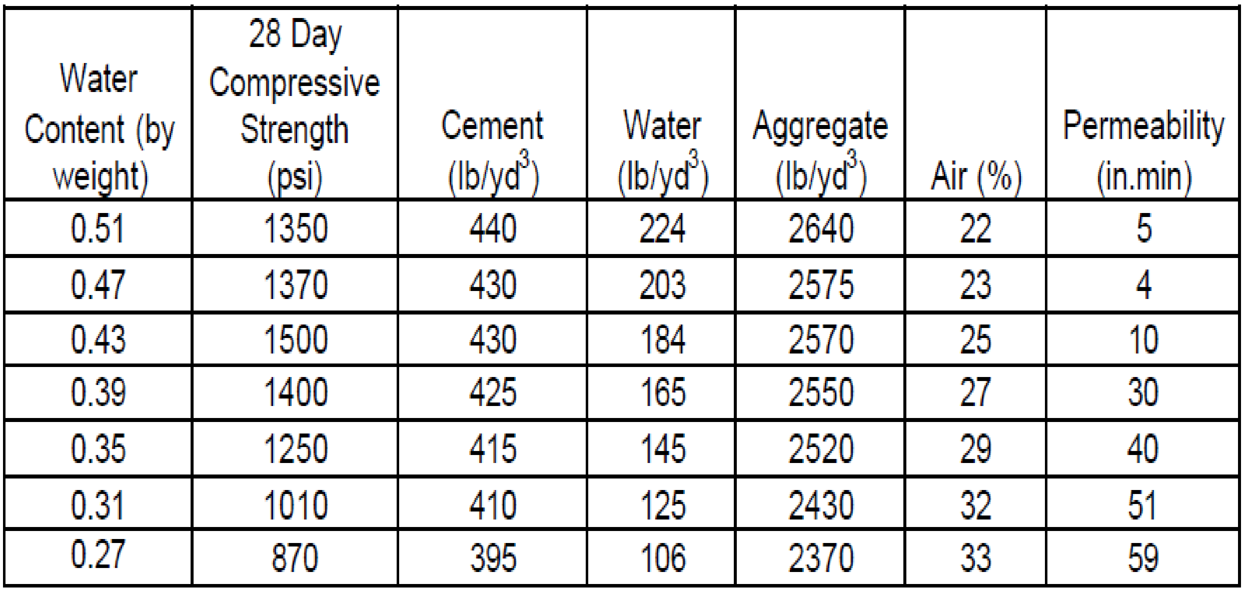
Type of Aggregate	Dry Density (lb/ft^3)	Compressive Strength (psi)
Rounded Quartzite Gravel	115	1250
Irregular Flint Gravel	99	700
Crushed Limestone	114	1000
Crushed Granite	106	1100

In 1988, Richard Menninger [18]released results on laboratory experiments on Porous concrete.He was carried out on multiple samples with varying material properties. These properties included water cement ratio, aggregate cement ratio, compaction, and curing time. Results were similar to those found by Malhotra in 1976. Menninger discovered a relationship between the 28 day compressive strength and water content while utilizing aggregate 3/8” in size and an aggregate cement ratio equal to 6. This relationship is seen in Table 2.1.4 and Figure 2.1.3. Menninger then investigated the correlation between the 28 day compressive strength and unit weight. This association is shown in Table 2.1.5 and Figure 2.1.4. Lastly Menninger once again studied the relationship between 28 day compressive strength and water content ratio but altered aggregate cement ratio and aggregate size. The results are seen in Table 2.1.6 and Figure 2.1.5. The results of these experiments led Menninger to deduce an optimum water cement ratio that would maximize water permeability but not necessarily maximize compressive strength. Menninger also determined that Porous concrete provided a lower compressive strength than that of conventional concrete and should only be utilized in areas restricted to automobile use or light duty areas.

Menninger went on to study the relationship between air content and compressive strength. As expected, an increase in air content decreases the compressive strength of concrete. This occurs because the space once occupied by aggregate now contains air thereby reducing the structural material in the concrete. This result is presented graphically in Figure 2.1.6.

Table 2.1.4 Relationship between 28 Day Compressive Strength and Water Content.

(3/8” Coarse Aggregate – Aggregate/Cement Ratio = 6)



Water Content (by weight)	28 Day Compressive Strength (psi)	Cement (lb/yd^3)	Water (lb/yd^3)	Aggregate (lb/yd^3)	Air (%)	Permeability (in.min)
0.51	1350	440	224	2640	22	5
0.47	1370	430	203	2575	23	4
0.43	1500	430	184	2570	25	10
0.39	1400	425	165	2550	27	30
0.35	1250	415	145	2520	29	40
0.31	1010	410	125	2430	32	51
0.27	870	395	106	2370	33	59

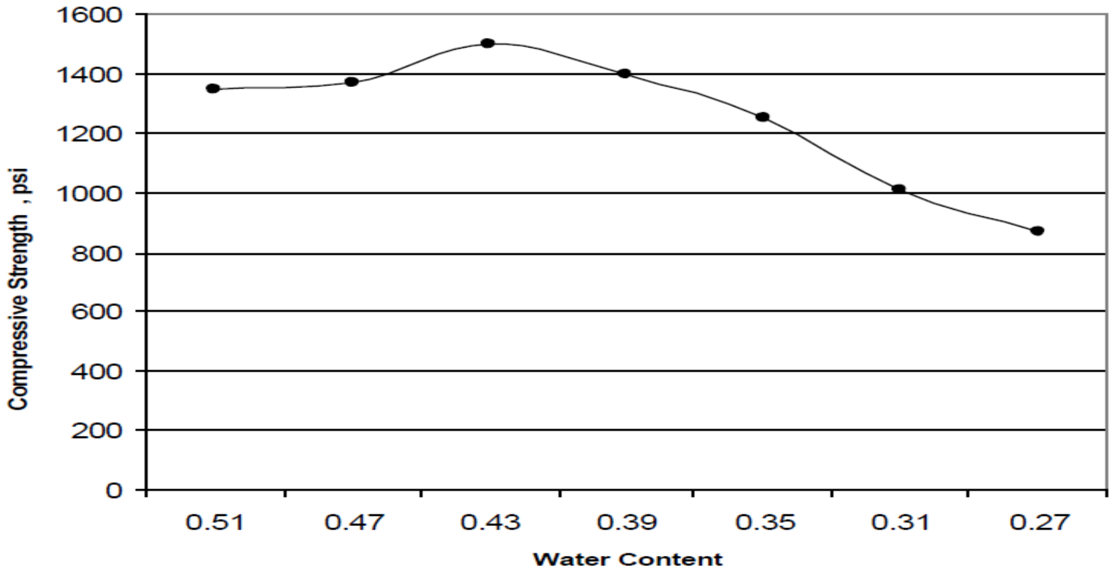
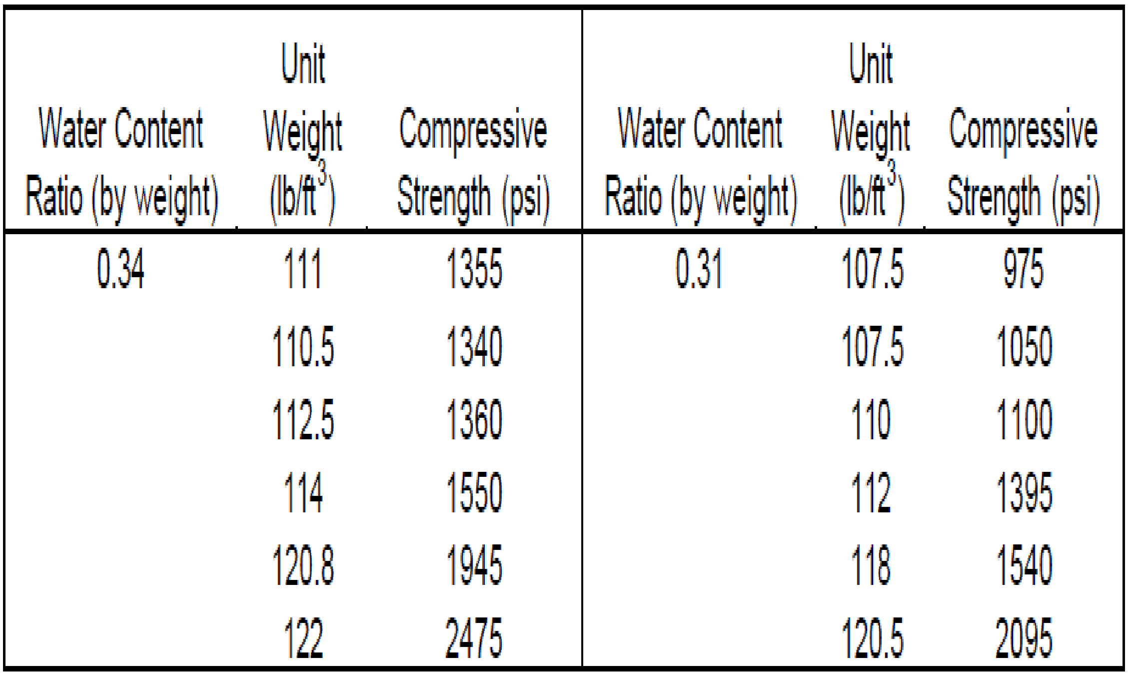


Fig 2.1.3 28Day Compressive Strength vs. Water Content

Table 2.1.5 Relationship between 28 Day Compressive Strength and Unit Weight.



Water Content Ratio (by weight)	Unit Weight (lb/ft^3)	Compressive Strength (psi)	Water Content Ratio (by weight)	Unit Weight (lb/ft^3)	Compressive Strength (psi)
0.34	111	1355	0.31	107.5	975
	110.5	1340		107.5	1050
	112.5	1360		110	1100
	114	1550		112	1395
	120.8	1945		118	1540
	122	2475		120.5	2095

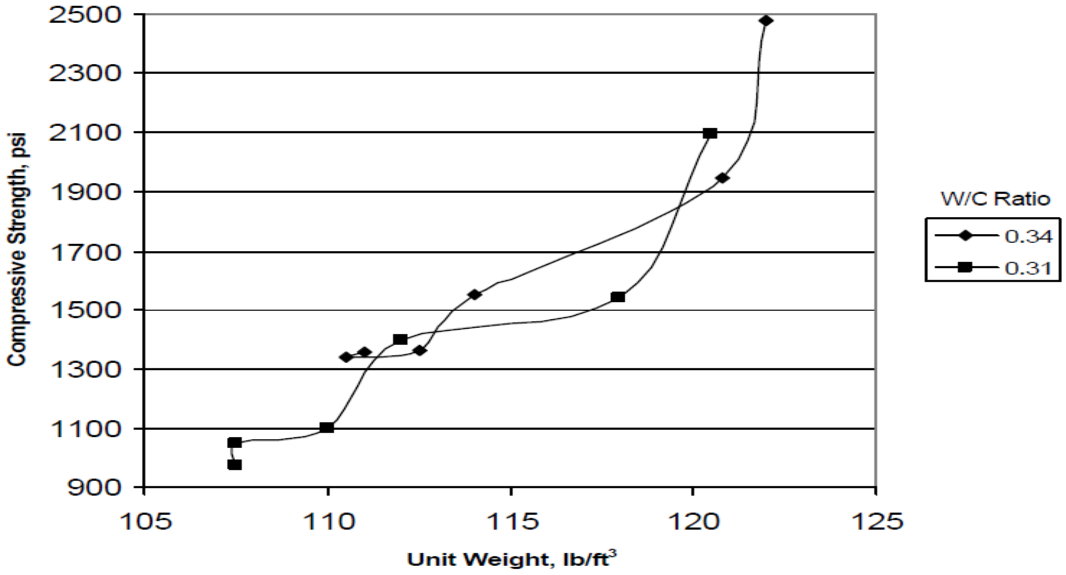


Figure 2.1.4: 28 Day Compressive Strength vs. Unit Weight

Table 2.1.6 Relationship between 28 Day Compressive Strength and W/C Ratio

Aggregate Cement Ratio	Aggregate Size	Water Cement Ratio	Compressive Strength (psi)
10	3/4"	0.27	625
		0.35	750
		0.42	800
		0.51	775
6	3/4"	0.25	775
		0.33	1150
		0.37	1400
		0.41	1250
		0.49	1050
6	3/8"	0.27	1100
		0.31	1250
		0.35	1400
		0.39	1800
		0.43	1650
		0.47	1400
		0.51	1700
4	3/4"	0.25	900
		0.33	1950
		0.41	2050
		0.49	2200

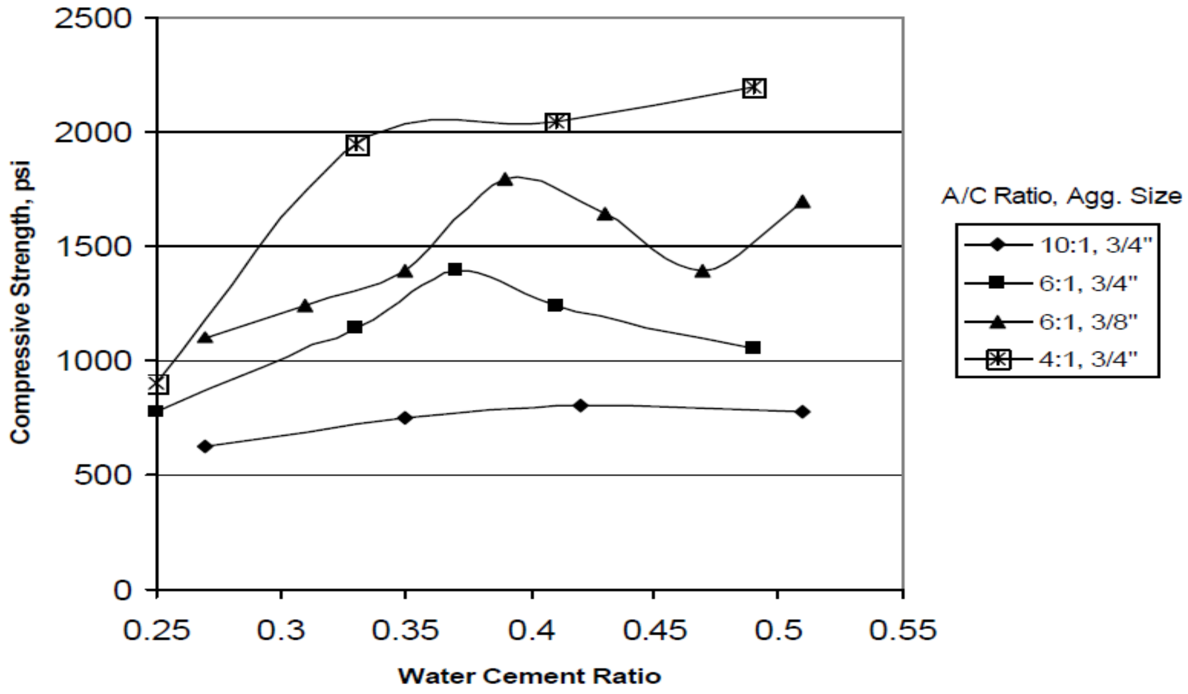


Figure 2.1.5: 28 Day Compressive Strength vs. W/C Ratio

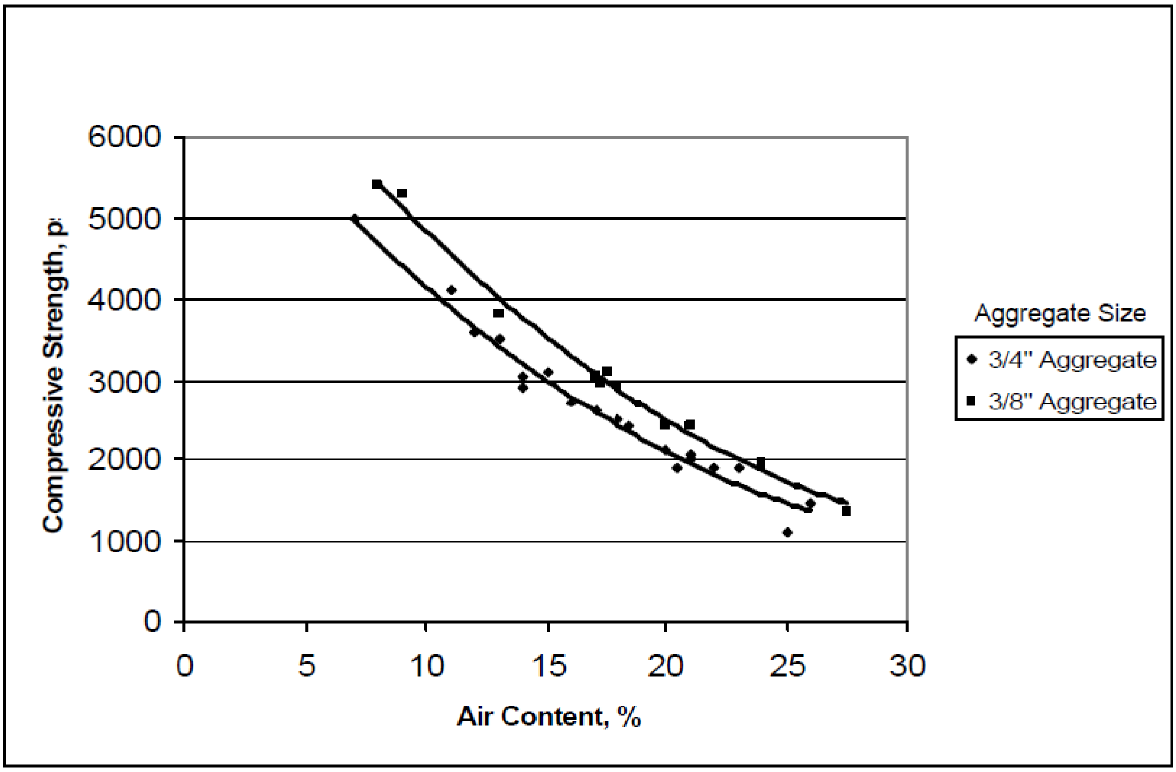
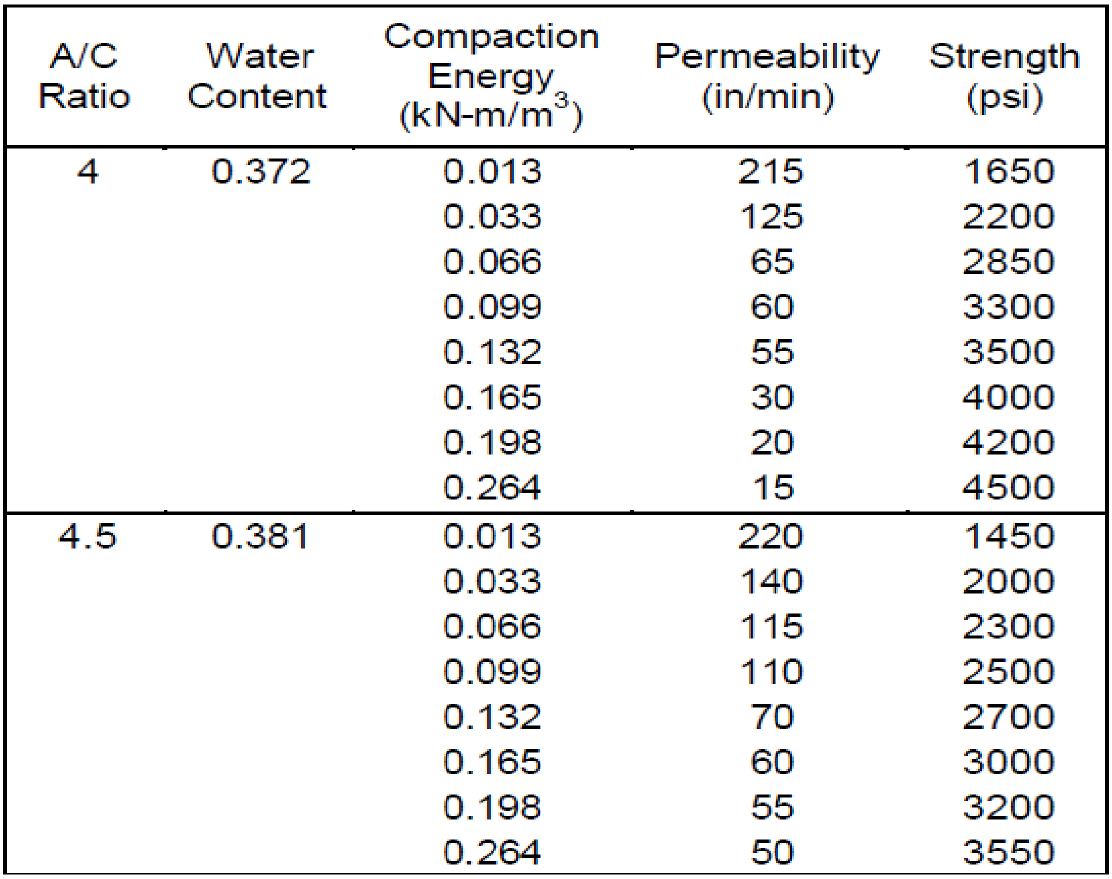


Figure 2.1.6: Compressive Strength vs. Air Content

In 1995, NaderGhafoori [19, 20, 21, 22, 23] researchon various aspects of Porous concrete.In various study, he investigated various sites throughout the United States that have utilized Porous concrete paving systems. His investigation led to a comparison of compressive strength attained at each of these sites. He also examined failures in the various pavements if any had occurred along with the water cement and aggregate cement ratios. Next, Ghafoori inspected applications of Porous concrete outside the United States and once again compared the compressive strengths.

Ghafoori also discusses, in detail, pavement thickness design for Porous concrete. He deduces that compressive strength depends on the water cement ratio, the aggregate cement ratio, compaction, and curing. He also provides a chart which displays the effects of varying the aggregate cement ratio and compaction energy have on the compressive strength and permeability. These results are shown in Table 2.1.7 .

Table 2.1.7 Relationship between Compressive Strength and A/C Ratios



A/C Ratio	Water Content	Compaction Energy (kN-m/m^3)	Permeability (in/min)	Strength (psi)
4	0.372	0.013	215	1650
		0.033	125	2200
		0.066	65	2850
		0.099	60	3300
		0.132	55	3500
		0.165	30	4000
		0.198	20	4200
		0.264	15	4500
4.5	0.381	0.013	220	1450
		0.033	140	2000
		0.066	115	2300
		0.099	110	2500
		0.132	70	2700
		0.165	60	3000
		0.198	55	3200
		0.264	50	3550

5	0.39	0.013	230	1250
		0.033	210	1800
		0.066	150	2100
		0.099	135	2300
		0.132	115	2400
		0.165	100	2500
		0.198	75	2700
		0.264	60	3000
6	0.418	0.013	240	1100
		0.033	210	1700
		0.066	190	2000
		0.099	150	2100
		0.132	150	2200
		0.165	130	2300
		0.198	120	2400
		0.264	100	2600

In 2003, Paul Klieger [24]performed experiments studying the effects of entrained air on the strength and durability of conventional concrete.Although never utilizing the amount of voids seen in Porous concrete (15%-35%), his research clearly shows the impact the presence of air has on the performance of concrete. He concluded that the reduction incompressive strength with the presence of air decreases as the size of aggregate decreases and as the cement content decreases. These are both due to the reduction in water. Graphical representations of his findings are shown in Figures 2.1.8, 2.1.9, and 2.1.10.

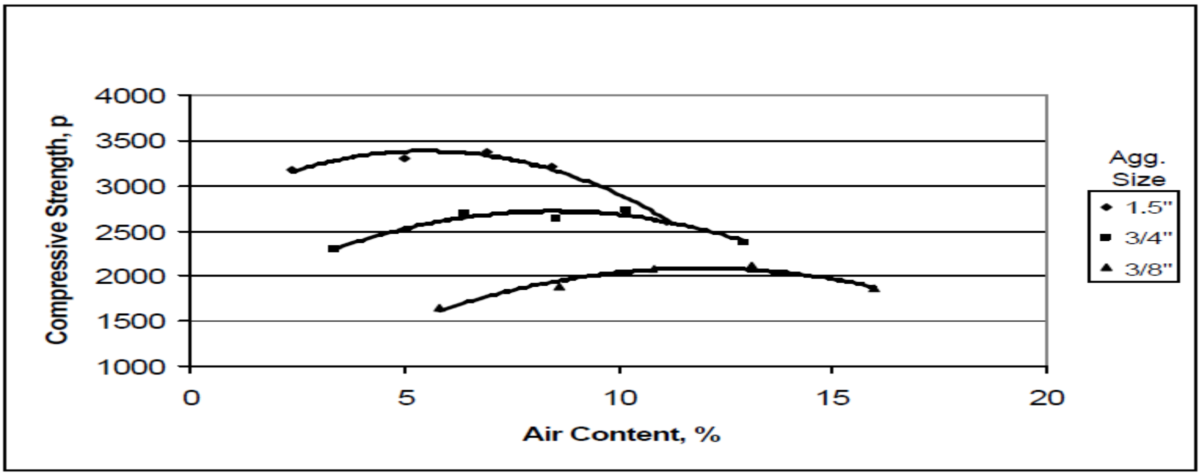


Figure 2.1.8 Compressive Strength vs Air Content – 4 sacks Cement

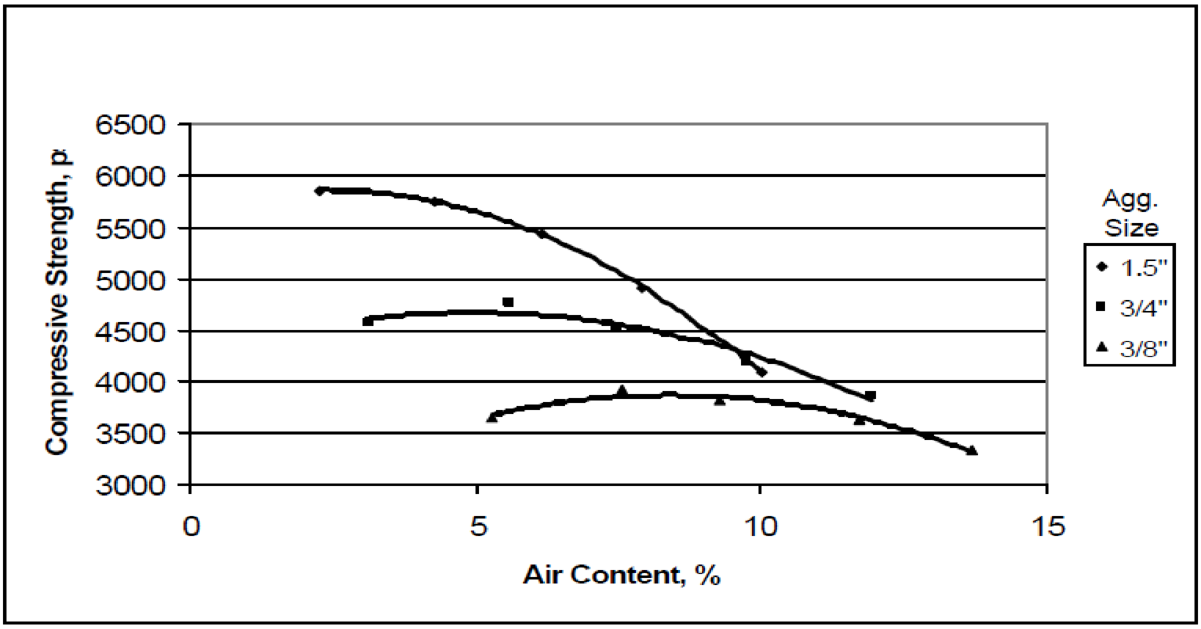


Figure 2.1.9 Compressive Strength vs Air Content – 5.5 sacks Cement

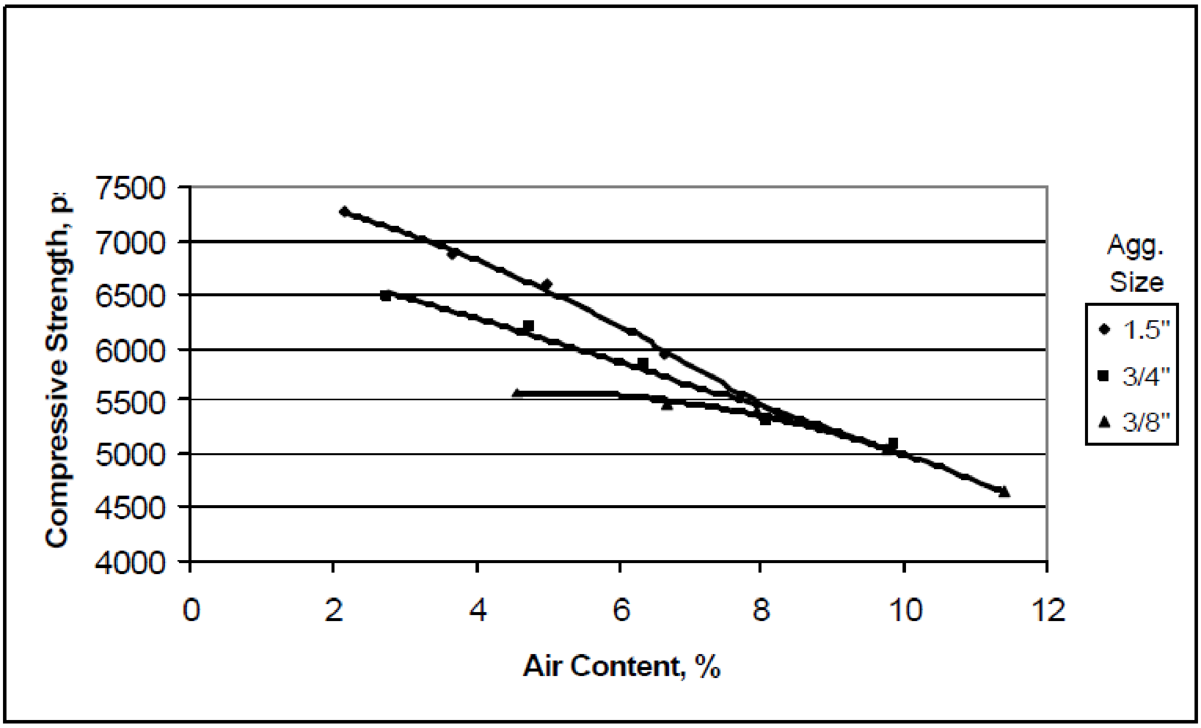


Figure 2.1.10 Compressive Strength vs Air Content – 7 sacks Cement

In 2004, Tennis et.al. [25]Recommended that workability for porous concrete should be assessed by forming a ball with the hand to established mouldability of porous concrete. Mouldability of porous concrete is quite sensitive to water content, hence the amount of water should be strictly controlled. Due to high porosity, porous concrete is a lightweight concrete. The unit weight of porous concrete is between 1,500 kg/m3 and 2,200 kg/m3. Porosity for porous concrete is ranged from 15 to 30%. Also, porosity of porous concrete termed as void content or void ration in percentage. This high porosity leads to a high permeability for the porous concrete. Because of the high void content, the compressive strength of porous concrete is lower than that for conventional concrete. From the results he finds the average compressive strength of porous concrete is around 20 MPa, while the lowest strength of 2.5 MPa and the highest strength of 34.5 MPa are reported.

They are used a narrow gradation size aggregate, sized between 3.75 mm and 19.0 mm, 2.36 mm and 9.5 mm, or sized from 0.5 mm to 1.18 mm. Coarse aggregate requires a saturated surface-dry condition or moist condition, because properties of porous concrete are very sensitive of amount of water in the mix. The water/cementitious materials ratio for porous concrete is normally around 0.3 to 0.4. They are also recommended that a water/cement ratio of 0.27to 0.30 is possible when it is made by adding an admixture. The optimum water/cement ratio for porous concrete is very important due to the mouldability of porous concrete. The optimum aggregate/cement ratioranges from 4 to 5 by mass. According to their results, a high amount of aggregate led to increased permeability and dramatically decreased compressive strength.

In 1991 Groves et .al [26]described on progressive change in the structure of hardened C_3S cement paste due to carbonation. They conclude that Calcium hydroxide and hydrated calcium silicate are the main hydration products of the adhered mortar on RCA. For that CO_2 can enter into the pores of adhered mortar and react with these reaction products as follows

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$$

$$C\text{-}S\text{-}H + CO_2 = CaCO_3 + SiO_2 .nH2O$$

The carbonation of calcium hydroxide and C-S-H increased the solid volume by 11.5% and 23.1%, respectively. Thus, carbonation can reduce the porosity of the adhered mortar.

In 2006, Claus Pade and Maria Guimaraes et.al[27] works on the CO_2 uptake of concrete in a 100 year perspective. They surveying on Nordic countries of Denmark,Iceland, Norway, and Sweden and encompasses various laboratory and theoretical work and estimated CO_2 uptake through carbonation of concrete produce in the year of 2003, during a 100 yrs period to amount to a significant proportion of the CO_2 emitted by calcinations of the raw mix used to produce the Portlandcement used in the concrete. Fig 2.1.7 shows the methodology for estimating the CO_2uptake from Nordiccountries.

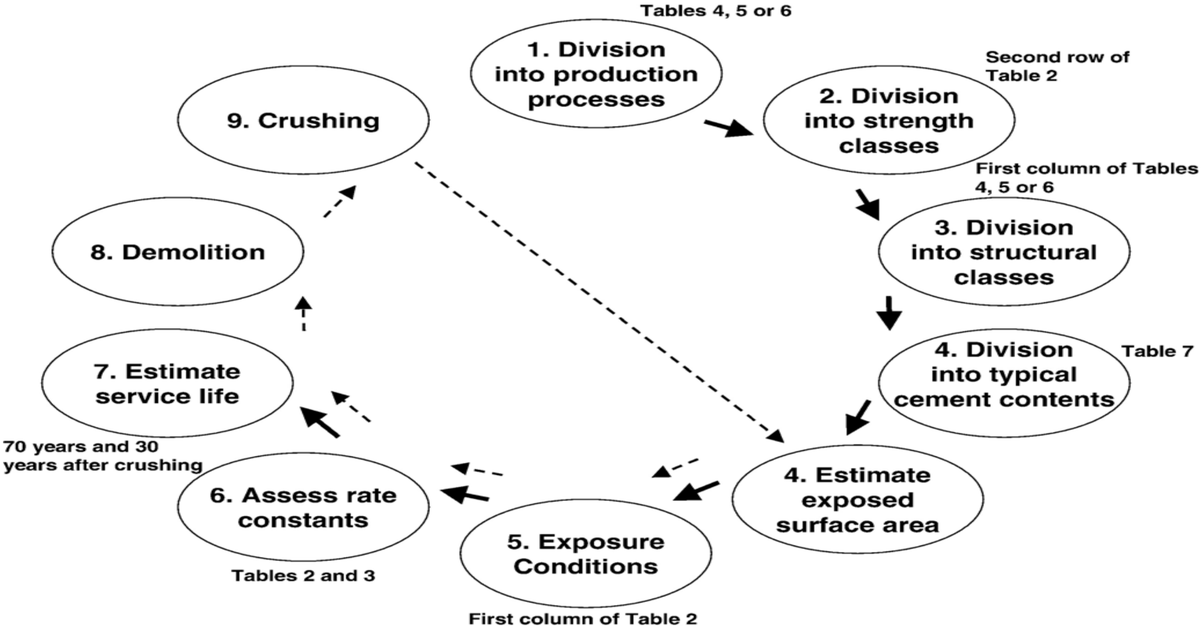


Fig 2.1.7:Methodology for estimatimg the CO_2 uptake from Nordic countries.

***Full arrows correspond to service life (70 years) and dotted arrows to secondary life (30 years).**

They decided demolition and subsequent crushing of concrete after service life increases the amount of carbonation. Crushed concrete maximized CO_2uptake prior to using it in embankment.

Jacobsen and Jahren estimated the carbonation ofconcrete in Norway and the amount of CO_2 absorbed by thatconcrete. Their study estimated that 16% of the CO_2 emitteddue to calcinations is reabsorbed by concrete during its servicelife.

In2006, Mallen [28] presents a paper on the reduction of permeability due to clogging by sediments. A field test of porous concrete pavement in Kogarah municipality, which is located approximately 15 km from Sydney central business district, was under taken. This field test had been carried out for 21 months. It is noted, the water permeability was reduced by 97% over 21 months, because of clogging by sediments and organic matters. This shows that performance of porous concrete can be significantly affected by the surface condition. However, more long term study is needed for better understanding.

In2006, Zhuge [29] was discussed that due to high porosity, porous concrete is a lightweightconcrete. The unit weight of porous concrete is between 1,500 kg/m3 and 2,200 kg/m3.

In **2006, Haselbach, L.M. and R.M.Freeman et.al [30]** were stated after experimentalinvestigation that porosity for porous concrete is ranged from 15 to 30%. Also, porosity ofporous concrete termed as void content or void ratio in percentage. This high porosity leadsto a high permeability for the porous concrete. Distribution of porosities of porous concretehas serious influence on the water permeability, therefore the porosities need to bedetermined.

In **2008, Zhuge [31]** used recycled aggregate as coarse aggregate for permeable concrete base course materials. The porous concrete using recycled aggregate were compared with the porous concrete using marble or dolomite. As a result, the recycled aggregate porous concrete showed significantly low compressive strength with similar void content and water permeability.

In 2011,Mary Vancura, Kevin MacDonald, et.al (32)attempt to compete a survey, the durability and condition of 29 in service Porous concrete pavements built in a wet, hard freeze environment were assessed, and 33 core samples were collected. From summarizing the survey, the common subsurface distresses observed in the core samples with optical microscopy instruments. In the distressed samples, cracks went through the aggregate, paste, and interfacial transition zone (ITZ). The cracks were similar to cracks in conventional concretes that formed due to known freeze/thaw damage. In addition to cracking patterns, it was discovered that none of the 33 Porous concrete samples contained the recommendedquantity or spacing of entrained air bubbles. There was a lack of entrained air bubbles despite the addition of air-entraining admixtures to all of the Porous concrete mixtures. It is unknown if the lack of entrained air bubbles contributed to the crack in Porous concrete.

In 2013,Rishi Gupta et. Al [33]has studied on the in situ performance of Porous concrete in British Columbia.The Modern day infrastructure calls for use of imporous surfaces and curb and gutter systems on pavements to rapidly collect and transport rain runoff. Due to this stormwater reaches the receiving water bodies rapidly, in greater volume and carries more pollutants than natural conditions. Porous pavement on parking lots, sidewalks, and driveways provides a solution to this problem. One such material that can be used to produce porous surfaces is Porous concrete. Even though no-fines concrete mix has been used for many years, there are still many outstanding issues related to its structural performance and issues with reduced percolation capacity over time especially when exposed to real conditions. They are describing a project in British Columbia, Canada where 1000 ft2 of asphalt was replaced with a Porous concrete system.

In 2014,K Cosic, and L Korat et.al [34] test on Influence of aggregate type and size on properties of Porous concrete. They were prepared five different concrete mixtures, including a standard dense concrete mixture and four Porous concrete mixtures with varied aggregate types (dolomite or steel slag) and differing proportionsof 4–8 mm to 8–16 mm aggregate fractions (30:60 or 60:30). The results suggest that a higher amount ofsmall aggregate fractions (4–8 mm) yielded higher density concrete mixtures and greater flexuralstrength. However, connected porosity as a main parameter for estimating Porous concrete efficiencywas surprisingly influenced more by the aggregate type than the size.

Abhijit S Gandage et .al[35] describe on study on reduction of pavement noise using porous concrete. They design and testing of alaboratory scale test set up noise absorption and comparisons of noise absorption frequencies by a cube specimen prepared using conventional concrete and porous concrete. They conclude from the noise generation studies that porosity of pavement materials reduces air pumping effect which reduces the tyrenoise. They show noise level 5-35% lower in case of porous concrete cube specimen.

F. Tittarelli, M. Carsana,, M.L. Ruello et.al[36] has studied on the Effect of hydrophobic admixture and recycled aggregate on physical–mechanical properties and durability aspects of no-fines concrete. They investigated and find out compressive strength in the range 7–30 MPa at 28 days of curing were optimized by changing the water/cement ratio from 0.41 to 0.34 and the aggregate/cement ratio from 8 to 4. Some mixtures were also repeated with the addition of a hydrophobic admixture and prepared by fully replacing the ordinary aggregate with recycled aggregate to evaluate durability effects. High susceptibility to carbonation was observed for all the no-fines mixes studied. The use of recycled aggregate increases capillary water absorption (about 50%); however, the related decrease in durability could be easily counteracted with the use of a hydrophobic admixture.

For durability purposes they have to test in laboratory by Carbonation test and after 28 days of curing, cube specimens of each mixture made in were exposed to a carbonation chamber at

CO_2 = (3 ± 0.2) %, T = (21 ± 2) ˚C and

R.H.= (60±10) %.

The progress of carbonation was evaluated by phenolphthalein tests applied on the fracture surfaces of the specimens (split by indirect tensile test). The percentage of carbonated material was estimated by means of image analysis. After 10 and 30 days of accelerated carbonation, compressive strength was also measured in order to assess possible effects of carbonation on the mechanical properties of the material.

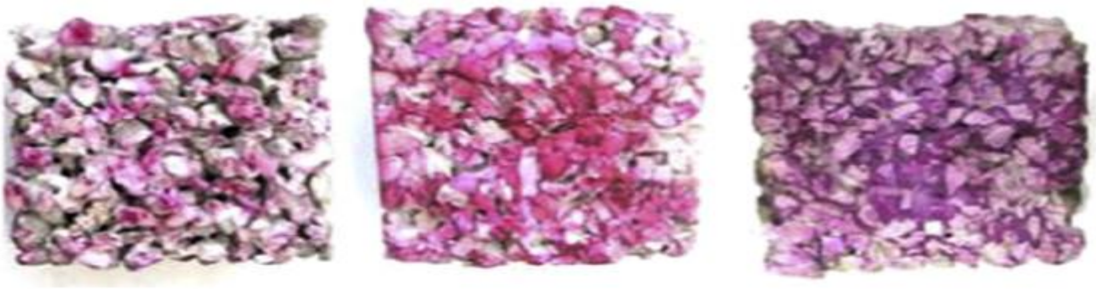


Fig 2.1.11: Phenolphthalein test on no-fines concretes after 30 days of exposure to carbonation chamber

They have experiment on various cement aggregate ratio with different water cement ratio for compressive strength on porous concrete. The result are shown in following pic

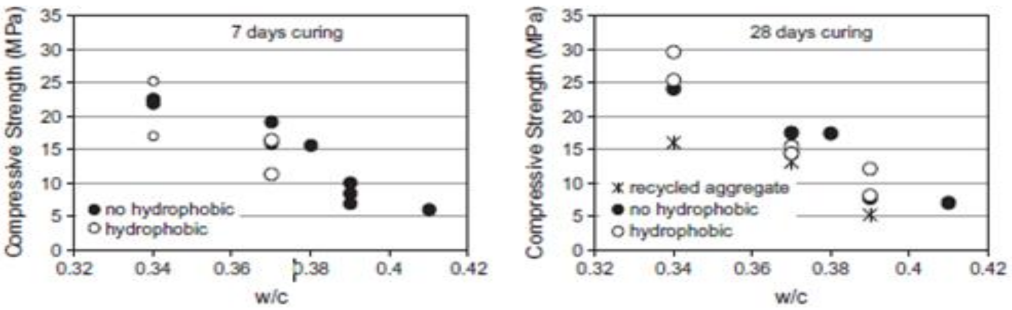


Fig 2.1.12: Compressive strength of W/C for different mixtures after 7 days and 28 days of curing

No-fines concretes with three different mix designs were manufactured. The effect of hydrophobic admixture, at two different dosages, and recycled aggregate on the performances of no-fines concrete was investigated in terms of physical–mechanical characterization, carbonation rate, and durability aspects. From the results they conclude the following points

- No-fines concretes with compressive strength ranging from 7 to 30 MPa were obtained by changing the w/c from 0.41 to 0.34 and the a/c ratio from 8 to 4;

- Due to macro-voids of the material, high susceptibility to carbonation in the depth of the material was observed for all the no-fines mixes studied in this work, even when exposed to an indoor environment.
- On one hand, the hydrophobic admixture decreases slightly the strength of no-fines concretes, but on the other hand, it improves the durability performance considerably by decreasing the capillary water absorption from its original value of about 70%, regardless the concrete strength class, by giving to the specimens with lower strength class the same rate of ionic release of the specimens with higher strength class;
- The total replacement of natural aggregate with recycled one, at the same mix-design, increases capillary water absorption of about 50%;

Darshan S. Shah, prof. Jayeshkumaret.al [37]has studied on durability and water absorption properties of Porous concrete .They experiment on Cylinders of size 100 mm Ø and 200 mm height to investigate water absorption and durability and properties. They were testing the cylinder at the end of 28 days for water absorption and 56 days for durability in which cylinders are immersed in Sodium Chloride (NaCl) Solution after 28 days of casting. Different concrete mix proportion such as 1:6, 1:8 and 1:10 with different size of gravel such as 18.75 mm and 9.375 mm should be used to check both these properties of Porous concrete. Test results indicates that Porous concrete made by 1:6 concrete mix proportion has more durability and less water absorption and Porous concrete made by 1:10 mix proportion has more water absorption and less durability that’s why durability and water absorption are inversely proportional to each other.

M. Aamer Rafique Bhutta, K. Tsuruta, and J. Mirza et.al [38]make a study onevaluation of high-performance porous concrete properties.They evaluate the properties of high performance porous concrete. It required no special vibration equipment and curing. The optimum mixture proportions were used toprepared of high performance porous concretes containing three sizes of coarse aggregates with appropriate amount of high water-reducing and thickening (cohesive) agents. Tests carried out on this concrete were: slump, slump-flow, void ratio, and coefficient of permeability, compressive and flexural strengths, and strength development rate. Furthermore, a test was proposed to determine the effects of high water-reducing and thickening (cohesive) agents on self-compaction of high performance porous concrete. It was used to evaluate its hardened properties from the viewpoint of practical application. Theyalso examined strength development rate was at curing age of 1, 3, 7, 14 and 28 days at 20^0 C and 60% relative humidity (R. H.). Consequently, high performance porous concrete exhibited good workability and cohesiveness with no segregation or bleeding, and developed high strength compared to conventional porous concrete. The results of proposed self-compaction test for this porous concrete also showed good workability and cohesiveness without any special compaction or vibration.

Fig.2.1. 13. Slump and slump-flow of CPC and HPPC.

They test out on Ordinary Portland cement and three different sizes of crushed coarse aggregates No. 5 (13–20 mm); No. 6 (5–13 mm) and No. 7 (2.5–5 mm) were used to prepare all porous concretes and find out the total void content with various type of aggregate in conventional Porous concrete and high performance Porous concrete.

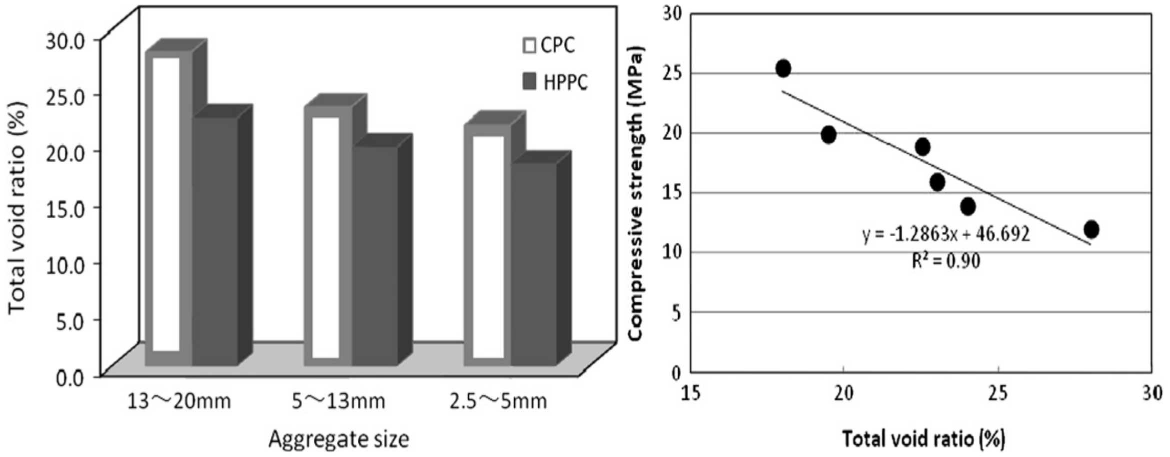


Fig 2.1.14 : total void ratio on diifrent aggregate size OF CPC AND HPCC

Fig.2.1.14 represents the relationship between total void ratio and compressive strength of porous concrete. Regardless of types of porous concrete and aggregate size, the compressive strength of increased. In the range of 15–30% total void ratio, the coefficient of permeability of all porous concretes increased linearly.

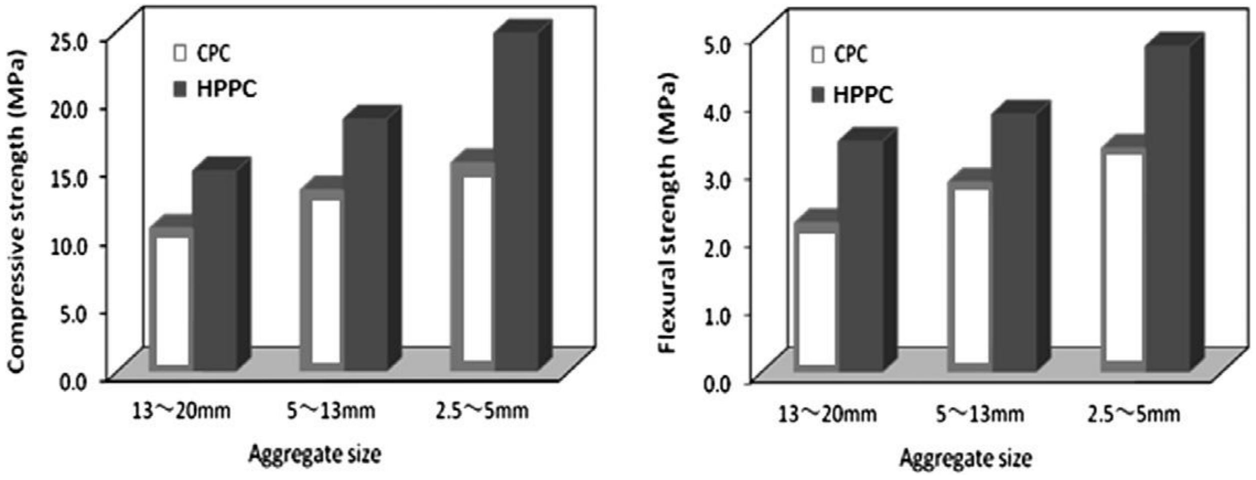


Fig 2.1.15: compressive strength and flexural strength on various aggregate size

R.V. Silva et .al [39]presents a study on Carbonation behavior of recycled aggregate concrete From the sourced of construction and demolition waste, the effect of incorporating recycled aggregates, on the carbonation behavior of concrete are identifies various influencing aspects related to the use of recycled aggregates, such as replacement level, size and origin, as well as the influence of curing conditions, use of chemical admixtures and additions, on carbonation over a long period of time. The effect of introducing increasing amounts of recycled aggregates on the carbonation depth and coefficient of accelerated carbonation is presented in table below. They were estimate the required accelerated carbonation resistance of a reinforced recycled aggregate concrete exposed to natural carbonation conditions with the use of accelerated carbonation tests. These results clearly show that increasing carbonation depths with increasing replacement levels when recycled aggregate concrete mixes are made with a similar mix design to that of the control natural aggregate concrete. The relationship between the compressive strength and coefficients of accelerated carbonation is similar between the control concrete and the recycled aggregate concrete mixes.

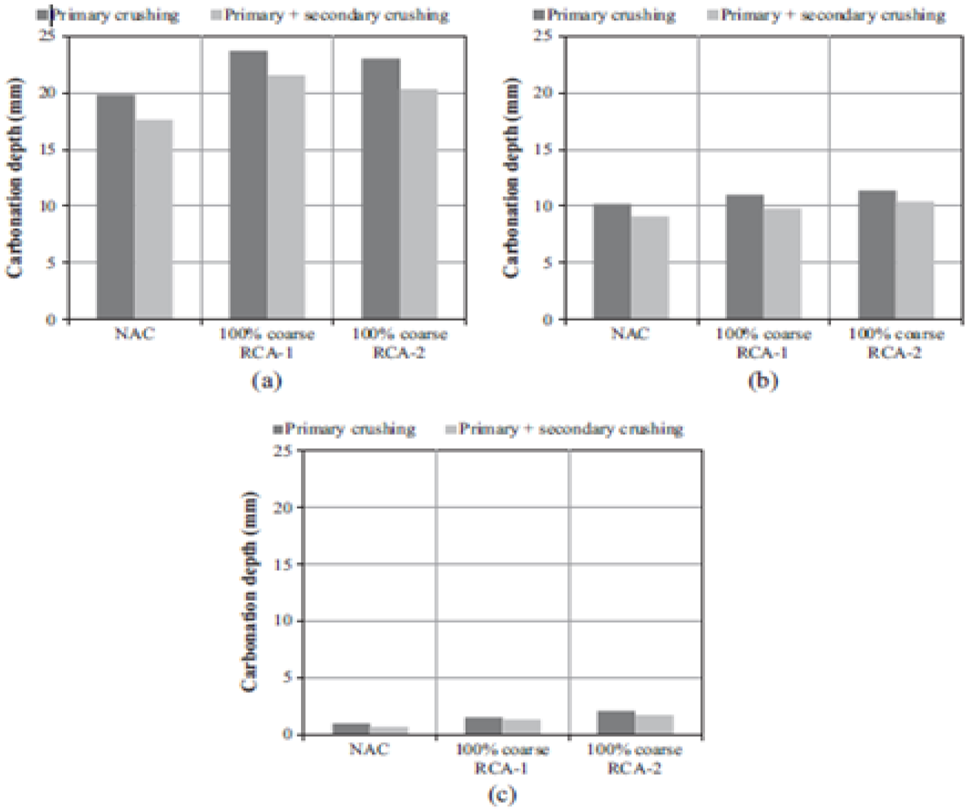


Fig 2.1.16: Carbonation depth of concrete with target strength

Ryu [40] produced concrete mixes with a w/c ratio of 0.55 andwith coarse RCA from materials with different strength and varyingadhered cement paste content. All RAC mixes with 100% coarseRCA exhibited 20% greater carbonation depths. With this in mind,the author concluded that the strength of the source concreteand the quantity of adhered mortar had little or no effect on thecarbonation depth of RAC when compared to that of the correspondingNAC, provided that the RCA used had similar waterabsorption.

Xiao et al. [41] evaluated the influence of adding RA sourcedfrom concrete with different strength on the carbonation of RAC.As expected, the incorporation of 100% coarse RCA resulted ingreater carbonation depths. RAC mixes produced with RCA sourcedfrom concrete specimens with compressive strength values of 20 MPa, 30 MPa and 50 MPa exhibited carbonation depths 80%,26% and 10% greater, respectively, than that of the control NAC.

Amorim et al. [42] studied the influence of the environmentalconditions on the durability-related performance of concrete withincreasing coarse RCA content. As the laboratory environment wasthe driest, with an average relative humidity of 60% and temperatureof 20^0 Cthe specimens cured in it had a greater carbonationdepth than those in the other environments considered in the testprogram. These specimens showed a clear increase in carbonationdepth as the replacement level increased (30% increasewhen 100% coarse RCA were used, at 91 days).

In 2012, Muhammad Aamer Rafique Bhutta et .al [43] has studied on the Properties of porous concrete from waste crushed concrete (recycled aggregate**) .**They develop porous concrete with acceptable permeability and strength using recycled aggregate from waste crushed concrete. The optimum mix proportions were employed to prepare porous concretes using normal and recycled aggregates. Various tests were done on porous concrete: void ratio, coefficient of permeability, compressive and flexural strengths. Theyexamined effect of recycled aggregate on total void ratio, strength and permeability. The total void ratio of porous concrete incorporating recycled aggregate was larger than that of porous concrete with normal aggregate. The compressive strength of porous concrete using recycled aggregate was lower than the normal aggregate.

The coefficient of permeability of porous concrete was determined in accordance with jci test method for permeability of porous concrete. The water permeability of porous concrete was determined over a period of 30s under a water head of 200 mm. The water permeability co efficient was calculating using the following equation

$$K_r = \frac{QH}{Ah(t2-t1)}$$

where

Kr: permeability coefficient (cm/s); H: length of specimen (cm);

Q: amount of discharge water from t1 to t2 (cm^3); h: difference of water head; t2–t1: time (s);

A: area of cross section of cylindrical specimen (cm^2).

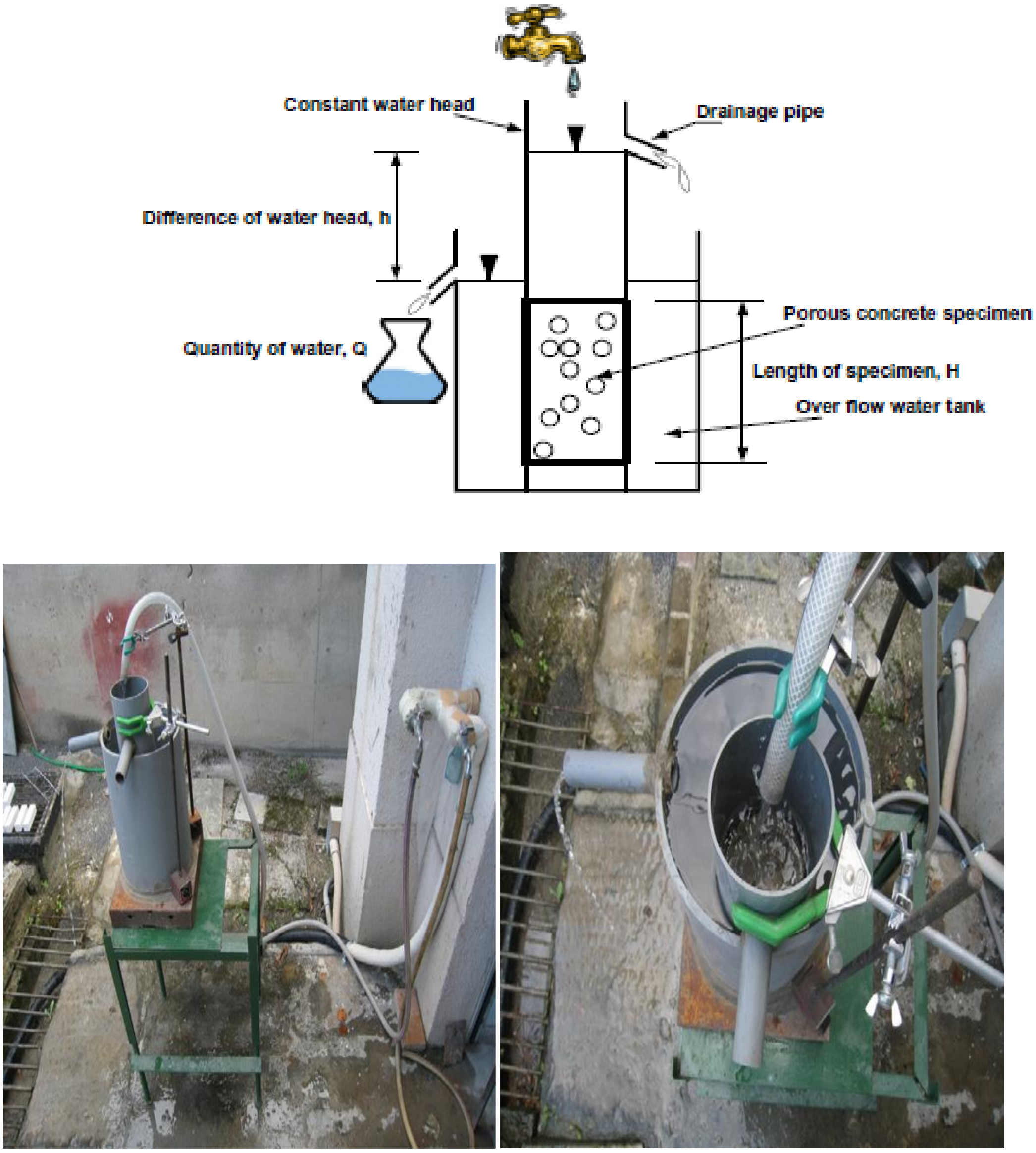


Fig2.1.17. Water permeability set-up for porous concrete.

They have test on various physical properties of different aggregate which are shown in Table 2.18.

Table 2.1.8 physical properties of aggregate

Type	**Gradation (mm)**	**Density (g/cm3)**	**Water absorption(%)**	**Absolute volume(%)**	**Unit weight (kg/m3)**
Normal aggregate	5-20	2.55	1.2	55.6	1620
Recycled aggregate	5-22	2.34	4.6	57.5	1542

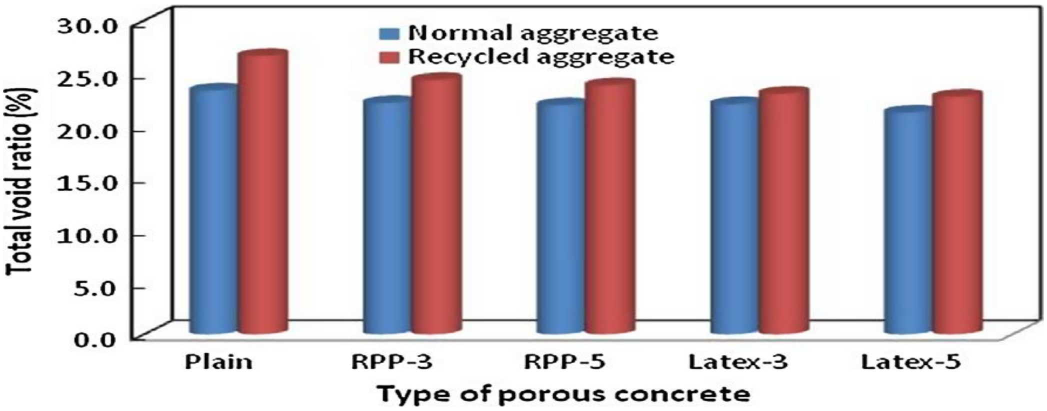


Fig. 2.1.18. Total void ratio vs. type of porous concrete

According to test they conclude, physical property of recycled aggregate absorbed more water than normal aggregate and the unit weight also be low in recycled aggregate. Total void ratio is more in porous concrete with recycled aggregate than porous concrete with natural aggregate(Ref fig 2.1.18).Compressive strength in porous concrete with natural aggregate show greater compressive strength than porous concrete with recycled aggregate (Ref Fig. 2.1.19). Regardless of polymer type and aggregate the co efficient of water permeability for all porous concrete become larger as the total void ratio in the range of 23- 28 %, the co efficient of water permeability of all porous concrete increases linearly(Ref Fig2.1.20**)**

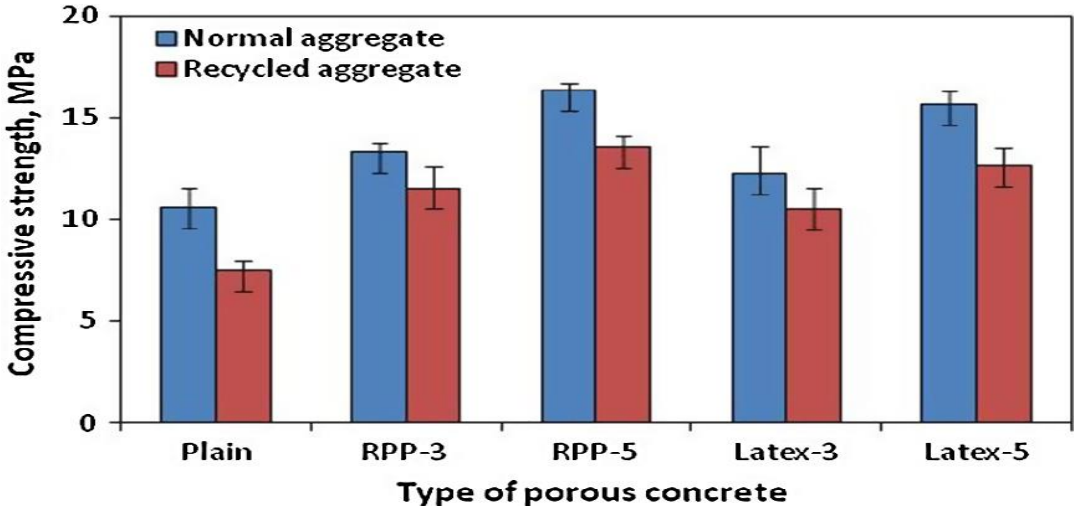


Fig 2.1.19. Compressive strength of various types porous concrete.

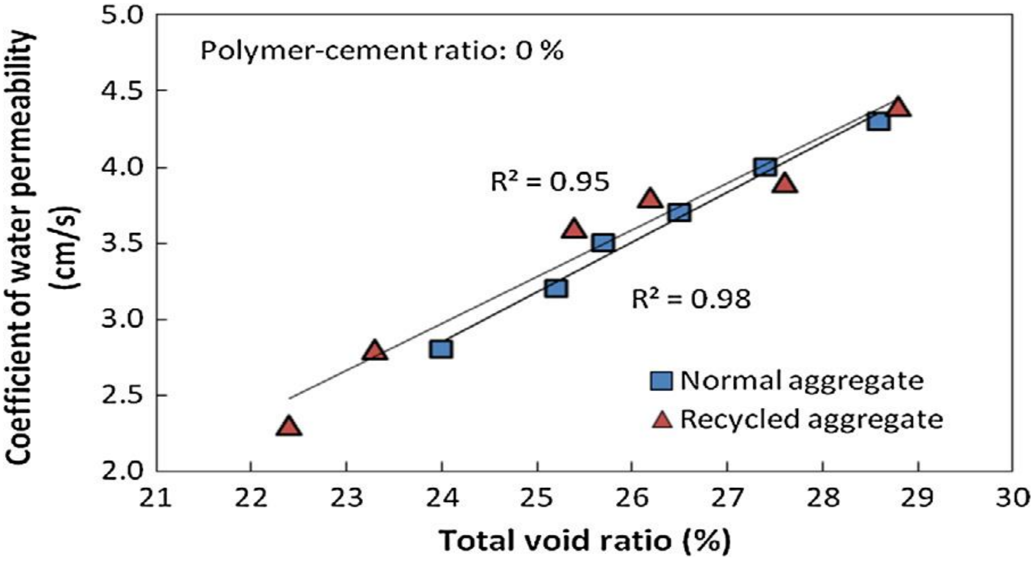


Fig 2.1.20 Effect of aggregate type on total void ratio and coefficient of water permeability.

CHAPTER 3.0 EXPERIMENTAL INVESTIGATION

3.1Introduction

The experimental investigation for the development of suitable porous concrete with natural and recycled coarse aggregate has been made at the Civil Engineering Department, Jadavpur University.The properties of different ingredients used for this experimental study are presented. The test conducted related to strength, permeability and durability of porous concrete have been also presented.

3.2Ingredients

The ingredients used in porousconcrete are described as follows:

3.2.1 Cement

Portland Slag Cement(Ultratech) is used for different mixes of porous concrete (IS 455:2015). The physical properties of the PSC are shown in Table 3.1.

Table 3.1: Physical Properties of PSC cement

Sl. no	Test	Results
1.	Sp. Gravity of cement	3.10
2.	Natural Consistency	32.5 %
3.	Initial setting time(min)	92 min
4.	Final setting time(min)	250 min
5.	Compressive strengthafter 7 days	27 MPa
6.	Compressive strengthafter 28 days	45 MPa

3.2.2 Aggregate

No fine aggregate is used for the porous concrete mixtures.There are two types of coarse aggregates are used for making the porous concrete .These are

(a) Natural coarse aggregate (NA)

(b) Recycled concrete aggregate (RCA)

(a) Natural coarse aggregate

Natural coarse aggregate consist ofCrushed Coarse aggregate of 12.5 mm passing and retained on 10 mm sieve isused.The specific gravity of the aggregate is 2.60. The waterabsorption of the aggregate is 0.5 %.

Fig3.1:Natural and Recycled aggregate Fig 3.2 :Mixes both aggregate (50 :50)

(b)Recycled concrete aggregate:

Recycled concrete aggregates mainly differ from natural aggregates in that they are composed by two materials of different nature: natural aggregate and cement mortar attached to it. Recycled concrete aggregate has been derived from the crushed concrete cube (Already tested) from the outskirts of Jadavpur university concrete laboratory which was used as landfill disposal. The recycled concrete aggregate is derived from the broken cube sample by manual hammering. The size of recycled concrete aggregate is taken by passing through 12.5 mm sieve and retained on 10 mm sieve.

The specific gravity and water absorption of recycled concrete aggregate are 2.50 and 4.80% respectively.

.

Fig 3.3: Disposal for landfill of concrete sample after testing

Attached mortar content in recycled aggregate

The objectiveof this study is to relate the attached mortar content to recycled concrete aggregate properties, to establish the mortar content from aggregate. It is obtained by hydrochloric acid solution, by the following steps.

1. Take 100 ml of conc. HCl and 4000 ml of water to mix the solution of 0.9 (N).
2. Take 400 gm of attached mortar of recycled concrete aggregate are immersed on that acidsolution of 48 hours (Fig 3.4).
3. After 48 hours the sample are taken out from acid solution and washed with water, removing the fine loose mortar from the aggregate (Fig 3.5).
4. Weigh the aggregate, the reduction of weight gives the amount of mortar attached (say 310 gm).
5. Attached mortar content on recycled aggregate = $\frac{400-310}{400}$= 22.5 %

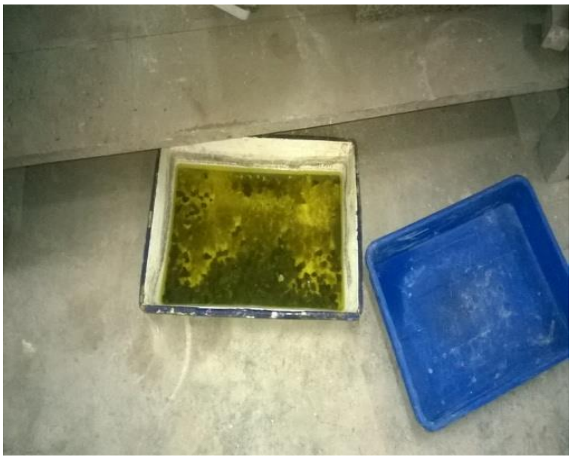


Fig 3.4: Recycled aggregate on Hcl solution

Fig3.5: Remove out recycled aggregate from Hcl solution after 48 hours

3.2.3 Water

Water used for making porous concrete mix is potable tap water of our laboratory.

3.3 Mix Proportions

Total 27 nos. of porous concrete mixtures have been made depending on the type of coarse aggregate, water cement ratio (W/C) and cement aggregate ratio (C/A) .The mix no M1N to M9N represents the porous concrete mix with natural aggregate,M1R to M9R represents theporous concrete mixwith recycled aggregate and M1NR to M9NR represents the porous concrete mix with 50 % natural aggregate and 50 % recycled aggregate for different coarse aggregate ratio with different water cement ratio. For each mix different specimen cast for the different test are shown in table 3.2.

Out of fifteen cubes of sizes 100 mm x 100 mm x 100 mmfor each mixtures, 9 cubes are tested for compressive strength at the age of 3 days, 7days, 28 days and 6 cubes are tested for carbonation test (in the duration of 10 days and 30 days).3 nos. of 150 mm x150 x 150 mm standard size cube are casted for each mix for measurement of water permeability test after 28 days of curing. 3 nos. of cylinders 200 mm height and 100 mm diameter are castfor split tensile strength and 3 nos. of prisms of sizes 100 mm x100 mm x500 mm are also cast for flexural strength after 28 days of curing.

Table3.2: Mixture proportion for porous concrete

SL NO	MIX NO	W/C RATIO	C/A RATIO	TYPE OF AGGREGATE	NO OF SAMPLE
1	M1N	0.35	1:4	NATURA L AGGREGATE (100 %)	FOR EACH MIX ➢ 9 nos. of 100 mm x 100 mm 100 mm size cube for Porosity , sorptivity and compressive strength (3, 7 , 28 days) Test ➢ 3 nos. of 100 mm x 200 mm size cylinder for split tensile strength(28 days) Test ➢ 3 nos. of 100 mm x 100 mm x 500 mm size prism for flexural strength(28 days) Test ➢ 3 nos. of 150 mm x 150 mm x 150 mm size cube for water permeability Test(28 days) ➢ 6 nos. of 100 mm x 100 mm x 100 mm size cube for carbonation Test(10 days & 30 days)
2	M2N	0.33			
3	M3N	0.30			
4	M4N	0.35	1:5		
5	M5N	0.33			
6	M6N	0.30			
7	M7N	0.35	1:6		
8	M8N	0.33			
9	M9N	0.30			
10	M1R	0.35	1:4	RECYCLED AGGREGATE (100 %)	
11	M2R	0.33			
12	M3R	0.30			
13	M4R	0.35	1:5		
14	M5R	0.33			
15	M6R	0.30			
16	M7R	0.35	1:6		
17	M8R	0.33			
18	M9R	0.30			
19	M1NR	0.35	1:4	NATURAL (50%) + RECYCLED (50%) AGGREGATE	
20	M2NR	0.33			
21	M3NR	0.30			
22	M4NR	0.35	1:5		
23	M5NR	0.33			
24	M6NR	0.30			
25	M7NR	0.35	1:6		
26	M8NR	0.33			
27	M9NR	0.30			

3.4. Mixing

All the Porous Concrete mixes are made in a rotating drum type mixer machine. In order to protect against any loss of materials, an initial butter batch is prepared in the mixer with the same proportions as the desired mix. Mixing procedure of Porous Concrete is as follows:

(1) The coarse aggregate is added to the mixer with about 5% (by mass) cement. This is mixed for 1 minute, until the aggregate is fully coated by a thin layer of dry cement.

(2) After this initial mixing, the remaining cement along with all water are added to the mixer.

(3) Mix at full speed for 2 min to homogenize the concrete.

(4) Let the concrete rest for 3 min.

(5) Mix again at full speed for 2 min before casting.

3.5 Curing

Different mixes of Porousconcrete samples are demoulded after 24 hrs casting and immersed in water to continue their curing until reaching testing age.

3.6 Test of porous concrete

3.6.1 Workability Test

The workability of different mixes of porous concrete is measured by slump test as per IS 1199-1959.

3.6.2Sorptivity Test

The sorptivity can be determined by the measurement of the capillary rise absorption rate on reasonably homogeneous material. Water is used for the test .After 7 days of curing, the specimen size 100mm x 100 mm x100 mm are drying in oven at temperature of 100 + 10 °C andare placed in water as shown in Fig 3.6with water level not more than 5 mm above the base of specimen . The flow from the peripheral surface is prevented by sealing it properly with non-absorbent coating with plaster of Paris. The quantity of water absorbed in time period of 4 hours is measured by weighting the specimen on a top pan balance weighing up to 0.1 mg.The surface water on the specimen was wiped off with a dampened tissue and each weighing operation was completed within 30 seconds.

Fig 3.6 Sorptivity test of cube sample

Sorptivity (S) is a material property which characterizes the tendency of a porous material to absorb and transmit water by capillarity. The cumulative water absorption (per unit area of the inflow surface) increases as the square root of elapsed time (t).

$$S = \frac{I}{\sqrt{t}}$$

Where,

I = Increase in mass per unit area (gm/ mm^2)since beginning of the test per unit cross sectional area in contact with water ; as increase in mass is due to the ingress of water , it is expressed in mm

t = time measured in min at which the mass is determined

S= sorptivity in mm/ min$^{0.5}$

3.6.3 Porosity

The porosity of the hardened porous concrete has been calculated from the measured dry mass andbuoyant mass (see Fig 3.7) using the following equation

$$V_r = \left[1 - \left(\frac{W2 - W1}{\rho w \ X \ V}\right)\right] X\ 100\%$$

Where,

Vr = porosity

W_1 =weight under water

W_2 = dry weight

V = volume of sample,

ρ_w = density of water.

The cube samples are used for this test. Density of water (ρw) is taken 1 gm/cc and volume of the samples taken as 1000 cm^3.

Fig 3.7: Submerged weight of porous concrete cube for porosity test

3.6.4 Water permeability

The constant head method of water permeability has been used to measure the permeability of porous concrete. Figure 3.8 shows the setup of the permeability test. Standard cubespecimens (150 mm x 150 mm x 150 mm cube size) are used for this test. Water head is adopted as 500 mm. To stop the water leakagefrom the side, the specimens are covered with plaster of Paris, as shown in Fig 3.8. The cubes are placed in between the two hard steel plates and tightened by circular clamps.The test cubes are covered with plumber's putty to prevent water leakage in the transversedirection which is shown in Fig 3.9. Under a given water head, the permeability testing has beencarried out until a steady state of flow was reached. The amount of water flowing through thespecimens over 30 seconds is measured and the permeability coefficient is calculated usingDarcy's First Law as given below:

Coefficient of permeability $K = \frac{Ql}{Aht}$

Where

A= cross-sectional area of cubes (mm^2)

Q= quantity of water collectedover 30 seconds (ml)

t= time (30s)

k= water permeability coefficient (mm/s)

h= water head (mm)

l= length of specimen (mm).

Fig 3.8: Constant head permeability test set up

Fig 3.9: Putty to prevent leakage in transverse direction

3.6.5. Compressive Strength Testing:

Compressive strength test has been performed according to IS: 516-1959 for all the mixes of porous concrete. The compressive strength reported is the average of three results taken from three identical cubes after 3 days, 7 days and 28 days of curing. Figure 3.10 shows the specimen shape during the failure of porous concrete.

Fig 3.10: The failure of cube specimen after testing

3.6.6 Split Tensile Strength

Splitting tensile strength has been performed according to IS: 5816:1999. The test is made at the age of 28 days. Average of three cylindricalspecimens of 100 mm diameter and 200 mm height is taken as tensile strength. The measured splitting tensile strength (f_{ct}), of the specimens are calculated to the following formula:

$$f_{ct}=\frac{2P}{\Pi Ld}$$

Where

P = Maximum load in Newton applied to the specimen

l = Length of the specimen (mm)

d = Diameter of the specimen (mm)

Fig 3.11: Crack in cylindrical specimen after tensile load is applying

3.6.7Flexural Strength

According to IS: 516-1959, the Flexural strength test has been performed. The bed of thetesting machine has two steel rollers, on which the specimen is supported and these rollers isto be so mounted that distance from centre to centre is 400 mm. The specimens size 100 mm ×100mm cross section and 500 mm length. The load is applied through similar rollers mounted atthe two points of the supporting span that is, spaced at 200 mm centre to centre. The load isapplied vertically and without subjecting the specimen to any torsional stresses or restraints. The load is increased until the specimen fails, and maximum load applied to the specimen duringthe test is recorded. One suitable arrangement which is shown in Fig 3.12 and failure ofspecimen shows in Fig 3.13 The flexural strength of the specimen is expressed as the modulusof rupture (f_b),and it is calculated by the following formula:

$$f_b = \frac{Pl}{bd^2}$$

Where,

P = max load in KN

b = maximum width of prism in mm

l= length which support are fixed

d = depth in mm of the specimen at the point of failure

: **Fig. 3.12: Arrangement for loading of flexural test specimen**

Fig. 3.13: Failureof prism Specimen after loading

3.6.8 Carbonation of concrete:

Carbonation of concrete is a chemical reaction where atmospheric CO_2 diffuses into the pore system of concrete through the pores of concrete and causes changes into the chemical composition of concrete. In carbonation the carbon dioxide reacts principally with calcium hydroxide to form calcium carbonate.

$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$

The calcium hydroxide is not the only substance that reacts with CO_2; the other hydration products and even the residual unhydrated cement compounds also take part into carbonation reactions. Although it is a long term process. The test set up has been made for higher rate of carbonation to determine the carbonation depth. Fig 3.14 shows the suitable arrangement of carbonation chamber with different samples.

Fig 3.14: carbonation test set up in carbonation chamber

Procedure for Carbonation treatment of porous concrete in carbonation chamber:

Step1: Open the carbonation chamber. Put the different samples of porous concrete of different cube sizes of cubes and cylinders in the chamber in two layers (Ref Fig 3.14). Then close the chamber by nuts and bolts with both side washer .The nuts and bolts are uniformly tightened otherwise there might be leakage of CO_2gas.

Step2: Open the CO_2 cylinder which is connected to the carbonation chamber by pipe line, regulator and pressure valve.

Step3: Control the pressure by revolving the regulator of first valve in clockwise direction to set a constant pressure of 2 bar (kg/ cm^2). The regulator is opened in anticlockwise direction and closed in clockwise direction.

Step4: Another pressure valve (second valve) is controlled to accurate the constant pressure. It is the final set up where CO_2 is reached to the carbonation chamber.

Step5: In carbonation chamber, another pressure meter valve is present where pressure of 2 bars is controlled. The valve is tightened properly to exert a constant pressure on this chamber.

Step 6: The carbonation test are measured in the duration of 10 days and 30 days.

Step7: Proper care should be taken during the test procedure.

Step8: For various reason if pressure gets reduced, again open and controlthe pressure valve in same manner to maintain the constant pressure up to specified age.

Step 9: If excess pressure is generated, a safety valve in carbonation chamber should control the accurate pressure.

Step 10: After the age of 10 and 30 days within carbonation chamber, the sample are taken out from the chamber and measured the depth of carbonation penetration by phenolphthalein indicator.

Phenolphthalein indicator is used to measure carbonation depth and is available from chemical suppliers. Phenolphthalein is a white or pale yellow crystalline materials .For use as an indicator it is dissolved in a suitable solvent in a 1 % solution. The indicator solution is clear liquid but turns purple above a PH of 8.5.

Fig 3.15: phenolpthalein indicator applied on porous concrete cube

It is clearly noticed that the surface of cubes become colorless after phenolphthalein indicator has been used on concrete cube surface, which means they are fully carbonated. To measure the depth of carbon di oxide (CO_2) penetration into the core of porous concrete cubes, they are broken into two equal parts longitudinally as shown in Fig 3.16and again apply phenolphthalein indicator on that fracture surfaces.

It has not changed color near the top and bottom surfaces, suggesting that these near-surface regions are carbonatedfor different mixes of porous concrete. Where the indicator has turned purple - the center of the concrete cube, the pH of the concrete pore fluid remains high (above 8.6, probably nearer 10) which means this portion is not carbonated.

Fig 3.16: Breaking of concrete cube sample in equal parts &applying phenolphthalein indicator on fractureconcrete cube and cylinder surface

CHAPTER 4 RESULT AND DISCUSSION

4.1 GENERAL

In the present experimental investigation, a uniform size of coarse aggregate (passing through 12.5 mm sieve and retained on 10 mm sieve) is used with low water cement ratio to achieve a maximum strength without inhibiting the permeability. This part concentrated on the results of the experimental investigation on different mixes of porous concrete. The relationships among water-cement ratio with density, porosity, sorptivity, compressive strength, water permeability, split tensile strength and flexural strength and carbonation test for different mixes of porous concrete are discussed. Various graph and tables are shown in this chapter. A comparison of porous concrete with natural aggregate, porous concrete with recycled concrete aggregate and porous concrete with 50% natural aggregate and 50 % recycled concrete aggregate are also described.

4.2. POROUS CONCRETE WITH VARIOUS TESTS RESULTS

The Slump test has been performed to determine the workability of fresh porous concrete as per IS: 1199-1959 .It is noted that the binding property of different mixes of porous concrete is very low due to absence of fine aggregate. It is difficult to measure the slump value .In almost all cases a collapsed slump has been obtained (Ref Fig 4.1).However, this generally do not make any difficulties in compaction.

Fig 4.1 : Slump test on porous concrete

The densities of the each of porous concrete mixtures at the age of 28 days are shown in table 4.1. The average density of the porous concrete with natural aggregate is 2010 kg/m^3.However the average density of conventional concrete mix is about 2400 kg/m^3.As expected the average density of porous concrete is less than the conventional concrete due to absence of fine aggregate and presence of more void space.

According to fig 4.2, it is noted that the density of porous concrete mixes (C/A ratio 1:4) decreases with increases in water cement ratio. This is due to the presence of more void space in the cement paste with increase in water cement ratio. Similar results are obtained for cement aggregate ratio 1:5 and 1:6.

The porous concrete with fully recycled concrete aggregate shows lower density than porous concrete with natural aggregate at all water cement ratio. Even for porous concrete with 50 % natural and 50% recycled aggregate has less density than porous concrete with natural aggregate but its value is more than that of porous concrete with fully recycled aggregate. It is noted that recycled concrete aggregate has lower density (Sp. Gravity 2.50) than natural coarse aggregate (Sp. Gravity 2.60) due to presence of weak attached mortar.

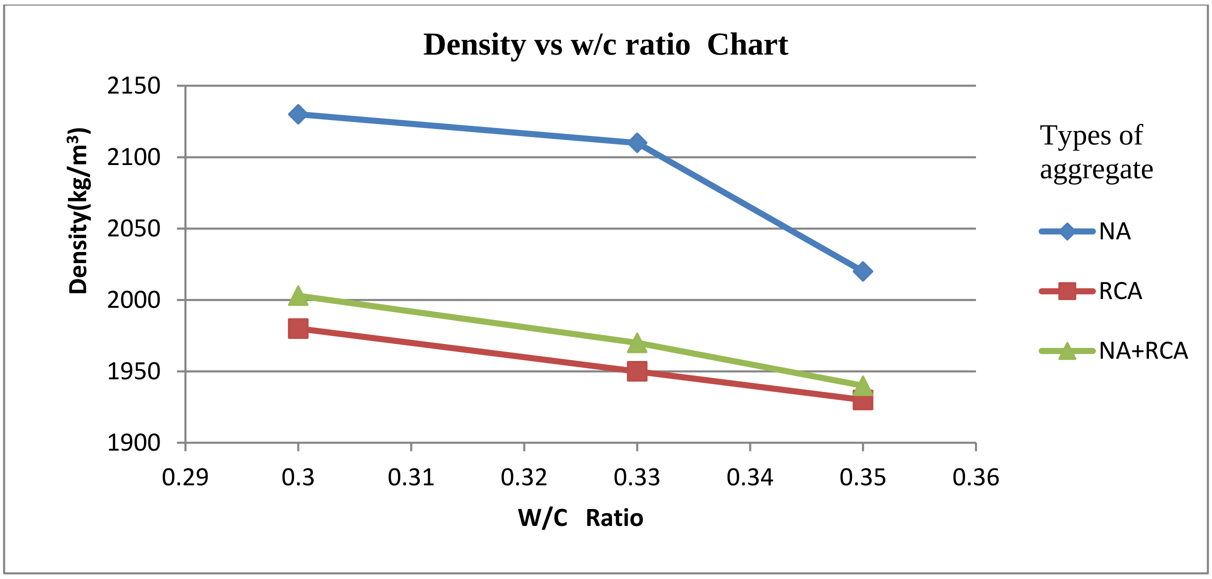


Fig 4.2: **Density vs. w/c ratio chart for C/A 1:4**

Table4.1: Density, Porosity, Sorptivity and Permeability for various mixes porous conc.

SL No	MIX NO	DENSITY (kg/m^3)	AVG.DENSITY (kg/m^3)	POROSITY (%)	AVG. POROSITY (%)	SORPTIVITY(mm/min$^{0.5}$)	WATER PERMEABILTY (mm/sec)
1	**M1N**	2020	2010	18	18	2.90 E-04	1.06
2	**M2N**	2050		16		2.32 E-04	1.04
3	**M3N**	2110		14		2.21 E-04	0.97
4	**M4N**	1985		20		3.62 E-04	1.09
5	**M5N**	2030		19		3.35 E-04	1.05
6	**M6N**	2005		17		3.29 E-04	1.02
7	**M7N**	1920		22		3.84 E-04	1.14
8	**M8N**	1970		20		3.75 E-04	1.12
9	**M9N**	2000		18		3.39 E-04	1.07
10	**M1R**	1930	1930	21	22	3.61 E-04	1.16
11	**M2R**	1950		20		3.39 E-04	1.10
12	**M3R**	1970		19		3.25 E-04	1.02
13	**M4R**	1910		23		4.02 E-04	1.20
14	**M5R**	1935		22		3.87 E-04	1.16
15	**M6R**	1965		21		3.61 E-04	1.10
16	**M7R**	1880		27		4.89 E-04	1.22
17	**M8R**	1905		23		4.80 E-04	1.18
18	**M9R**	1930		23		4.37 E-04	1.12
19	**M1NR**	1940	1950	19	20	2.97 E-04	1.04
20	**M2NR**	1965		17		2.81 E-04	1.02
21	**M3NR**	2000		16		2.58 E-04	1.00
22	**M4NR**	1930		21		3.61 E-04	1.07
23	**M5NR**	1950		20		3.29 E-04	1.05
24	**M6NR**	1985		18		3.16 E-04	1.02
25	**M7NR**	1900		23		4.26 E-04	1.10
26	**M8NR**	1910		21		4.10 E-04	1.07
27	**M9NR**	1950		20		3.80 E-04	1.04

The porosity for each of porous concrete mixtures are shown in Table 4.1. The average porosity of porous concrete with natural aggregate, with recycled concrete aggregate and with 50% natural and 50% recycled concrete aggregate are 18%, 22% and 20% respectively.

Fig 4.3 exhibits the relationship between porosity vs. water cement ratio of cement aggregate ratio of 1:4. The Porosity will increases with increases of water cement ratio for all the mixes of porous concrete. This is due to presence of more void space in cement paste with higher water cement ratio. The porosities of different mixes of porous concrete show similar trends for cement aggregate ratio of 1:5 and 1:6.

It is also noted that recycled aggregate porous concrete has higher porosity at all water cement ratio than that of porous concrete with natural aggregate and porous concrete with 50% natural and 50% recycled aggregate. This is due to old weak attached mortar and more water absorption capacity in recycled concrete aggregate.

The sorptivity value of different mixtures of porous concrete are shown in table 4.1.From fig 4.4 shows the linear relationship between sorptivity value with water cement ratio for cement aggregate ratio of 1:4. The sorptivity value with water cement ratio shows the similar trends as in the case of porosity for the cement aggregate ratio 1:5 and 1:6.

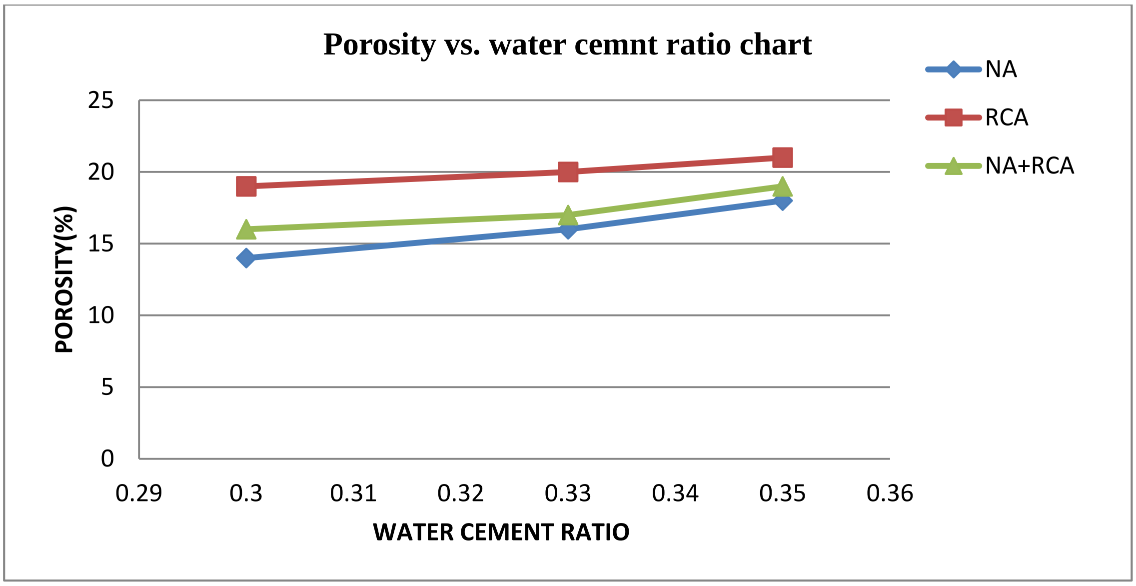


Fig 4.3: Porosity vs. w/c ratio chart for C/A ratio 1:4

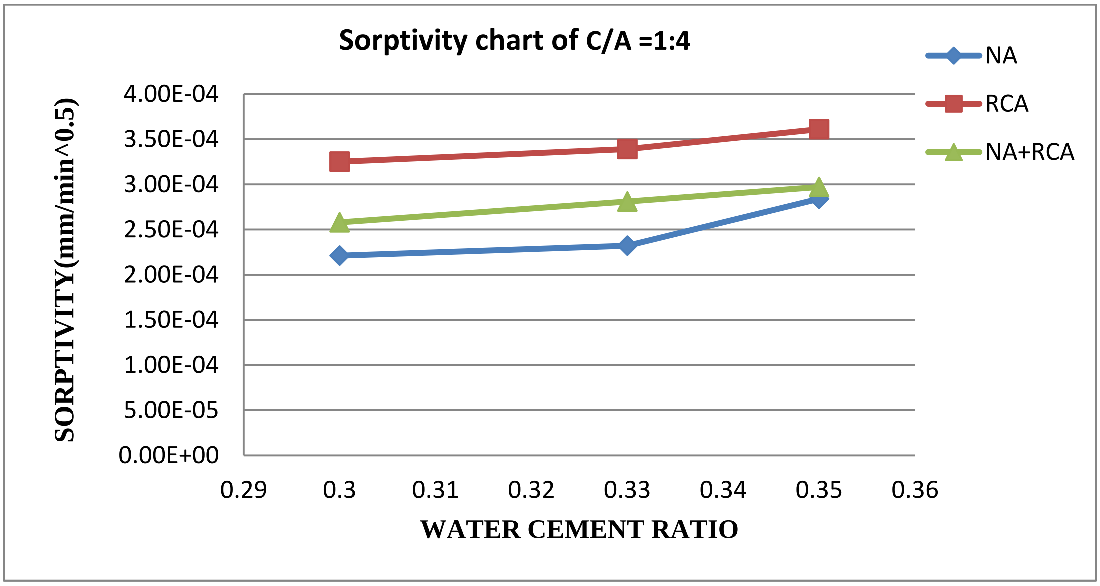


Fig 4.4: Sorptivity vs. water cement ratio chart for C/A ratio 1:4

The coefficient of water permeability determined by constant head method for each of porous concrete mixtures are shown in table 4.1 and Fig 4.4 .The maximum permeability achieved in porous concrete with natural aggregate, with recycled aggregate and with 50 % natural and 50 % recycled aggregate are 1.14 mm/sec , 1.16 mm /sec and 1.22 mm/ sec respectively. So for all the mixes for different aggregate of porous concrete, the co efficient of water permeability is always greater than 1 mm/sec, which is highly porous material for drainage purposes to recharge the ground water table.

Linear relationship observed between permeability with water cement ratio for cement aggregate ratio 1:4 (Ref Fig 4.4). This trend has been also noted for cement aggregate ratio 1:5 and 1:6. The chart exhibits the co efficient of water permeability of porous concrete mixes increases with increase in water cement ratio. This is due to more void space with increase in water cement ratio.

It is also noted that porous concrete with recycled aggregate mixture are always greater than that of porous concrete with natural aggregate and porous concrete with 50 % natural and 50 % recycled aggregate . This is due to the weak attached mortar paste formation and more water absorption capacity in recycled concrete aggregate.

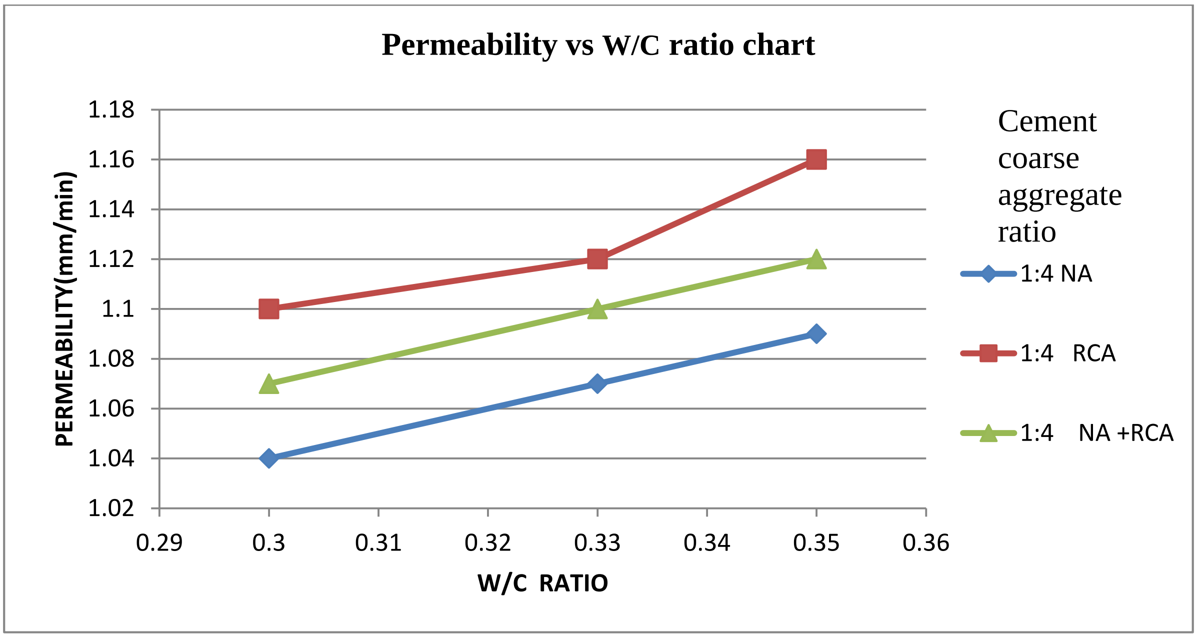


Fig 4.5: Permeability and w/c ratio for NA, RCA, and NA+ RCA of C/A 1:4

Table4.2: Compressive Strength, Tensile Strength and Flexural Strength of various mixes of porous concrete

TYPES OF AGGREGATE	MIX NO	COMPRESSIVE STRENGTH (MPa)			TENSILE STRENGTH (MPa)	FLEXURAL STRENGTH (MPa)
		3 days	7 days	28 days		
NATURAL AGGREGATE (100 %)	**M1N**	6.52	7.35	10.88	0.98	2.00
	M2N	7.50	9.77	13.80	1.10	2.40
	M3N	8.20	11.20	14.70	1.16	2.60
	M4N	4.75	6.00	8.50	0.80	1.60
	M5N	5.00	7.50	9.60	0.87	2.00
	M6N	6.00	8.25	11.20	1.02	2.40
	M7N	-	4.75	6.75	0.50	1.20
	M8N	-	5.10	7.80	0.72	1.60
	M9N	5.00	7.35	10.35	0.92	1.90
RECYCLED AGGREGATE (100 %)	**M1R**	5.12	5.45	6.75	0.70	1.20
	M2R	5.45	6.12	7.45	0.88	1.50
	M3R	6.00	7.50	9.40	1.02	1.80
	M4R	-	4.80	5.60	0.50	1.00
	M5R	-	5.00	6.00	0.67	1.20
	M6R	3.50	5.50	7.50	0.92	1.50
	M7R	-	3.50	5.00	0.40	0.45
	M8R	-	4.80	6.10	0.56	0.65
	M9R	-	5.00	6.20	0.62	0.90
NATURAL (50%) + RECYCLED (50%) AGGREGATE	**M1NR**	6.00	7.10	9.80	0.80	1.80
	M2NR	6.50	8.00	12.20	0.95	2.20
	M3NR	7.10	9.40	13.70	1.05	2.40
	M4NR	5.10	6.40	9.00	0.75	1.50
	M5NR	5.75	7.25	11.30	0.82	1.85
	M6NR	6.30	8.50	12.80	1.00	2.10
	M7NR	-	4.00	6.75	0.50	1.00
	M8NR	3.75	4.80	7.35	0.55	1.50
	M9NR	5.50	7.10	10.25	0.72	1.65

- Dot line indicates very low value compressive strength which cannot be measured.

The results of cube compressive strength at 3, 7,and 28 days of all the mixes for porous concrete are presented in table 4.2.The results of tensile strength and flexural strength have been included in table 4.2 for comparison. Fig 4.6, 4.7, & 4.8 show the variation of compressive strength with water cement ratio for porous concrete with natural aggregate, with recycled concrete aggregate, and with natural and recycled (50:50) respectively. As expected, the compressive strength of all the mixes of porous concrete increases with ages. The study is limited to 28 days only. However more long term data is need particularly for the present cases as Portland slag cement has been used in all the mixes.

The cube compressive strength of porous concrete with natural aggregate of different C/A ratios is increases with the decrease in water cement ratio (Ref Fig 4.9 a). Similar trend is also noticed for porous concrete with recycled aggregate (Ref Fig 4.9 b) and with natural and recycled aggregate (50:50) (Ref Fig 4.9 c). With the increase in water cement ratio, the voids in the cement paste becomes more thereby reduce the strength of paste at the interface of aggregate and paste.

However for a particular C/A ratio and W/C ratio, the cube compressive strength of porous concrete with Recycled aggregate is less than porous concrete with natural aggregate at all ages. This reduction is mainly due to the presence of weak mortar attached to the aggregate. For conventional concrete, the use of recycled aggregate in place of natural aggregate also reduces the compressive strength of concrete. Again the mixtures of natural aggregate and recycled aggregate (50:50) for porous concrete shows the compressive strength in between the compressive strength of porous concrete with fully natural aggregate and fully recycled aggregate.

The relationship between water/cement ratio with splitting tensile strength and flexural strength for different cement aggregate ratios of porous concrete with natural aggregate, with recycled aggregate and with both aggregate (50:50) are shown in Fig 4.10 and Fig 4.11 .it is noted that the result followed the similar trends as in the case of compressive strength of porous concrete cube at 28 days.

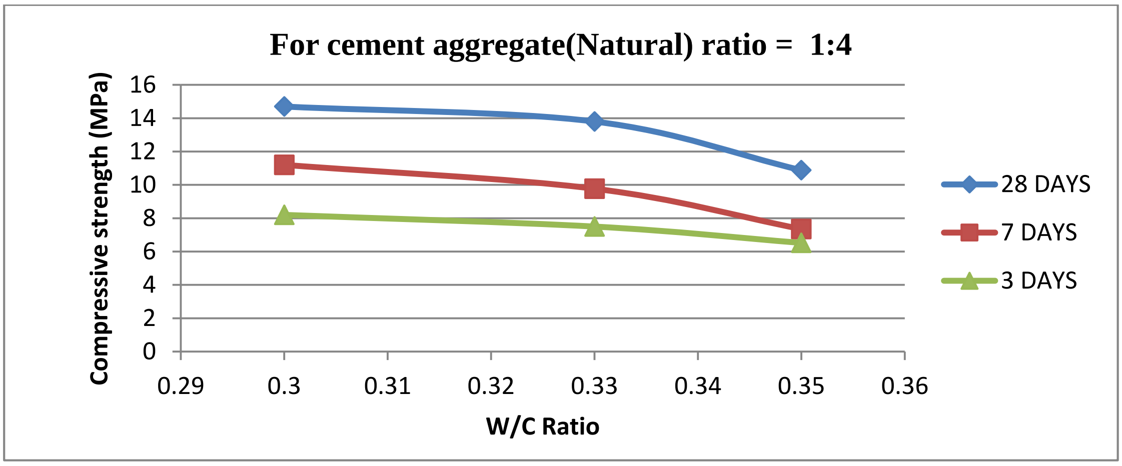


Fig4.6 (a): Compressive Strength vs. water cement ratio for different age of C/A 1:4

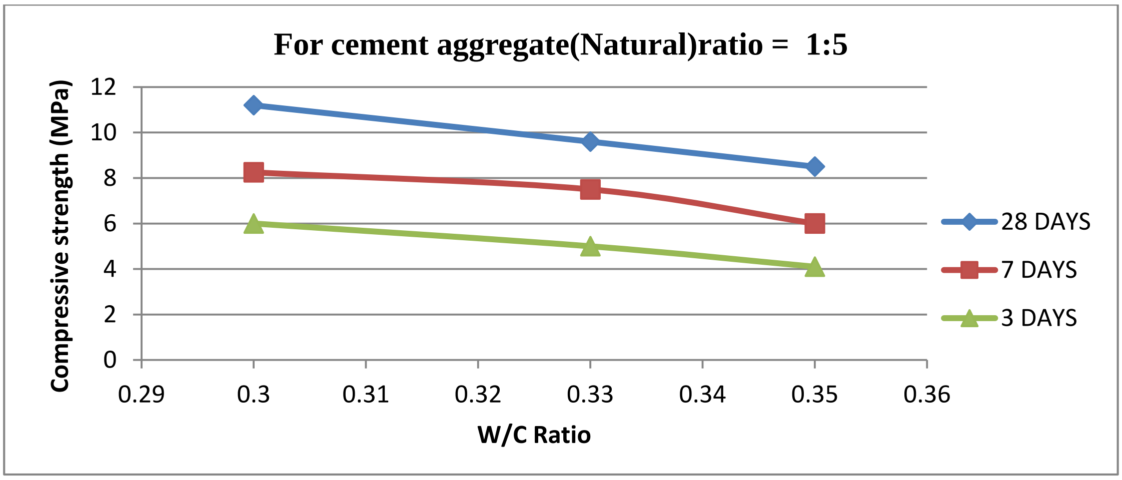


Fig4.6 (b): Compressive Strength vs. water cement ratio for different age of C/A 1:5

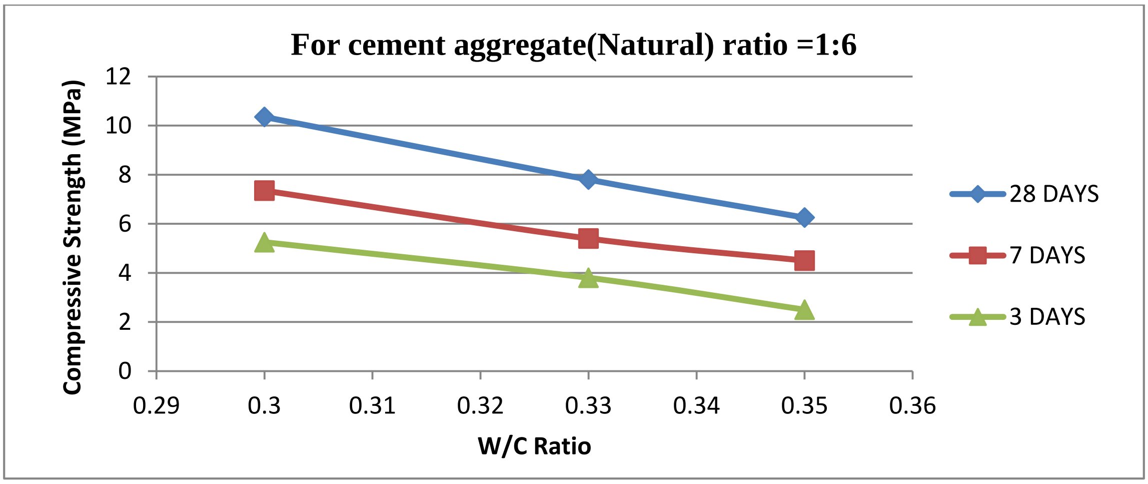


Fig 4.6 (c): Compressive Strength vs. water cement ratio for different age of C/A 1:6

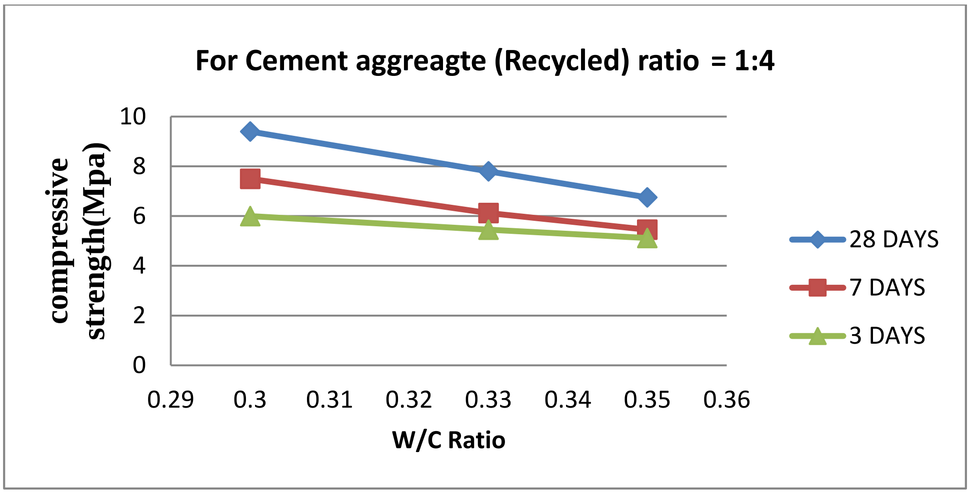


Fig 4.7 (a): Compressive Strength vs. water cement ratio for different age of C/A 1:4

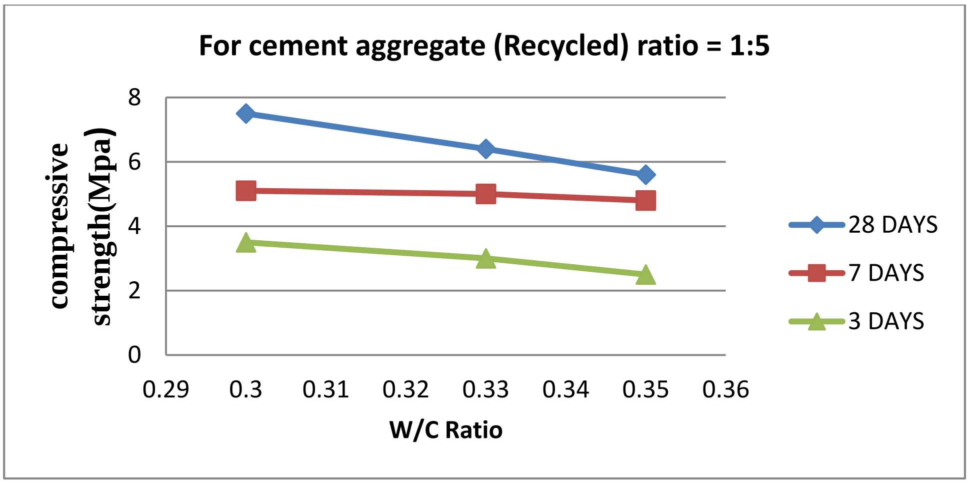
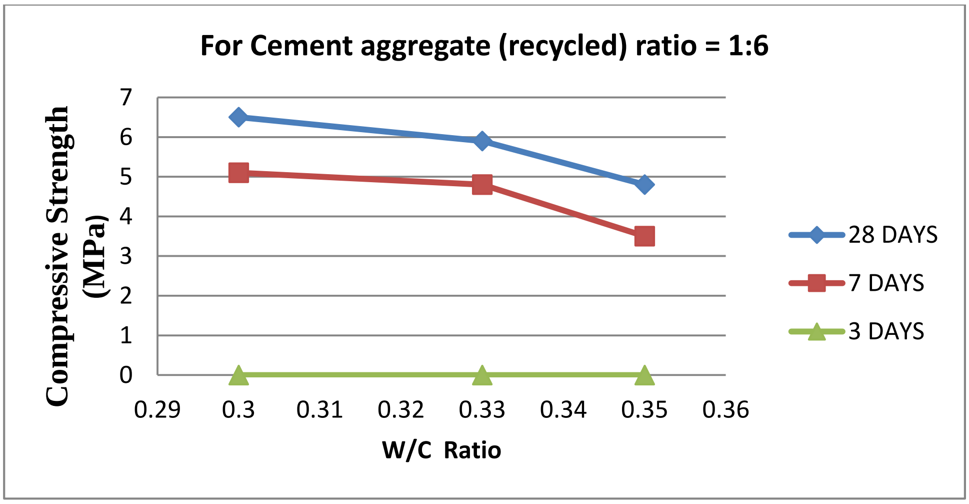


Fig 4.7 (b): Compressive Strength vs. water cement ratio for different age of C/A 1:5



* 3 days strength are very less and cannot be measured

Fig 4.7 (c): Compressive Strength vs. water cement ratio for different age of C/A 1:6

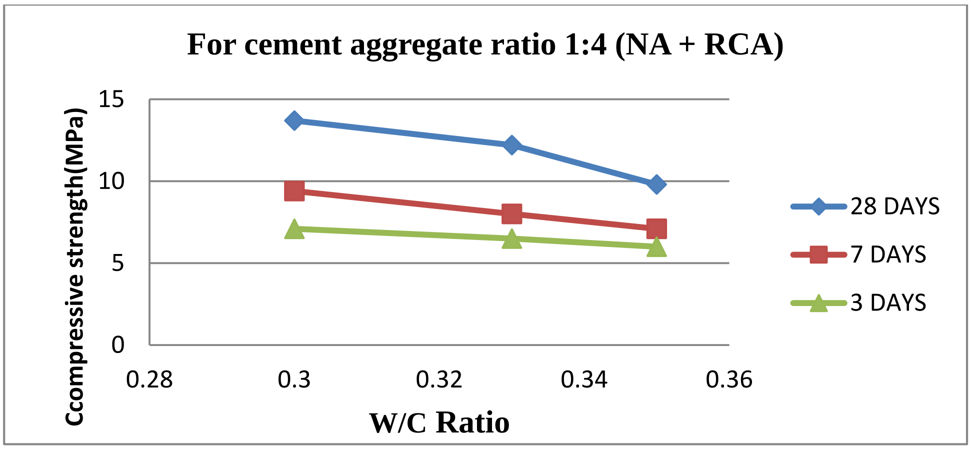


Fig 4.8 (a): Compressive Strength vs. water cement ratio for different age of C/A 1:4

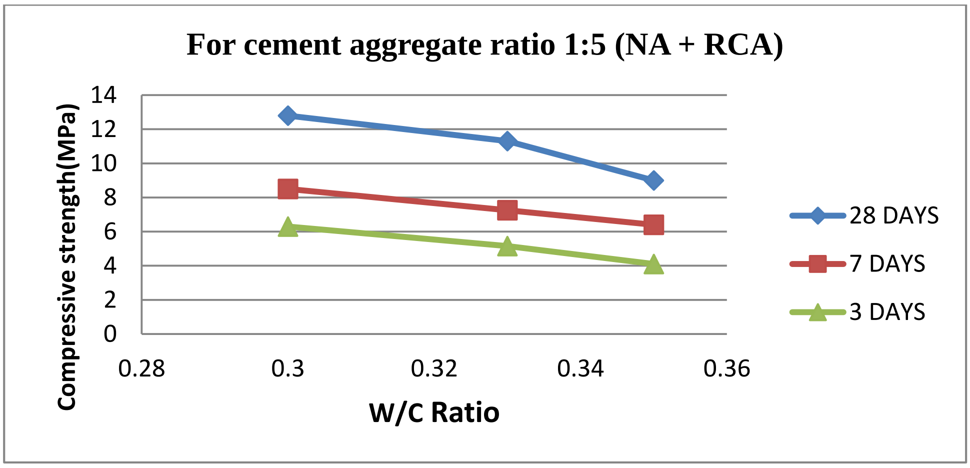


Fig 4.8 (b): Compressive Strength vs. water cement ratio for different age of C/A 1:5

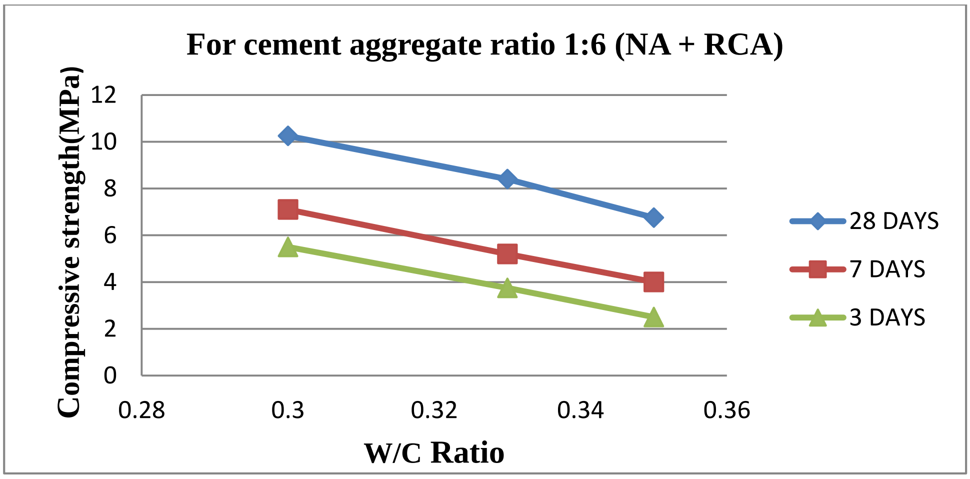


Fig 4.8 (C): Compressive Strength vs. water cement ratio for different age of C/A 1:6

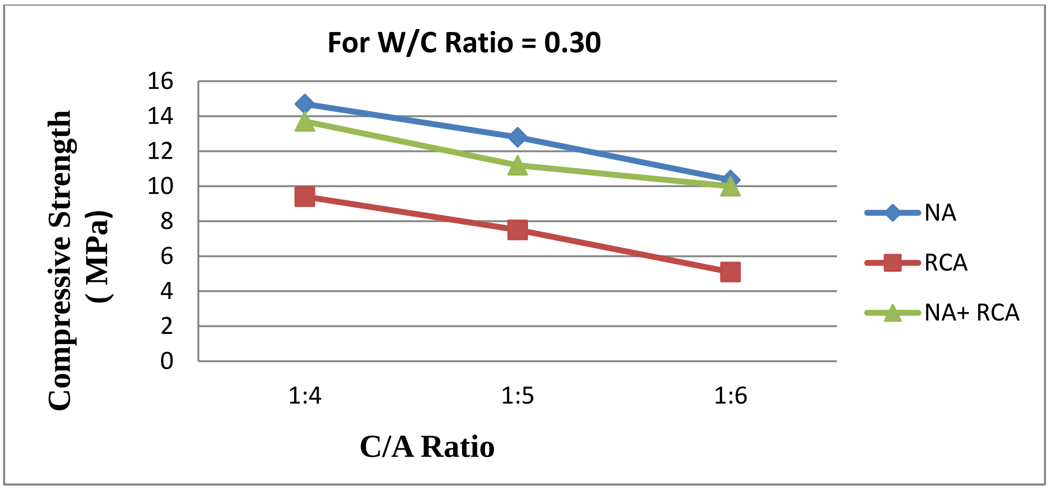


Fig 4.9 (a) Compressive Strength vs. C/A ratio for W/C ratio 0.30

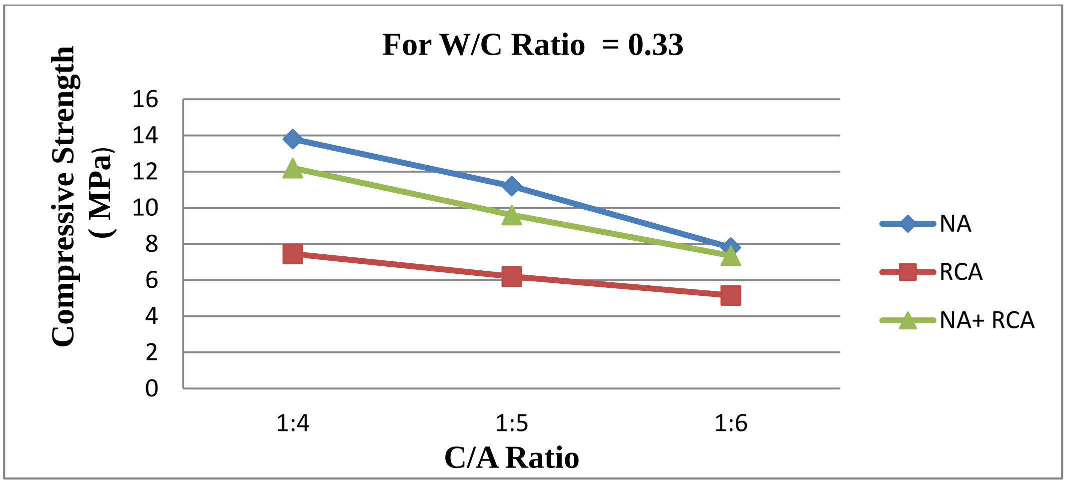


Fig 4.9 (b) Compressive Strength vs. C/A ratio for W/C ratio 0.33

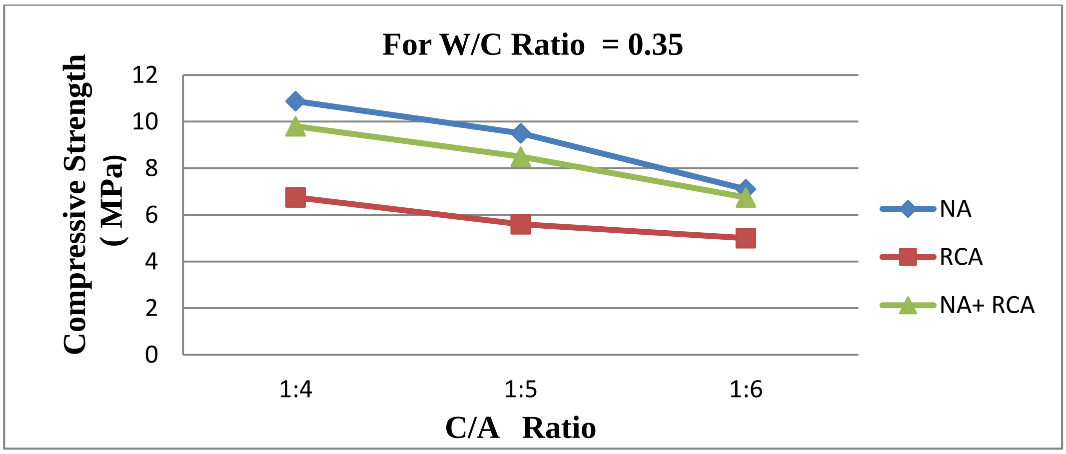


Fig 4.9 (c) Compressive Strength vs. C/A ratio for W/C ratio 0.3

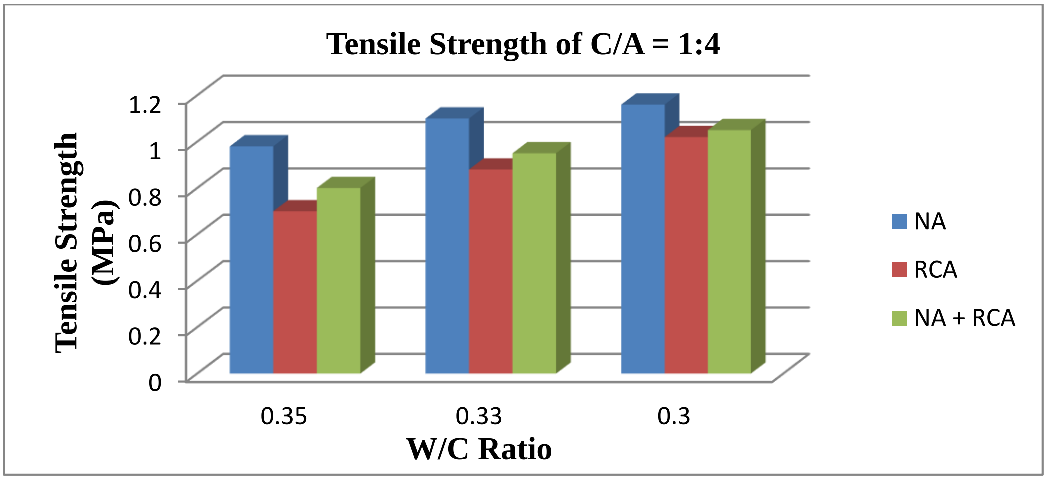


Fig 4.10 (a) Tensile strength vs. water cement ratio for C/A ratio 1:4

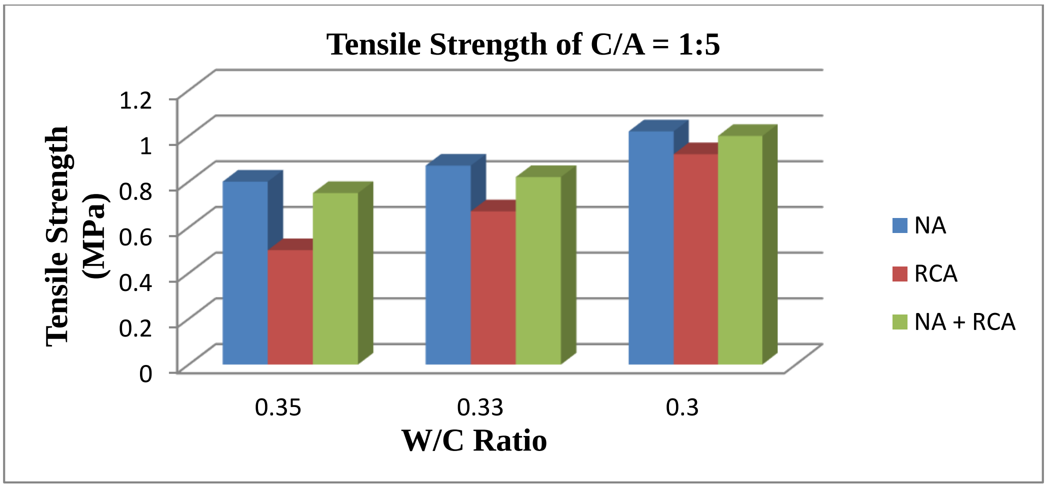


Fig 4.10 (b) Tensile strength vs. water cement ratio for C/A ratio 1:5

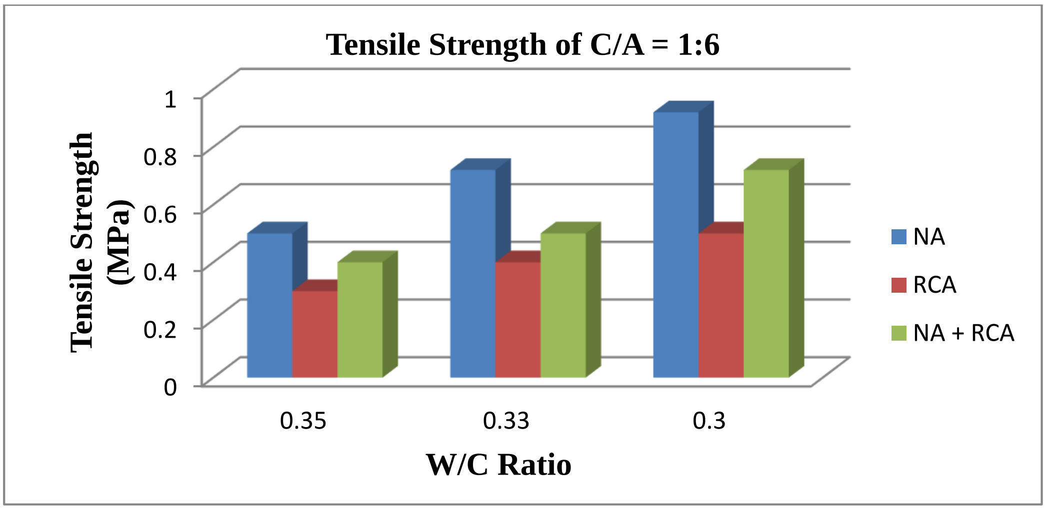


Fig 4.10 (c) Tensile strength vs. water cement ratio for C/A ratio 1:6

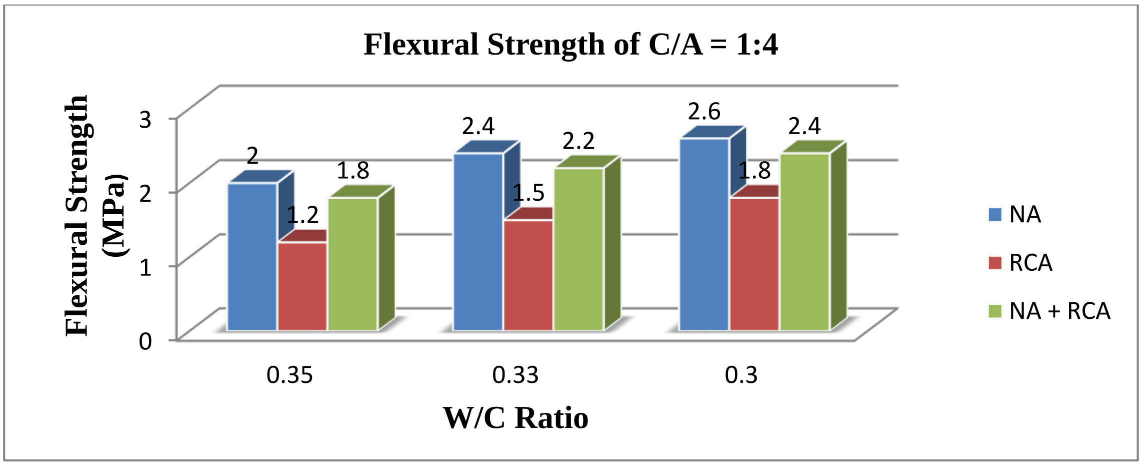


Fig 4.11 (a) Flexural strength vs. W/C ratio chart for C/A ratio 1:4

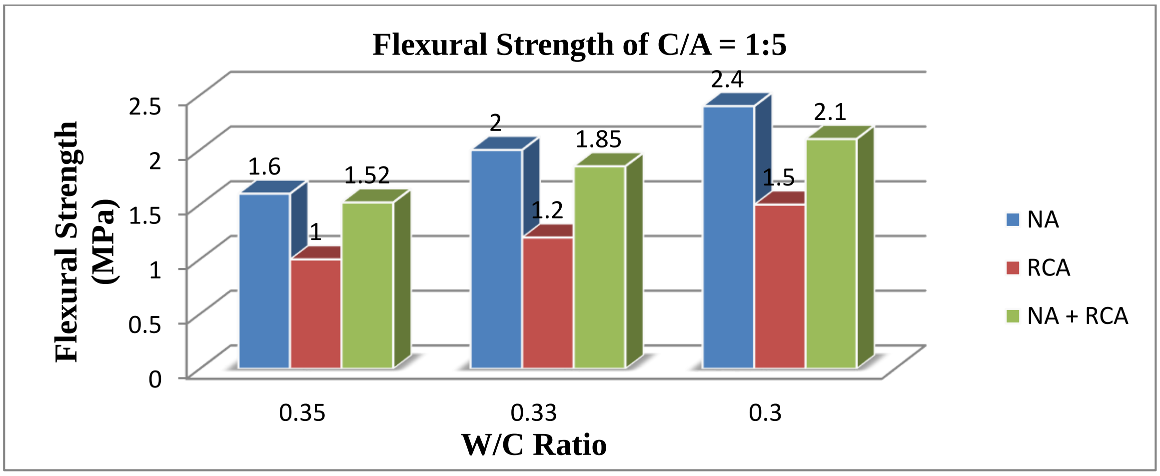


Fig 4.11 (b) Flexural strength vs. W/C ratio charts for C/A ratio 1:5

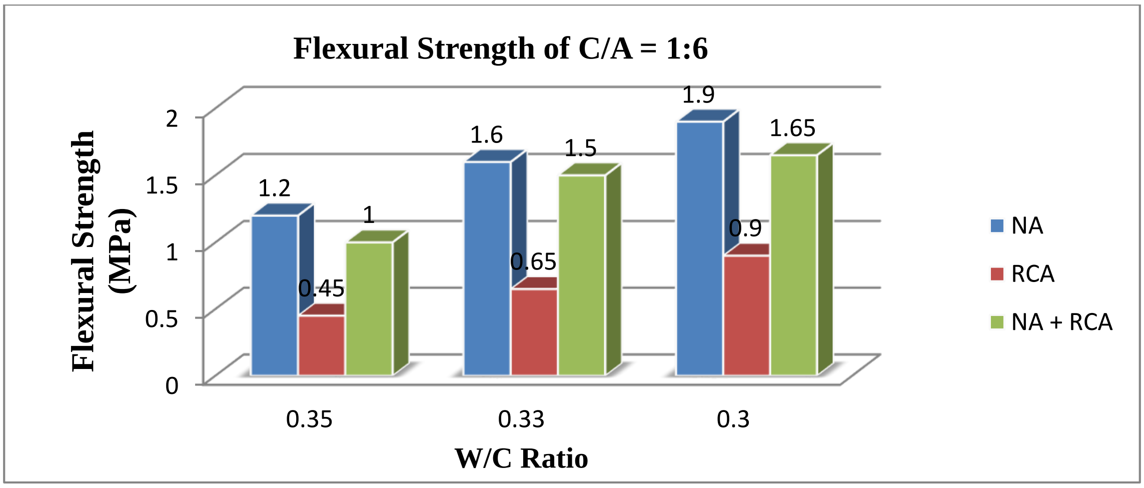


Fig 4.11 (c) Flexural strength vs. W/C ratio chart for C/A ratio 1:6

Fig 4.12 and Fig 4.13 shows the measurement of carbonation depth after 10 days and 30 days of accelerated carbonation. Table4.3 summarized the depth of Carbonation value for various mixes of porous concrete.

Fig4.12: Measurement of Depth of carbonation in porous concrete cube after 10 days of carbonation chamber

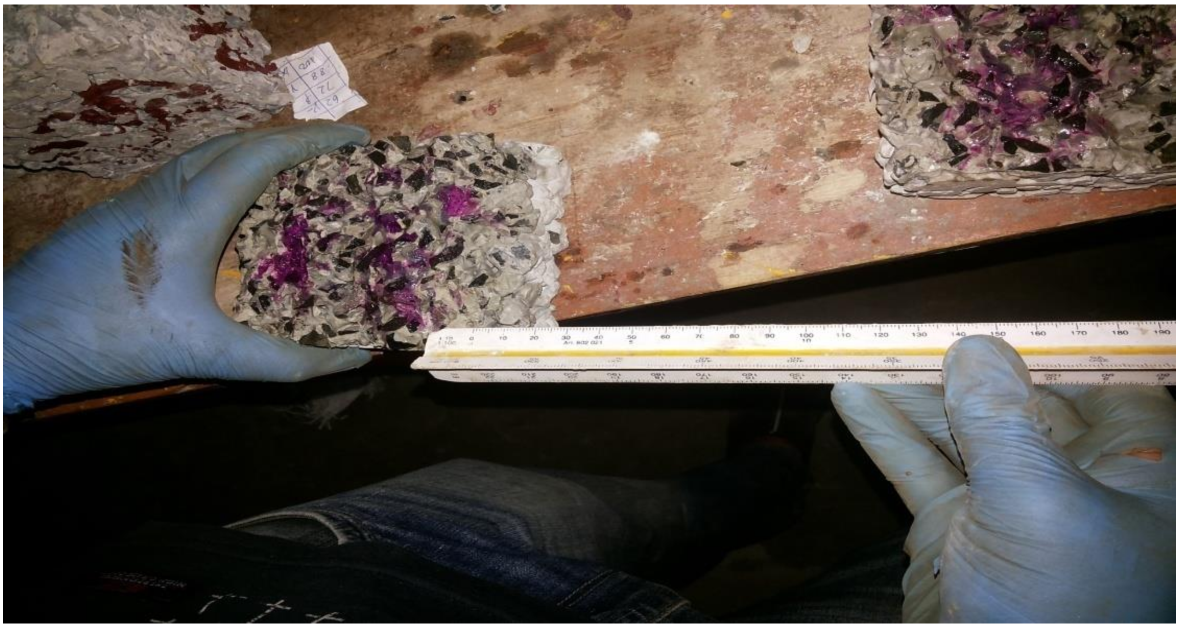


Fig4.13: Measurement of depth of carbonation in porous concrete cube after 30 days of carbonation chamber

Table 4.3: Depth of Carbonation of various mixes of porous concrete

SL NO	MIX NO	TYPE OF AGGREGATE	DEPTH OF CARBONATION (mm)	
			10 DAYS	30 DAYS
1	M1N	NATURAL AGGREGATE (100 %)	4	6
2	M2N		3	5
3	M3N		2	4
4	M4N		7	10
5	M5N		6	8
6	M6N		5	7
7	M7N		9	10
8	M8N		7	9
9	M9N		6	8
10	M1R	RECYCLED AGGREGATE (100 %)	8	11
11	M2R		7	10
12	M3R		6	8
13	M4R		15	18
14	M5R		13	16
15	M6R		12	15
16	M7R		20	22
17	M8R		18	21
18	M9R		16	19
19	M1NR	NATURAL (50%) +RECYCLED (50%) AGGREGATE	7	9
20	M2NR		5	7
21	M3NR		4	6
22	M4NR		12	15
23	M5NR		10	13
24	M6NR		9	12
25	M7NR		15	19
26	M8NR		14	18
27	M9NR		14	17

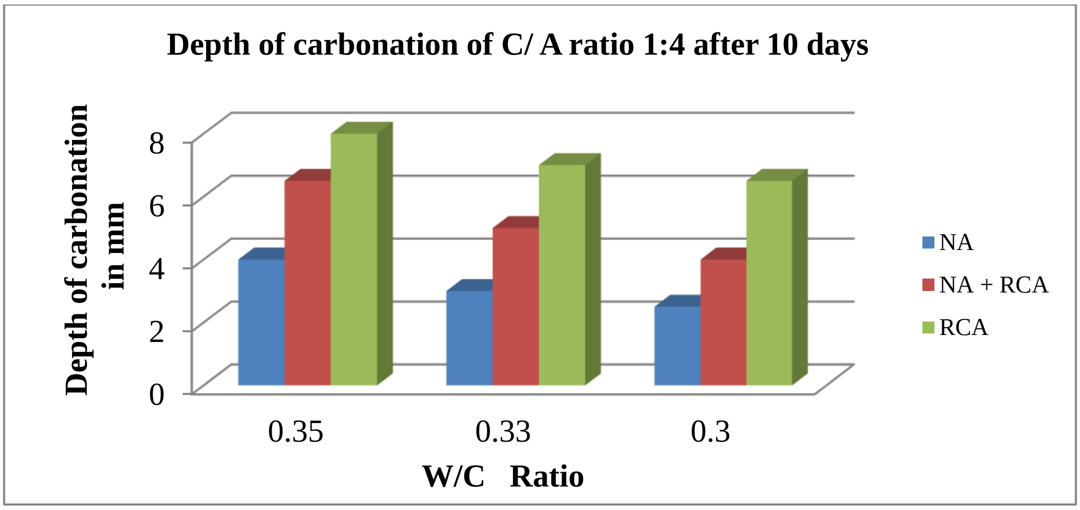


Fig 4.14(a): Carbonation depth for different mixes of C/A 1:4

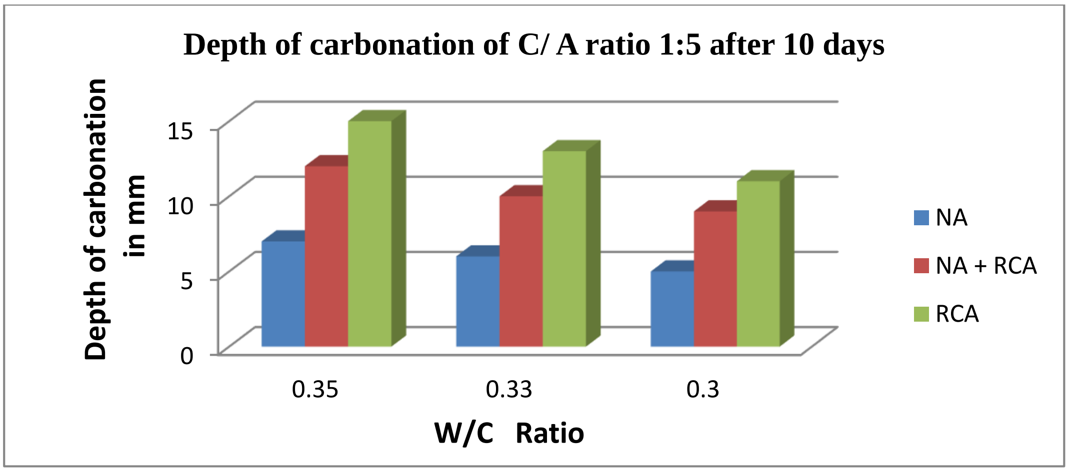


Fig 4.14(b): Carbonation depth for different mixes of C/A 1:5

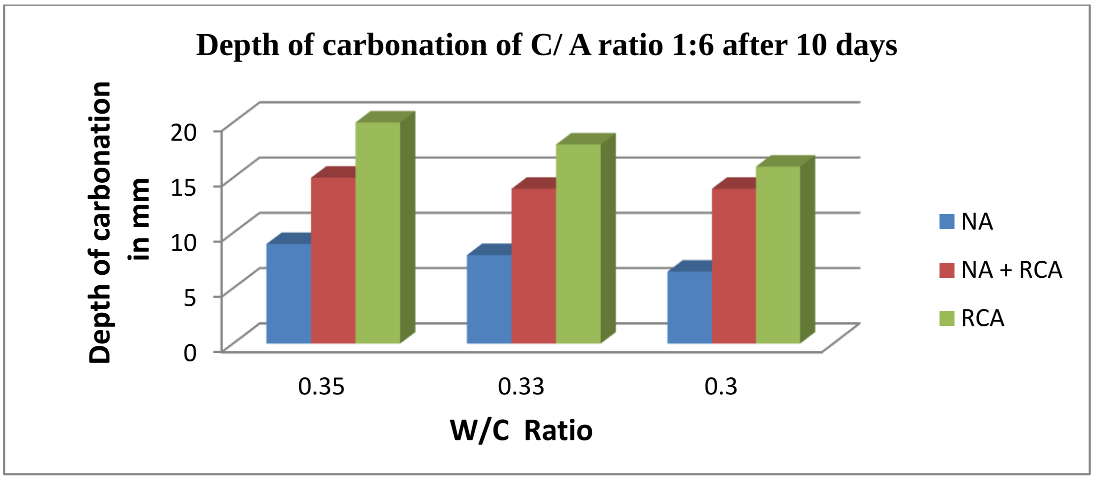


Fig 4.14(c): Carbonation depth for different mixes of C/A 1:6

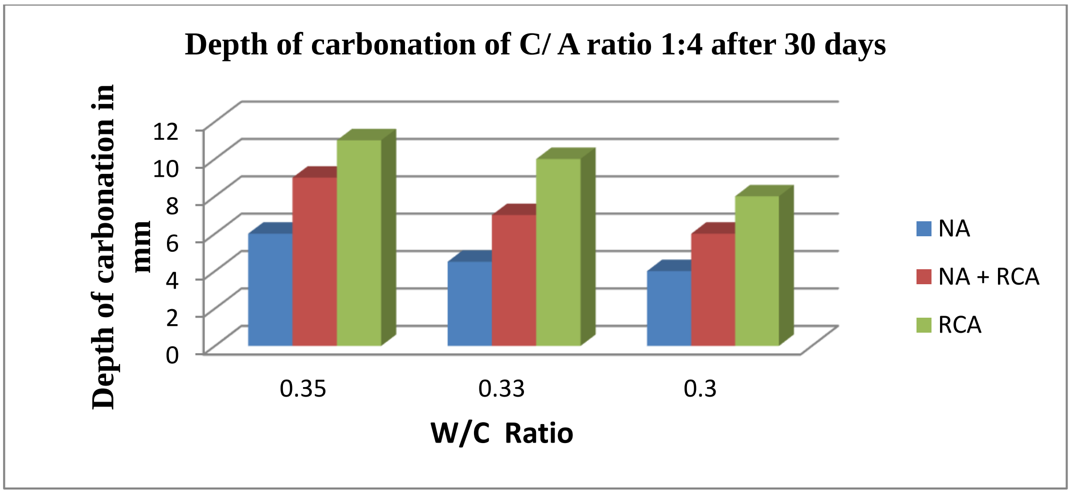


Fig 4.15(a): Carbonation depth of for different mixes of C/A 1:4

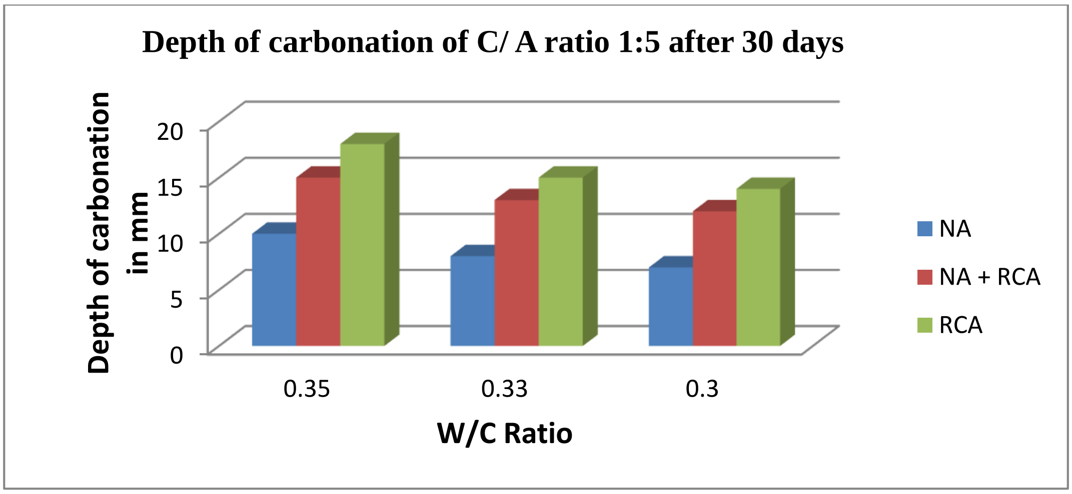


Fig 4.15(b): Carbonation depth for different mixes of C/A 1:5

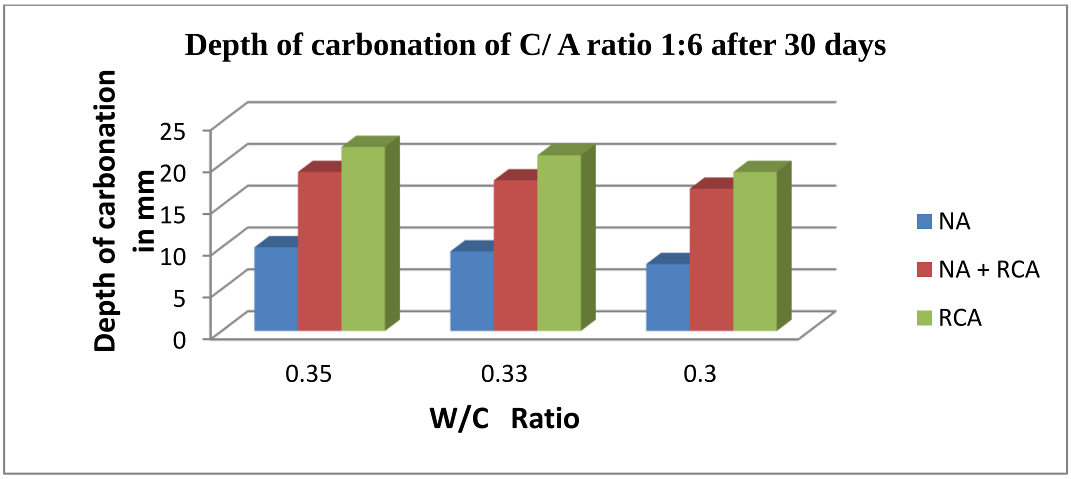


Fig 4.15(c): Carbonation depth for different mixes of C/A 1:6

The Fig 4.14 and Fig 4.15 shows the depth of carbonation(mm) vs. water cement ratio for cement aggregate ratio of 1: 4 , 1:5 and 1:6 after 10 days and 30 days inside the carbonation chamber. The depth of carbonation for porous concrete with natural aggregate with recycled aggregate and with both 50 % natural and 50 % recycled aggregate are also included. It has been noticed that the higher the cement aggregate ratio (1:6),the higher is the depth of carbonation value for all porous concrete mixtures due to its less cement paste formation than cement aggregate ratio of (1:4, and 1:5).It is also noted that the depth of carbonation is increased with increased in water cement ratio for more void space available in cement paste for higher water cement ratio.

Generally the porous concrete with recycled aggregate absorb more CO_2 for all water cement ratio than that of porous concrete with natural aggregate and porous concrete with 50 % natural and 50 % recycled aggregate . From the above chart it can be conclude that recycled aggregate porous concrete absorb two times more depth of carbonation than natural aggregate porous concrete. This is due to weak mortar paste and more void space present in recycled aggregate. It is also noted that the rate of carbonation is high at initial age and progressively it is low. The study is limited to 30 days in carbonation chamber at a pressure of 2 bar.