

**STRENGTH PROPERTIES OF
RECYCLED CONCRETE AGGREGATE USING
DIFFERENT TYPES OF CEMENT**

Thesis submitted in partial fulfilment of requirement for the award of

Degree of

Master of Engineering

In

Structural Engineering

Submitted By

Newton

(Roll No. 821022003)

Under the Guidance of:

Dr. Naveen Kwatra

Associate Professor & Head
Deptt. of Civil Engineering
Thapar University, Patiala

Dr. Shweta Goyal

Assistant Professor
Deptt. of Civil Engineering
Thapar University, Patiala



DEPARTMENT OF CIVIL ENGINEERING

THAPAR UNIVERSITY

PATIALA – 147004


July 2014

DECLARATION

I, Newton, hereby declare that this thesis report entitled "Strength Properties of RCA Concrete Using Different Types of Cements" is an authentic record of my study carried out as the requirements for the award of degree of Master of Engineering in Structural Engineering, in the Civil Engineering Department, Thapar University, Patiala, under the supervision of Dr. NAVEEN KWATRA, Associate Professor and Dr. SHWETA GOYAL Assistant Professor, Deptt of Civil Engineering, Thapar University Patiala. This matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

Date:

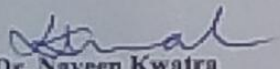
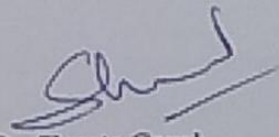
Place:


Newton

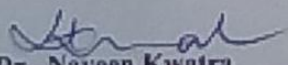
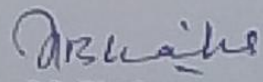
Roll No 821022003

CERTIFICATE

This is to certify that above statement made by the student concerned is correct and true to the best of my knowledge & belief.


Dr. Naveen Kwatra
Associate Professor
Civil Engineering Department
Thapar University, Patiala
Dr. Shweta Goyal
Assistant Professor
Civil Engineering Department
Thapar University, Patiala

Countersigned by


Dr. Naveen Kwatra
Associate Professor and Head
Civil Engineering Department
Thapar University, Patiala
Dr. S.S. Bhatia
Dean Academic Affairs
Thapar University, Patiala

ACKNOWLEDGMENT

A thesis cannot be completed without the help of many people who contribute directly or indirectly through their constructive criticism in the evolution and preparation of this work. It would not be fair on my part, if I don't say a word of thanks to all those whose sincere advice made this period a real educative, enlightening, pleasurable and memorable one.

First of all, a special debt of gratitude is owned to my supervisor **Dr. Naveen Kwatra, Associate Professor and Dr. Shweta Goyal, Assistant Professor**, Department of Civil Engineering, Thapar University, Patiala for their gracious efforts and keen pursuits, which has remained as a valuable asset for the successful completion of research work. Their dynamism and diligent enthusiasm has been highly instrumental in keeping my spirit high. Their flawless and forthright suggestion blended with an innate intelligent application has crowned my task a success. Apart from the subject of my work, I learnt a lot from them, which I am sure, will be useful in different stages of my life.

I would like to express my gratitude to all the other faculty and staff members of Department of Civil Engineering, Thapar University, Patiala for their kind cooperation and encouragement which helped in the completion of work.

I am extremely thankful to **Mr. Ram Simran** for helping me carry out experimental work.

My deepest gratitude goes to my parents, my family and friends for their unflagging love, constant encouragement, helpful advice, and a constant support during my study program and this thesis would certainly not have existed without them.

Finally I bow to almighty, who gave me strength to carry out this work with sincerity and dedication

(Newton)
Roll No 821022003

ABSTRACT

Continuous industrial development poses serious problems of construction and demolition waste disposal. Whereas on the one hand, there is critical shortage of natural aggregates (NA) for production of new concrete, on the other the enormous amounts of demolished concrete produced from deteriorated and obsolete structures creates severe ecological and environmental problem. One of the ways to solve this problem is to use this 'waste' concrete as aggregates. Such 'recycled' aggregate could also be a reliable alternative to using natural aggregates in concrete construction.

This research investigates the inter-relationships between aggregate properties and concrete properties. Three different types of cements alongwith four recycled coarse aggregate (RCA) replacement percentages (i.e., 0%, 30%, 60% and 90%) with water-cement ratio 0.42,0.45,0.48 & 0.51 are considered in this work. Based on the test results, the influences of both recycled coarse aggregate replacement percentages and water-cement ratio on the compressive strength were investigated. It is observed that a combination of PPC along with 90% replacement of aggregate with RCA will lead to the products of both economical, and sustainable mix.

CONTENTS

CONTENT	PAGE NO.
CERTIFICATE	i
ACKNOWLEDGEMENT	ii
ABSTRACT	iii
CONTENTS	iv-vii
LIST OF TABLES	viii-ix
LIST OF FIGURES	x-xii
CHAPTER-1 INTRODUCTION	
1.1 GENERAL	1-2
1.2 HISTORICAL BACKGROUND AND DEVELOPMENTS	2
1.3 APPLICATION OF RECYCLED AGGREGATE	3-4
1.4 PROSPECTS IN INDIA	4-5
1.5 RCA PRODUCTION PROCESS	6
1.5.1 Recycling plant	6
1.5.2 Sources of recycled aggregate	6
1.5.3 Equipments used during recycling process	6-7
1.5.4 Transportation	7
1.5.5 Crushing plant	7-9
1.5.6 Screening plant and washing plant	10-11
1.5.7 Stockpile	11
1.6 BARRIERS IN PROMOTING USE OF RECYCLED AGGREGATE CONCRETE	12-13
1.7 PHYSICAL PROPERTIES OF RECYCLED CONCRETE AGGREGATE	13
1.7.1 Surface texture and shape	13-14
1.7.2 Particle size distribution	14-15

1.7.3	Specific gravity	15
1.7.4	Water absorption	15
1.7.5	Bulk density	15
1.7.6	Crushing and impact values	15
1.8.	POINTS TO BE KEPT IN MIND WHILE USING RCA	17
1.8.1.	Absorption and surface moisture	17
1.8.2.	Adhered mortar content	17-18
1.9	OBJECTIVE OF RESEARCH	18
1.10	SCOPE OF WORK	18 -19
1.11	ORIENTATION OF THE THESIS	19
CHAPTER-2 LITERATURE REVIEW		
2.1	PROPERTIES OF RECYCLED CONCRETE AGGREGATE	20
2.1.1	General	20
2.2	EFFECT OF RCA ON FRESH PROPERTIES OF CONCRETE	21
2.2.1.	Initial slump	21
2.2.2	Workability	21-24
2.2.3.	Air content in fresh state	24-25
2.3	EFFECT OF RCA ON PROPERTIES OF CONCRETE IN HARDENED STATE	25
2.3.1	Tensile and flexural strength	25
2.3.2	Permeability	26
2.3.3.	Bond strength	26
2.3.4.	Creep and shrinkage	26
2.3.5.	Durability of hardened rac	26
2.3.6	Carbonation	26-27
2.3.7.	Freezing and thawing resistance	27
2.3.8	Compressive strength	28-31
2.4	EFFECT ON COMPRESSIVE STRENGTH USING STEEL SLAG AS PARTIAL REPLACEMENT OF NATURAL AGGREGATE	32-33

2.5	EFFECT ON COMPRESSIVE STRENGTH USING GROUND ASH AS PARTIAL REPLACEMENT OF NATURAL AGGREGATE	34-36
2.6	CLOSING REMARKS	36

CHAPTER-3 EXPERIMENTAL PROGRAMME

3.1	INTRODUCTION	37
3.2	EXPERIMENTAL DETAILS	37
3.3	MATERIAL PROPERTIES	37
3.3.1	Ordinary Portland cement (OPC)	38-39
3.3.2	Portland Pozzolonic cement (PPC)	40-41
3.3.3	Steel slag cement (SSC)	42-43
3.3.4	Coarse aggregates	42-43
3.3.5	Fine aggregates	43-44
3.3.6	Mixing water	44
3.3.7	Admixture	45
3.3.8	Recycled coarse aggregate	45-48
3.4	MIX DESIGN	48-49
3.5	TEST SET UP FOR SLUMP VALUE	50-51
3.6	CASTING OF SPECIMENS	51
3.6.1	Casting for compressive strength test	51-52
3.7	TESTING OF SPECIMENS	52
3.7.1	Test setup for compressive strength test	52-54
3.8	CLOSING REMARKS	54

CHAPTER-4 RESULTS AND DISCUSSIONS

4.1	INTRODUCTION	55
4.2	WORKABILITY	55
4.2.1	Effect of water cement ratio and RCA replacement ratio	55-58
4.2.2	Effect of cement type	58-60
4.3	COMPRESSIVE STRENGTH	60
4.3.1	Effect of recycled coarse aggregate on compressive strength using OPC	61-63
4.3.2	Effect of recycled coarse aggregate on compressive strength using PPC	64-66

4.3.3	Effect of recycled coarse aggregate on compressive strength using SSC	67-69
4.4	EFFECT OF RECYCLED COARSE AGGREGATE IN COMPRESSIVE STRENGTH USING DIFFERENT TYPE OF CEMENT	70
4.4.1	Effect of recycled coarse aggregate on increase/decrease in compressive strength using OPC&PPC	70-73
4.4.2	Effect of recycled coarse aggregate on increase / decrease in compressive strength using OPC & SSC	74-77
CHAPTER 5 CONCLUSIONS		
6.1	INTRODUCTION	78
6.2	MAIN CONCLUSION OF STUDY	78
REFERENCES		79-83

LIST OF TABLE

S.NO	TITLE	PAGE NO
1.1	Requirements of RCA specified in technical codes (Xiao et al. 2012)	16
1.2	Requirements for high quality RCA in <i>JIS 5021:2005</i>	16
2.1	Different Mix Proportions considered by Qasrawi (2013)	22
2.2	Different Mix Proportions considered by Henry , Pardo , Kato (2011)	24
2.3	Different Mix Proportions by Rahal (2007)	29
2.4	Different Compressive strengths by Rahal (2007)	30
2.5	Compressive strength of concrete by Radonjanin (2012)	34
2.6	Different mix proportions by Radonjanin(2012) for different admixtures	35
3.1	Physical Properties of OPC	38
3.2	Chemical properties of ordinary Portland cement	38
3.3	Compressive Strength of OPC (Grade-43)	39
3.4	Chemical composition of PPC	39
3.5	Physical properties of PPC	40
3.6	Compressive strength of PPC	40
3.7	Chemical composition of Slag Cement	41
3.8	Physical properties of Slag cement	41
3.9	Compressive strength of slag cement	41
3.10	Gradation of 20mm aggregates	42
3.11	Gradation of 10mm aggregates	43
3.12	Gradation of fine aggregates	44
3.13	Physical properties of fine aggregates	44
3.14	Technical data of admixture	45
3.15	Gradation of natural coarse aggregate	47
3.16	Gradation of recycled coarse aggregate	47

3.17	Physical properties of the recycled and natural coarse aggregate	48
3.18	Mix proportion for controlled sample	49
3.19	Mix proportion for mixes different replacements of NA and RCA	49
4.1	Dose of super plasticizer for mixes with different replacements and w/c ratio	56
4.2	Cube compressive strength 7 and 28 days using OPC	61
4.3	Cube compressive strength 7 and 28 days using PPC	64
4.4	Cube compressive strength 7 and 28 days using SSC	67
4.5	Increase / decrease in Cube compressive strength 7 and 28 days using OPC & PPC	71
4.6	Increase / decrease in Cube compressive strength 7 and 28 days using OPC & SSC	75

LIST OF FIGURE

FIGURE NO	TITLE	PAGE NO
1.1	Enterprise Park at Stapleton, Denver, United States <i>(Etkin-Johnson, 2012)</i>	4
1.2	Load into Primary Crusher (Source: Boral, 2002)	8
1.3	Electromagnetic Separation Process(Source: Boral, 2002)	9
1.4	Picking Shed (Source: Boral, 2002)	9
1.5	Wet Separation Process (Aquamator) (Source: Boral, 2002)	9
1.6	Screening Plant(Source: R. R. Equipment Company, 2003)	10
1.7	Washing Plant (Source: R. R. Equipment Company, 2003)	11
1.8	Recycling Portland Cement Concrete Flow Chart(Source: Recycling of Portland cement concrete)	11
1.9	Different types of RCA	14
2.1	Slump values for all mixes by HishamQasrawi (2013)	23
2.2	Trends of Air Content w.r.t RCA replacement ratio by HishamQasrawi (2013)	25
2.3	28 days compressive strength versus w/c ratio <i>(Rahal 2007)</i>	30
2.4	Compressive strength development from 7 to 91 days by Henry (2011)	31
2.5	compressive strength w.r.t RCA replacement ratio by Qasrawi(2013)	32
2.6	Density of concretes Radonjanin (2012)	34
2.7	compressive strength behavior by Radonjanin (2012)	36
3.1	Experimental details for compressive strength	37
3.2	(a) Waste concrete used for producing RCA	46
	(b) RCA obtained from the jaw crusher	46

3.3	Gradation curve of coarse aggregate	47
3.4	Slump flow test	51
3.5	Casting of cubes	52
3.6	Compressive Strength test chart	53
3.7	concrete cube specimens	53
3.8	Compressive strength test machine	54
3.9	Cube Samples under machine	54
4.1	Dose of superplasticizer w.r.t different w/c ratios and replacement ratios using OPC	57
4.2	Dose of superplasticizer w.r.t different w/c ratios and replacement ratios using PPC	57
4.3	Dose of superplasticizer w.r.t different w/c ratios and replacement ratios using SSC	58
4.4	Dose of superplasticizer for different types of cements w/c ratio 0.42	59
4.5	Dose of superplasticizer for different types of cements w/c ratio 0.45	59
4.6	Dose of superplasticizer for different types of cements w/c ratio 0.48	60
4.7	Dose of superplasticizer for different types of cements w/c ratio 0.51	60
4.8	Cube compressive strength 7 and 28 days using OPC with w/c ratio 0.42	62
4.9	Cube compressive strength 7 and 28 days using OPC with w/c ratio 0.45	62
4.10	Cube compressive strength 7 and 28 days using OPC with w/c ratio 0.48	63
4.11	Cube compressive strength 7 and 28 days using OPC with w/c ratio 0.51	63
4.12	Cube compressive strength 7 and 28 days using PPC with w/c ratio 0.42	65

4.13	Cube compressive strength 7 and 28 days using PPC with w/c ratio 0.45	65
4.14	Cube compressive strength 7 and 28 days using PPC with w/c ratio 0.48	66
4.15	Cube compressive strength 7 and 28 days using PPC with w/c ratio 0.51	66
4.16	Cube compressive strength 7 and 28 days using SSC with w/c ratio 0.42	68
4.17	Cube compressive strength 7 and 28 days using SSC with w/c ratio 0.45	68
4.18	Cube compressive strength 7 and 28 days using SSC with w/c ratio 0.48	69
4.19	Cube compressive strength 7 and 28 days using SSC with w/c ratio 0.51	69
4.20	Effect of recycled coarse aggregate on increase / decrease in compressive strength using OPC & PPC at w/c ratio 0.42	72
4.21	Effect of recycled coarse aggregate on increase / decrease in compressive strength using OPC & PPC at w/c ratio 0.45	72
4.22	Effect of recycled coarse aggregate on increase / decrease in compressive strength using OPC & PPC at w/c ratio 0.48	73
4.23	Effect of recycled coarse aggregate on increase / decrease in compressive strength using OPC & PPC at w/c ratio 0.51	73
4.24	Effect of recycled coarse aggregate on increase / decrease in compressive strength using OPC & SSC at w/c ratio 0.42	76
4.25	Effect of recycled coarse aggregate on increase / decrease in compressive strength using OPC & SSC at w/c ratio 0.45	76
4.26	Effect of recycled coarse aggregate on increase / decrease in compressive strength using OPC & SSC at w/c ratio 0.48	77
4.27	Effect of recycled coarse aggregate on increase / decrease in compressive strength using OPC & SSC at w/c ratio 0.51	77

CHAPTER-1

INTRODUCTION

1.1 GENERAL

Concrete is most widely used construction material in the world and also one of the most important materials employed in public works and building construction projects. Concrete is used since so many decades. It means that we have utilized a tremendous amount of concrete and also will have to continue to use it. As Concrete is the world's most widely used construction material, but at the same time, it is not an environmentally friendly material because it destroys and uses up large quantities of natural resources and it is also a source of environmental impact because after its use, it is generally deposited in landfills.

The basic ingredients of the concrete are cement, fine and coarse aggregates and water. Aggregate is a broad category of coarse material used in construction, including sand, gravel, crushed stone, slag, recycled concrete and geosynthetic aggregates. Aggregates are the most mined materials in the world. Fine and coarse aggregates are naturally occurring resources, which results that these resources are depleting at a very high rate. Growing awareness on protection of environment and conservation of natural resources, together with this the problem of waste disposal, especially, the demolition rubble has become a major concern for planners and engineers, environmentalists results in making efforts to use the waste produced from the demolition of various structures as a substitute of natural aggregates. Researchers has suggested the possibility of appropriately treating and reusing concrete as aggregate in new concrete, especially in lower level applications.

To make this feasible, a significant amount of experimental works have been carried out worldwide. Previous investigations were mainly engaged in the processing of demolished concrete, the mixture design, and the physical and mechanical properties as well as the durability improvements.

Although there is growing emphasis on the use of recycled coarse aggregate for making new concrete in the West and far Eastern countries like Japan and Korea, there is relatively little awareness of the potential application of such aggregates in India. Moreover after China, India is the leading consumer of cement in the world, which by implication means that India is also one of the leading consumers of concrete-making materials like fine and coarse aggregate. Since aggregate sources are not inexhaustible, it is imperative to create awareness about the potential use of recycled coarse aggregate in the manufacture of concrete in India.

1.2 HISTORICAL BACKGROUND AND DEVELOPMENTS

The recycling of demolished rubble dates back to as early as Second World War. The extensive and large scale bombardment of cities during the Second World War left huge amount of building rubble and military fortifications in most of the European countries. With the shattered economy, acute transportation problem and no equipment to work in aggregate quarries, the problem of reconstruction posed a big challenge. Further the disposal of huge amount of demolition waste was another serious problem. As a consequence to these twin problems of reconstruction and disposal, the idea of reusing demolished concrete and building rubble as an alternative aggregate for concrete was first conceived in the year 1976. Consequent to this Kishore, Revande (1998), number of European countries notably Germany, England and the Netherlands made systematic attempts to reuse demolition material in the pavements. If natural aggregates are not available than recycled aggregates generated from construction and demolished waste is a good alternative. For example in U.S.A. alone, the quantity of demolition waste generated during 1970's was of the order of 27 million tones a year and concrete amounts for nearly 75% of this quantity. The state of art reports indicate that the quantity of concrete discarded every year has reached staggering figures of about 50 to 65 million tones in the United states, 50 to 60 million tones in the European economic communities, 10 to 12 million tones in Japan and 12 to 15 million tons in France.

Research reports indicate positive and encouraging results advocating utilization of recycled aggregate for construction purposes, especially for concrete blocks, tiles, floorings, low rise buildings, retaining walls, sewerage structures, sub base course of pavement, etc.

1.3 APPLICATION OF RECYCLED AGGREGATE

Utilizations of recycled constructions material in the form of aggregate is widely accepted for pavements, base and sub-base course and to some extent for foundation purpose, Since 1976 a number of full scale pavement rehabilitation projects have been successfully completed in U.S.A. by using this recycling technology.

The first successful use of recycled aggregate for production of new concrete was in Iowa in 1976. A 41-year old concrete pavement was crushed and used as aggregate in production of concrete for a new one mile long and 22.5 cm thick highway pavement. In another project in Iowa, in 1978, crushed old concrete was used as aggregate for production of a new 17 miles (27.2 km) long and 20 cm thick highway pavement. In 1980, the Minhesota Department of Transportation recycled a 16 miles (25.6km) long plain concrete pavement into a new concrete pavement on a trunk highway. Reconstruction of 8.5 miles (14km) of Detroists John C. lodge free way by using this recycling technology has been reported in 1988.

In the Netherlands, recycled aggregate concrete has been used for partition wall in an apartment building. Some countries have already come up with code of practice on recycled aggregate and recycled aggregate concrete for construction purpose.

The new J-Cube Capital Mall in Singapore (completed in 2011) (www.ies.org.sg). is an example of the use of recycled coarse aggregate concrete in a structural application. Built on the site of the demolished Jurong Entertainment Centre, the new mall utilized the reclaimed concrete as aggregate in 50% of the new concrete structural elements that comprise the superstructure.

A case study from North America was the demolition of the former Stapleton Airport in Denver, Colorado in which 2.1 million kilograms (2100 tonnes) of recycled concrete were utilized from old runway, office and warehouse structures in the construction of the New Enterprise Park at Stapleton. In total, 4300 m³ of recycled concrete incorporating approximately 1400 tonnes of RCA was used in the construction of the tilt up wall panels, making it the largest application of recycled concrete in a tilt-up application (Etkin-Johnson, 2012).as shown in Fig 1.1



Fig 1.1 Enterprise Park at Stapleton, Denver, United States
(Etkin-Johnson, 2012)

1.4 PROSPECTS IN INDIA

There is severe shortage of infrastructural facilities like houses, hospitals, roads etc. in India and large quantities of construction material for creating these facilities are needed. The Planning Commission allocated approximately 50% of capital outlay for infrastructure development in successive 10th and 11th five year plans. Rapid infrastructural development such highway, airports, etc. and growing demands for housing has led to scarcity and rise in cost of construction materials. Most of waste materials produced by demolished structures disposed off by dumping them as landfill. Dumping of wastes on land is causing shortage of dumping places in urban areas. Therefore it is necessary to start recycling the re-use of demolition concrete waste to save environment, cost and energy.

Central Pollution Control Board, Delhi has estimates current quantum of solid waste generation in India to the tune of 48 million tons per annum out of which, waste from construction industry accounts for more than 25%. Managing of such high quantum of waste puts enormous pressure on solid waste management system. The total quantum of waste from construction industry is estimated to be 12 to 14.7 million tons per annum out

of which 7-8 million tons are concrete and brick waste. According to findings of survey 70% of the responded has given the reason for not adopting recycling of waste from construction Industry is "Not aware of recycling techniques" while the remaining 30% have indicated that they are not even aware of recycling possibilities by TIFAC (2001).

The problems in India are not as alarming as in the West; however it would not be very far off, as India too seriously think of reusing demolished rubble and concrete for production of recycled construction material, especially, in the form of aggregate. There are some parts in Northern India, especially, in the Gangetic basin, where crushed stone aggregate are not available within several kilometers of radius Kishore, Revande (1998). Further, the volume of concrete construction is expected to increase manifold in the coming decades and simultaneously there would be several structures in urban areas which have outlined their existence and need their replacement with the new ones. Conservation of natural resources in order to keep ecological balance is the need of the hour for India too.

Demolished rubble obtained from various structures is predominantly made of concrete. It has foreign mater such as various types of finishes, cladding material, lumber, dirt, steel, hardware, wood, plastic etc., attached to them directly or indirectly. These foreign mattes in the demolition rubble are impurities and it is necessary to remove them to obtain final recycled aggregate free from foreign material.

IL&FS Eco smart has planned a comprehensive project comprising of efficient collection and appropriate re-use / disposal of about 500 tons of C&D Debris per day. A comprehensive MSW (municipal solid waste) Management Program has been developed for MCD (Municipal Corporation of Delhi) which would take care of debris through disposal and reuse. This would improve the situation in Delhi at No Additional Cost to MCD of practical utilization of recycled aggregate have been reported so far. However, the prospects of utilizing recycled aggregate are quite bright and the next few years we will see remarkable contribution using recycled aggregate and technology in the Construction sector.

1.5 RCA PRODUCTION PROCESS

Once a concrete structure has been demolished, large amount of concrete remain as waste material. The production of recycled coarse aggregate from the demolished concrete debris involves several steps the same are discussed in following paragraphs:

1.5.1 Recycling Plant

Recycling plant normally located in the suburbs of cities due to the noise pollution that make by the equipments that used during recycling process. According to Aggregate and Quarry (n.d.), all the machinery used have to fit with the effective mufflers to reduce the noise from the processing activity.

1.5.2 Sources of Recycled Aggregate

Traditionally, recycled aggregate are mainly produced from the crushing of Portland concrete pavement and structures building

1.5.3 Equipments used during Recycling Process

The equipments that used during recycling process are various from the site conditions and also country to country. There are few different types of equipment had been used effectively to break up the Portland cement pavement and structural building.

The equipments are as below:

- (1) ***Diesel pile – driving hammer.*** It is mounting on a motor grader that sticks in the Portland cement pavement on around 30cm grid pattern.
- (2) ***Rhino – horn – tooth – ripper – equipped hydraulic excavator.*** It is used to remove all the steel reinforcement that remaining in the Portland cement pavement.

Structural Building

1. ***Mechanical by hydraulic crusher with long boom arm.*** The concrete and steel reinforcements are broken by the crusher through the long boom arm system. This method is suitable for the dangerous buildings.
2. ***Wrecking ball.*** The building is demolished by the impact energy of the wrecking ball which suspended from the crawler crane.

3. **Implosion.** A design included pre – weakening of the structure, the placement of the explosives and the building collapse in a safe manner have to develop.

1.5.4 Transportation

After the structural buildings and Portland cement pavements are demolished, the concrete debris has to send to the recycling plants for processing. Construction and Demolition Waste Recycling Information mentioned that it is good to use the roll off containers or large dump body trailers to transport the mixed load of construction and demolition debris. This is the most effective and cost effective means of the transportation. It also mentioned that the construction and demolition debris can be transport by the closed box trailers and covered containers.

1.5.5 Crushing Plant

Crushing is the initial process of producing the construction and demolition debris into recycled aggregate. The concrete debris is crushed into pieces in this process. Aggregate and Quarry (2001) stated that generally the equipments used for crushing process are either jaw or impacted mill crushers. It also stated that all the recycling crushers have a special protection for conveyor belts to prevent damage by the reinforcement steel that in the concrete debris. They are fitted with the magnetic conveyors to remove all the scrap metal.

According to Recycling of Portland Cement Concrete , the equipments used to crush and size the existing concrete have to include the jaw and cone crushers. The concrete debris will break down to around 3 inches by the primary jaw crusher. It also mentioned that the secondary cone crushers will breaks the materials to the maximum size required which vary between $\frac{3}{4}$ and 2 inches.



Figure 1.2: Load into Primary Crusher

(Source: Boral, 2002)

During the crushing process, all the reinforcing steels have to remove away. Professor S L Bakoss and Dr R Sri Ravindarajah (1999) stated that there are three methods of sorting and cleaning the recycled aggregate, which are electromagnetic separation, dry separation and wet separation. Electromagnetic separation process is removal of reinforcing steel by the magnet that fitted across the conveyor belt in the primary and secondary crushers. Dry separation process is removing the lighter particles from the heavier stony materials by blowing air. This method always causes lot of dust. Wet separation process is the aquamator, which the low density contaminants are removed by the water jets and float – sink tank, and this will produces very clean aggregate.

According to COST 337 Unbound Granular Materials for Road Pavements, the wood pieces that contained in the concrete debris can be removed by hand – picking from a special platform over the discharge conveyor.

After finish the crushing process, the materials are then sent to the screening plant.



Figure 1.3: Electromagnetic Separation Process
(Source: Boral, 2002)



Figure 1.4: Picking Shed
(Source: Boral, 2002)



Figure 1.5: Wet Separation Process (Aquamator)
(Source: Boral, 2002)

1.5.6 Screening Plant and Washing Plant

Screening is the process that separates the various sizes of recycled aggregate. The screening plant is made of a series of large sieves separates the materials into the size required.

Recycling of Portland Cement Concrete stated that the size of screen that used to separate the coarse recycled concrete aggregate and fine recycled aggregate is 3/8 inch. The size of screen used to separate the coarse recycled aggregate can be under or over 3/4 inches. It also stated that one more screen should be used to separate those particles that more than the specified size.

After the screening process, the recycled are then sent to the washing plant. COST 337 Unbound Granular Materials for Road Pavements stated that the recycled aggregate that produced have to be very clean when using in the high quality product situation.



Figure 1.6: Screening Plant
(Source: R. R. Equipment Company, 2003)



Figure 1.7: Washing Plant
 (Source: R. R. Equipment Company, 2003)

1.5.7 Stockpile

After all the recycling process, recycled aggregate are stored in the stockpile and ready to use. All the recycled aggregate are stored according to the different size of aggregate. According to Recycling of Portland Cement Concrete (n.d.), the stockpile has to prevent from the contamination of foreign materials. It also mentioned that the vehicles used for stockpiling have to be kept clean of foreign materials.

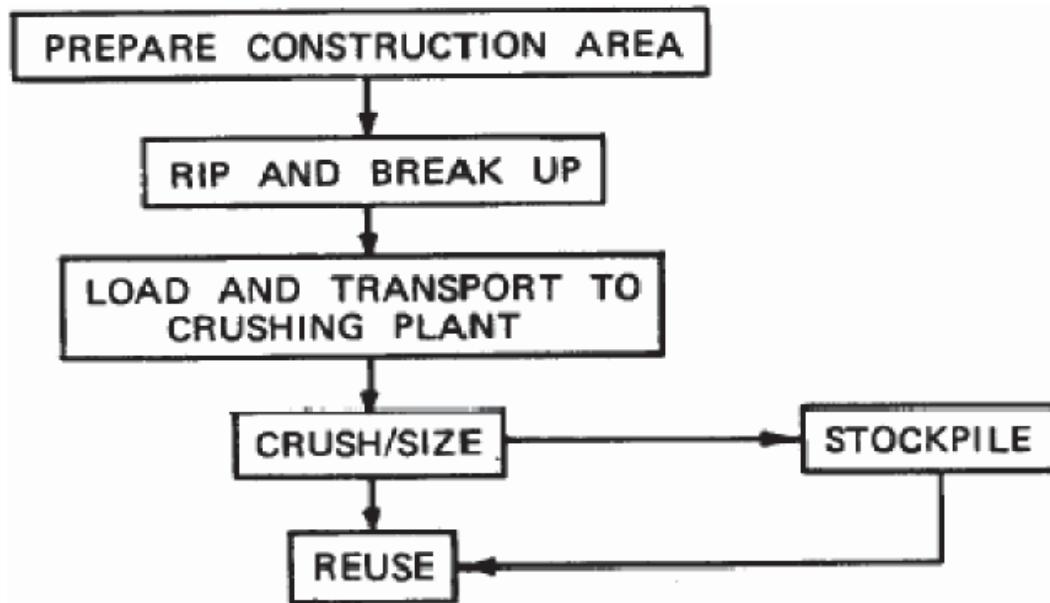


Figure 1.8: Recycling Portland Cement Concrete Flow Chart
 (Source: Recycling of Portland cement concrete)

1.6 BARRIERS IN PROMOTING USE OF RECYCLED AGGREGATE CONCRETE

Acceptability of recycled material is hampered due to a poor image associated with recycling activity, and lack of confidence in a finished product made from recycled material. Cost of disposal of waste from construction industry to landfill has a direct bearing on recycling operations. Low dumping costs in developing countries also acts as a barrier to recycling activities. Imposition of charge on sanitary landfill can induce builders and owners to divert the waste for recycling. Some of these issues act as barriers in promoting more widespread use of recycled aggregate and concrete made with recycled aggregate.

Lack of appropriately located recycling facilities

Construction and demolition waste is generated in small quantities at locations which could be widely separated. Therefore, portable equipment is needed, which can be used and set up close to a demolition site. Transporting waste over large distances makes the proposition of using C&D waste uneconomical. Lack of such plants is a major barrier for 'Newcomers' in the field of C&D waste management. Commissioning of appropriately located recycling crusher units in a pilot plant can help in lowering barriers against recycling of construction & demolition waste.

Absence of appropriate technology

There are very few commercially viable technologies for recycling construction and demolition wastes, and methods that can be used to crush C&D waste on a commercial scale are urgently required. In fact, when the technology is established, other issues such as quality control of raw material and finished product, etc. can be taken up.

Lack of awareness

Lack of awareness towards recycling possibilities and environmental implications of using only fresh mined aggregates are the main barriers due to which C&D waste is disposed only in landfills. Creating awareness and dissemination of information relating

to the above barriers and the properties of concrete made with recycled aggregate are essential to mobilize public opinion and instill confidence in favour of the recycling option. There is a need to create a market for recycled products by involving the construction industry and encouraging them to use recycled materials in projects.

Lack of government support

A lack of government support and commitment towards development of recycling industry is often seen. Developing appropriate policy supported by proper regulatory framework can provide necessary impetus. It will also help in data compilation, documentation and control over disposal of waste material.

Lack of proper standards

Apart from the specifications of RILEM (RILEM, 1994), JIS and those used in Hong Kong, only very limited codal specifications/standards regarding use of recycled aggregates are available. In fact, use of concrete with 100% recycled coarse aggregate for lower grade applications is allowed in Hong Kong, though for higher grade applications (above M35 concrete), only 20% replacement is allowed, and the concrete can be used for general applications, except in water retaining structures. In Japan, JIS has drafted a Technical Report, TRA 0006 “Recycled Concrete Using Recycled Aggregate” to promote the use of concrete made with recycled aggregate. Development of relevant standards for recycled materials would provide producers with targets and users an assurance of quality of material. Standards formulated in the above mentioned countries can be a guideline for development of specifications.

1.7 PHYSICAL PROPERTIES OF RECYCLED CONCRETE AGGREGATE

1.7.1 Surface texture and Shape

Recycled Concrete Aggregates have an irregular and granular structure (different types as shown in Fig 1.16) ,due to the adhered mortar which can be a point of concern as it is a factor which contributes toward higher water absorption, workability and ultimately the strength characteristics of the concrete made using RCA. The structure of RCA mainly

depends upon the parent source of concrete rubble. RCA from poorly compacted concrete are of irregular shape and the adhered mortar is not dense and thus exhibits weak bond between the mortar and the aggregate. While aggregates derived from concrete cubes yields aggregates with irregular shape and better bond between mortar and aggregate.

Aggregate particle shape and surface texture.







Aggregate type	Particle shape classification	Surface texture classification
Natural	Rounded/irregular – shaped by a combination of attrition and crushing 	Smooth/rough – combination of river stone and crushed gravel 
RCA-1	Angular/irregular – shows fairly well-defined edges at the intersection of plane surfaces 	Rough – noticeable roughened fracture surfaces resembling crushed limestone 
RCA-2	Irregular – resembles crusher run gravel but with a large amount of adhered mortar. Particles are not angular like the RCA-1 	Granular – due to large amount of adhered mortar, more brittle surface, loose adhered rounded mortar particles 

Fig 1.9 Different types of RCA

1.7.2 Particle Size Distribution

Sieve analysis is carried out as per IS 2386 for crushed recycled concrete aggregates and natural aggregates. Recycled coarse aggregates are reduced to various sizes during the process of crushing and sieving, which gives the best particle size distribution. The amounts of fine particles less than 4.75mm after recycling of demolished waste can be in the order of 5-20% depending upon the original grade of demolished concrete. The best quality natural aggregate can be obtained by primary, secondary and tertiary crushing,

whereas the same can be obtained after primary & secondary crushing in case of recycled aggregate. The single crushing process is also effective in the case of recycled aggregate.

1.7.3 Specific Gravity

The specific gravity in saturated surface dry condition of recycled concrete aggregate varies from **2.35 to 2.58** which are less but satisfying the results. If specific gravity is less than 2.4, it may cause segregation, honey combing also yield of concrete may get reduced.

1.7.4 Water Absorption

The RCA from demolished concrete consist of crushed stone aggregate with old mortar adhering to it, the water absorption ranges from **1.5% to 7.0%**, which is relatively higher than that of the natural aggregates.

1.7.5 Bulk Density

The bulk density of recycled aggregate is generally lower than that of natural aggregate due to less Bulk Density the mix proportion gets affected. The bulk density of recycled coarse aggregate is about 1290–1470 kg/m³. The SSD density of recycled coarse aggregate is about 2310–2620 kg/m³. [*Xu and Shi(2006), Xiao, (2008)*]:

1.7.6 Crushing and Impact Values

The recycled aggregate is relatively weaker than the natural aggregate against different mechanical actions. As per IS 2386 part (IV), the crushing and impact values for concrete wearing surfaces should not exceed 30% & for other than wearing surfaces 45% respectively. The crushing and impact values of recycled aggregate satisfy the BIS specifications limit. From crushing & impact test it is found that use of recycled aggregate is possible for application other than wearing surfaces.

Different requirements for RCA specified by xiao, 2012 is as given in table 1.1 and specifications w.r.t *JIS 5021:2005* are given in table 1.2

Table 1.1: Requirements for RCA specified in Technical Codes (Xiao et al. 2012)

Items	DG/TJ08-2018-2007		RILEM			BS8500	JIS TRA0006
	Type I(Structural use)	Type II	Type I	Type II	Type III		
SSD density (kg/m ³)	>2400	>2200	>1500	>2000	>2400	—	—
Absorption (%)	<7	<10	<20	<10	<3	—	<7
Masonry content (%)	<5	<10	—	—	—	<5	—
Crushing value (%)	<30	—	—	—	—	—	—
Soundness (mass loss %)	<18	—	—	—	—	—	—
Flakiness index (%)	<15	—	—	—	—	—	—
Clay content (%)	<4	—	—	—	—	—	—
Sulphate content (%)	<1.0	—	<1	<1	<1	<1	—
Chlorides content (%)	<0.25	—	—	—	—	—	—
Organic material (%)	<0.5	—	<1	<0.5	<0.5	—	—
Fine particle (%)	—	—	<3	<2	<2	<5	<2
Material with SSD<2200 kg/m ³	—	—	—	<10	<10	—	—
Material with SSD<1800 kg/m ³	—	—	<10	<1	<1	—	—
Material with SSD<1000 kg/m ³	—	—	<1	<0.5	<0.5	<0.5	—
Impurity content (%) (metal, glass, plastics, asphalt and wood)	<1	—	<5	<1	<1	<1	—
Asphalt content (%)	—	—	—	—	—	<5	—
Metal content (%)	—	—	<1	<1	<1	—	—
Sand content (<4 mm) (%)	—	—	<5	<5	<5	—	—

Table 1.2: Requirements for high quality RCA in JIS 5021:2005

Items	Coarse aggregate	Fine aggregate
Oven-dry density, g/cm ³	not less than 2.5	not less than 2.5
Water absorption, %	not more than 3.0	not more than 3.0
Abrasion, %	not more than 35	NA
Solid volume percentage for shape determination	% not less than 55	not less than 53
Amount of material passing test sieve 75 µm,	% not more than 1.0	not more than 7.0
Chloride ion content	not more than 0.04	

The particle shape analysis of recycled aggregate indicates similar particle shape of natural aggregate obtained from crushed rock. The recycled aggregate generally meets all the standard requirements of aggregate used in concrete.

1.8. POINTS TO BE KEPT IN MIND WHILE USING RCA

Although, RCA are normally used as direct replacement of coarse aggregate, however, certain points must be kept in mind while using recycled coarse aggregate in concrete.

1.8.1. Absorption and Surface Moisture

Aggregates are porous materials and water can be absorbed onto the body of the aggregates. The absorption capacity is generally defined as the total amount of water required to bring the aggregate to a saturated surface dry (SSD) condition. Aggregates may exist in various moisture states: oven dry, air-dry, saturated surface dry, or moist state.

Only free water is available for mixing in concrete and it is this moisture which contributes to the water cement ratio. It is the size and number of internal pores that are responsible for absorption of water in aggregate and it is seen that recycled coarse aggregates have a higher water requirement than natural aggregates due to the higher water absorption value of adhered mortar. The rate of absorption also plays a significant role in concrete mix proportioning including recycled coarse aggregates. In general, recycled coarse aggregates take longer time to absorb moisture than natural aggregates and, as a result, it may not reach full saturation during the mixing period. Therefore, it has been recommended to pre-soak the recycled coarse aggregates to compensate for the slower absorption rate.

1.8.2. Adhered Mortar Content

After crushing of concrete, the resultant recycled coarse aggregate concrete contains both natural stone and old mortar. This old adhered mortar can account for, about 25 to 60 percent by volume of the aggregate itself. It was noted that the finer the aggregate, the more the adhered mortar content. The residual mortar content can have negative impacts also on such concrete properties as absorption, density, abrasion resistance etc. The amount of residual mortar present on recycled coarse aggregate depends largely on the crushing process by which the aggregates are produced. As the number of crushing of the aggregates increases, the amount of adhered mortar is reduced. It was also observed that use of impact crusher produces higher percentage of recycled coarse aggregate with less amount of residual mortar and it is also suggests that the adhered mortar in recycled

coarse aggregate give lower strength than the fresh mortar produced in new concrete. As a result, it is concluded that the adhered mortar in recycled coarse aggregates is the weakest point in concrete produced with coarse recycled coarse aggregates. To obtain good quality concrete using recycled aggregate it is necessary to follow some minimum requirements. The adhered mortar is a porous material. Its porosity depends upon the w/c ratio of the recycled concrete employed. The crushing procedure and the dimension of the recycled aggregate have an influence on the amount of adhered mortar. The density and absorption capacity of recycled aggregates are affected by adhered mortar and they must be known prior to the utilization of recycled aggregates in concrete production in order to control properties of fresh and hardened concrete. The absorption capacity is one of the most significant properties which distinguish recycled aggregate from raw aggregates, and it can have an influence both on fresh and hardened concrete properties. [Etxeberria et al., 2007]

1.9 OBJECTIVE OF RESEARCH

The objective of the work is to explore the possibility and effect of replacement of natural aggregate with recycled concrete aggregate in concrete, therefore to conserve natural resources in order to keep ecological balance and to fulfill present demand of construction material in infrastructure development sector which is increasing at an alarming rate. Use of recycled concrete aggregate as a part replacement of natural aggregate in concrete will enhance the utility of waste material and at the same time minimize the demand for natural aggregates. Further, the effect of type type on cement properties of RCA is explored.

1.10 SCOPE OF WORK

The scope of the work is to prepare the concrete by using different type of cement with replacing the natural aggregate with recycled concrete aggregates by (0%, 30%, 60% and 90%). The compressive strength of concrete after 7 days and 28 days and workability are compared for recycled concrete aggregate concrete and natural aggregate concrete.

- Collection of C&D debris to procure graded aggregates
- Design of concrete with recycled and naturally available aggregates.
- Compressive strength test of 7 days and 28 days specimens.

- Comparison of strength and workability for natural aggregate concrete and recycled concrete aggregate concrete.

1.11 ORIENTATION OF THE THESIS

The entire thesis has been divided into five chapters:

Chapter 1 Deals with the introduction of recycled aggregate and its production processes and utilization parameters . The reason for the use of recycled aggregate instead of natural aggregate is also discussed in this chapter.

Chapter 2 Presents the literature review of previous studies on Recycled aggregate concrete.

Chapter 3 Deals with the experimental programme.

Chapter 4 Deals with the results and discussions.

Chapter 5 Deals with the conclusions and recommendations drawn from this study.

References

CHAPTER 2

LITERATURE REVIEW

2.1 PROPERTIES OF RECYCLED CONCRETE AGGREGATE

2.1.1 General

Recycled aggregate concrete has been studied since the late 1970s, but its use for structural application only recently gained new attention for the increased appreciation by the community for sustainable development and safeguarding the natural environment. The use of RAC is allowed in many European countries as well as in Japan and in the US. Other countries are pushing to allow or to increase the structural use of RAC. Concrete mixes using recycled aggregate can be designed in much the same way as those using natural aggregate, provided the extra absorption in the former is appropriately accounted for when determining the unit water content. The recommendations of the RILEM committee for proportioning of recycled aggregate concrete are given below:

- When designing a concrete mix using recycled aggregate of variable quality, a higher standard deviation should be employed in order to determine a target mean strength based on a required characteristic strength.
- When coarse recycled aggregate is used with natural sand, it may be assumed at the design stage, that the free w/c ratio required for a certain compressive strength will be the same for recycled aggregate as for conventional concrete.
- For a recycled aggregate mix to achieve the same slump, the free water content will be approximately 5% more than for conventional concrete.
- The sand-to-aggregate ratio for recycled aggregate concrete is the same as when using natural aggregate.
- Trial mixes are mandatory and appropriate adjustments depending upon the source and properties of the recycled aggregate should be made to obtain the required workability, suitable w/c ratio, and required strength, of recycled aggregate concrete.

2.2. EFFECT OF RCA ON FRESH PROPERTIES OF CONCRETE

Some of the required fresh properties of fresh concrete are workability characteristics of concrete, which include slump, loss of slump and bleeding. All these aspects are discussed in the following section.

2.2.1. Initial slump

Neville (1995) pointed out that various mixing conditions such as w/c, water-reducing admixture ratio, and grading and volume of recycled aggregates would control the initial slump of recycled aggregate concrete.

Aggregate type: *Yang et al.(2008)* graded the aggregate as per KS14 and found that the initial slump of fresh concrete slightly decreased with the increase of the replacement level of recycled aggregates but was hardly affected by their type.

Poon et al. (2007) observed that the initial slump slightly increased with the increase of the replacement level of recycled coarse aggregates used in a saturated surface dry state.

Water volume: *Poon et al.(2004)* studied the moisture condition of the aggregate on initial slump showed that the initial slump of recycled aggregate concrete was significantly affected by the moisture condition of aggregates.

Water in aggregate: *Lin et al.(2004)* concluded that the initial slump of recycled aggregate concrete was mainly affected by w/c and volume ratio of recycled coarse aggregate rather than the type of recycled aggregates. In addition, particle distribution and shape of aggregates would also have an influence on the initial slump of fresh concrete.

2.2.2 Workability

The workability of RAC for the same water content in the concrete is lower as reported by many researchers, especially when the replacement levels exceed 50% (Topcu and Sengel,2004). In order to improve the workability, certain measures in the direction of changing the moisture condition of the RA, have been suggested (Oliveira et al., 1996; Poon et al., 2002,2004). In another study several concrete mixes were prepared with varying methods of recycled coarse aggregate preparation, in terms of saturation. It was found that, extra water corresponding to absorption of the aggregate mixed during

concrete preparation produced the most consistent results as far as workability is concerned (Rao, 2005).

The air content of the RAC is slightly higher (~4% to ~5.5%) than concrete made with natural aggregate (Katz, 2003) at 100% replacement. This increased air content could be attributed to the higher porosity of the RA. The bulk density of fresh concrete made with natural aggregates is in the range of ~2400 kg/m³, whereas the concrete made with recycled aggregates is significantly lighter, ~2150 kg/m³, regardless of the type of cement (Topcu and Guncan, 1995; Katz, 2003). The lower density is the result of the specific gravity of the aggregates, which is related to the type of concrete used for producing the aggregate. In addition, increased air content in the recycled concrete, leads to an additional reduction in the density of the fresh concrete.

Qasrawi et al. (2013) conducted an experimental study for innovative use of Steel slag, the by-product of steel and iron producing processes along with varying percentages of RCA. The mix proportions used are shown in table 2.1.

Table 2.1 Different Mix Proportions considered by Qasrawi (2013)

Mix proportions.						
Replacement ratio (by volume of CA)	Cement (kg/m ³)	Water (kg/m ³)	Coarse aggregate (kg/m ³)	Fine aggregate (kg/m ³)	RCA (kg/m ³)	SSA (kg/m ³)
<i>w/c = 0.65</i>						
0	303	197	985	775	0	0
25	303	197	740	775	218	305
50	303	197	495	775	436	610
75	303	197	245	775	654	915
100	303	197	0	775	873	1221
<i>w/c = 0.55</i>						
0	358	197	985	740	0	0
25	358	197	740	740	218	305
50	358	197	495	740	436	610
75	358	197	245	740	654	915
100	358	197	0	740	873	1221
<i>w/c = 0.45</i>						
0	438	197	985	675	0	0
25	438	197	740	675	218	305
50	438	197	495	675	436	610
75	438	197	245	675	654	915
100	438	197	0	675	873	1221

Qasrawi (2013) concluded the relationship between the percentage of the coarse aggregate replaced by RCA or SSA and the percentage of the original slump for all mixes

as shown in Fig 2.1. The workability of concrete reduces by the increase in the RCA or SSA content. The reduction is more significant in the lower w/c ratios. This can be attributed to the increase in water demand which is difficult to predict. The use of slag as 67%-partial replacement of RCA did not have any enhancement on the workability of concrete. The reduction in workability is attributed to the fact that slag aggregate particles are angular resulting in reduction of the mobility of concrete.

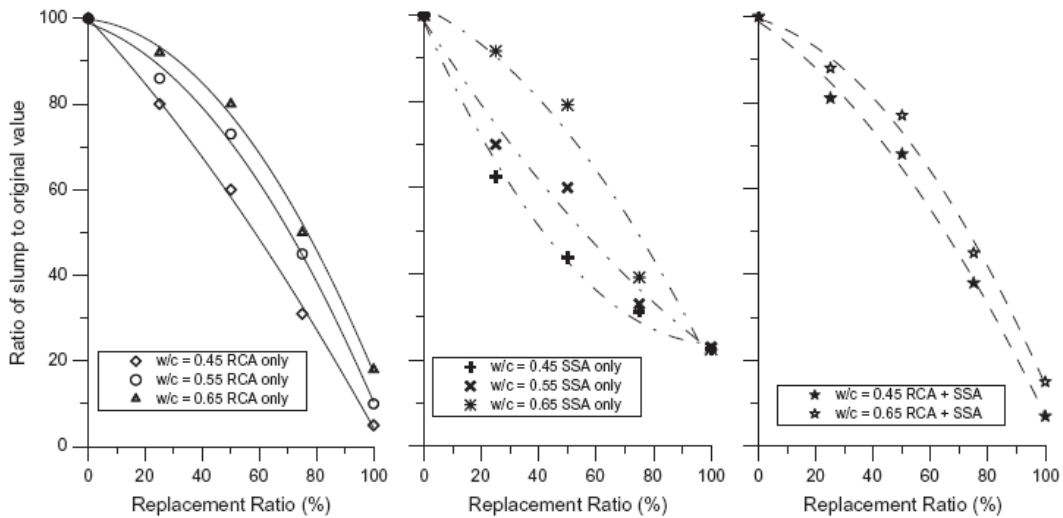


Fig 2.1 Slump values for all mixes by Hisham Qasrawi (2013)

Michael Henry, German Pardo, Tsugio Nishimura and Yoshitaka Kato et al (2011) used different low-grade recycled aggregates with different water binder ratios and analysed different properties. Concrete mix proportions and fresh concrete properties are given in Table 2.2. Three different water–binder ratios (0.3, 0.375, and 0.45), two different binder combinations (C50%-FA50% and C50%- FA25%-BS25%), and three different recycled aggregate replacement ratios (0%, 50%, and 100%) were selected for this experimental investigation. The mixing water content was also reduced from the standard 170 kg/m³ to 135 kg/m³ to reduce binder content. The 50% replacement of cement with mineral admixtures and decreased binder content conditions were set for all mix proportions based upon previous experiments which investigated the balance between mechanical and environmental performance considering binder composition and content (Pardo et al. 2010). A control concrete with a water–binder ratio of 0.5 and no waste or recycled materials was also prepared to serve as a reference for normal-use concrete.

Table 2.2 Different Mix Proportions considered by Henry , Pardo , Kato (2011)

Mix proportions and fresh properties.

Series	(kg/m ³)							Slump (cm)	Air (%)
	W	C	FA	BS	S	NA	RA		
Control	171	342	-	-	746	1015	-	11.0	4.0
WB30-RA0	135	225	225	-	659	1067	-	15.0	2.0
WB30-RA50						533	478	13.5	6.0
WB30-RA100						-	957	16.0	4.0
WB375-RA0		180	180	-	721	1095	-	6.5	4.7
WB375-RA50						548	491	12.0	5.5
WB375-RA100						-	982	9.0	4.5
WB45-RA0		150	150	-	772	1114	-	7.5	4.5
WB45-RA50						557	500	9.5	3.7
WB45-RA100						-	999	12.0	5.6
WB45-BS-RA0			75	75	788	1125	-	7.5	5.6
WB45-BS-RA50						563	506	7.5	3.5
WB45-BS-RA100						-	1011	5.5	4.0

2.2.3. Air content in fresh state

Qasrawi et al.(2013) concluded the results of the air content for the various types of mixes. Generally, the air content increased when RCA or SSA was introduced. It has been observed that up to 25% replacement, the increase in air content is marginal and close to the expected value of ACI 211.1 for maximum size of aggregate of 20 mm. For the higher percentage replacements, the air content was 1.5–2 times the expected value. The increase in air content in RAC can be attributed to the mortar adhered to the aggregate. The increase in air content in SSA may be attributed to difficulties in compaction due to the higher angularity of the aggregate when compared to natural aggregate. Mixes containing both RAC and SSA, showed similar trend as shown in fig 2.2.

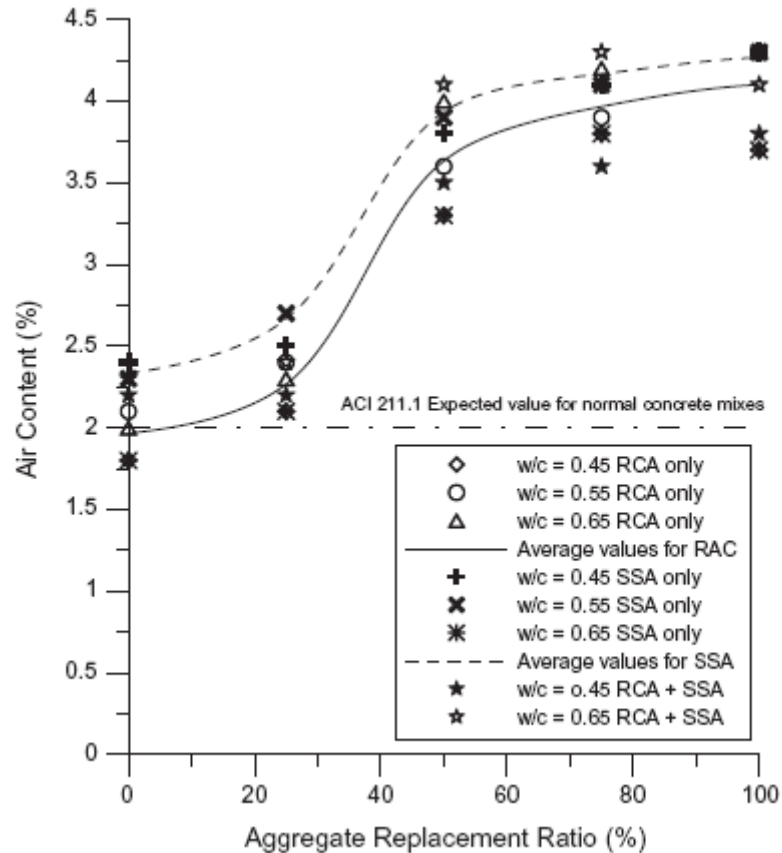


Fig 2.2 Trends of Air Content w.r.t RCA replacement ratio by Hisham Qasrawi (2013)

2.3. EFFECT OF RCA ON PROPERTIES OF CONCRETE IN HARDENED STATE

2.3.1. Tensile and flexural strength

The ratio of the flexural and the splitting strengths to the compressive strength is in the range of 16–23% and 9–13%, respectively (Katz, 2003). These values are about 10–15% lower compared to the recommendations of ACI 363R. A study by Rao, shows a reduction in strength of 15–20% compared to reference concrete at 100% replacement (Rao, 2005). In another study, where the direct tensile strength of concrete was determined, it was found that difference in the tensile strength of RAC and reference concrete at 28 days was less than 10% (Ajdukiewicz and Kliszczewicz, 2002). Studies have also shown that use of supplementary cementitious admixtures, such as silica fume, etc. helps improve the properties of RAC. Generally, concrete made from recycled coarse and fine aggregates has reductions in tensile strengths of less than 10% and a maximum of 20% reduction for the worst case (Hansen 1986).

2.3.2 Permeability

Concrete made from recycled aggregates w/c ratios of 0.5 to 0.7, has permeability two to five times that of concrete made with natural aggregates (Hansen 1986). Rasheeduzzafar (1984) found that the low strength and corresponding high water absorption for recycled concrete could be offset by lowering the w/c of the recycled concrete by 0.05 to 0.10.

2.3.3. Bond strength

Very limited work on bond strength of RAC has been done. Nevertheless, it has been reported that, the effect of use of RA on the bond stress at failure is quite small compared to factors such as the type of bars used (plain rounds or ribbed bars). A reduction of up to 10% in the bond strength of the RAC has been reported at 100% replacement by RA (Ajdukiewicz and Kliszczewicz, 2002).

2.3.4. Creep and shrinkage

The use of RA in concrete induces a large shrinkage due to the high absorption of these aggregates. Some studies by show that in RAC at the age of 90 days, the shrinkage could be about 0.55–0.8 mm/m, whereas the comparable value for NAC is only about 0.30 mm/m (Katz, 2003). However, the test results for creep in normal laboratory conditions are not so clear, though some studies have shown the tendency to be reversed, i.e. the creep after 1 year is about 20% lower than concrete with NA (Ajdukiewicz and Kliszczewicz, 2002). Though more work is needed in the area, it appears that the overall behavior of RAC and NAC may be comparable when viewing the combined effect of shrinkage and creep.

2.3.5. Durability of hardened RAC

Durability studies have been done to better understand the effect of using different qualities of RA on the properties of the RAC. Though, some studies have shown that RAC is significantly more permeable than NA concretes, it should also be noted that the durability properties can be improved by using fly ash, condensed silica fume, etc.

2.3.6 Carbonation

On the basis of carbonation test done after 6 months of curing, the carbonation depth of the recycled concrete has been found to be 1.3–2.5 times greater than that of the reference

concrete (Crentsil et al. 2001; Levy Salomon and Paulo, 2004). It is seen that for the same water-binder ratio, the carbonation depths of RAC are slightly higher than that of NAC (Otsuki et al. 2003). This increase in the carbonation depth could be attributed to increased permeability of the RAC on account of the presence old mortar adhering to the original aggregate, and the old interfacial transition zone (ITZ) between them.

2.3.7. Freezing and thawing resistance

There is no common opinion in the literature as far as the frost resistance of RAC is concerned. In a study where the effect of mortar content adhering to the aggregate on the freezing and thawing resistance of RAC was studied, it was found that provided the quality of the concrete rubble is good, the adhering mortar may not adversely affect the performance of RAC (Gokce et al. 2004). In another study it was found that the freezing and thawing resistance of RAC using RA made from non-air-entrained concrete was quite poor, though the RAC met the requirements of air entrainment. On the other hand, the concretes made with the recycled coarse aggregates originated from air-entrained concretes were highly frost resistant (Salem and Burdette, 1998; Zaharieva et al. 2004). The likely shortcomings in the performance of RAC to freezing and thawing can be attributed to the pore structure of the previously hardened cement paste that adheres to the surface of the recycled aggregate. This porous matrix absorbs water during mixing, increasing the water-cement ratio of the paste.

A report by the Building Contractors Society of Japan (1978), however, indicated that concrete made from recycled coarse and fine aggregates had significantly reduced resistance to freezing-and-thawing damage. They also found that if the fine aggregates were replaced with virgin materials, the freezing-and-thawing resistance was comparable to the original concrete. Another Japanese study indicated that air entrained concrete made with recycled aggregates has less freezing-and-thawing resistance than the concrete made with virgin materials (Hasaba et al. 1981). One of the differences between most of the Japanese and American studies is the quality of the concrete from which the recycled aggregates were made. The American work has been based primarily on recycled pavements while the Japanese work was from fairly low-quality concrete.

2.3.8 Compressive strength

Xiao et al. (2012) concludes that compressive strengths of recycled coarse aggregate are generally lower than those of conventional concrete. Furthermore, compressive strength values decrease with the increase of RCA amounts. Several reasons could be responsible for the reduction of the compressive strength for RAC, including an increased concrete porosity and a weak aggregate-matrix interface bond.

Butler et al. (2011) however, concluded that recycled coarse aggregate concrete had higher compressive strength values than the natural aggregate concrete. This is likely due to the stronger mortar–aggregate bond between the RCA and the new mortar.

Kim et al. (2012) observed that compressive strength decreased when the coarse aggregate was replaced with the recycled. Additional replacement of the fine aggregate reduced the strength as the recycled fines amount increased. When the fine aggregate replacement was greater than 60% the strength reduction became more significantly. Reason for reduction in compressive strength is

- (i) remained mortar on the surface of the recycled aggregate,
- (ii) cracks in the aggregate itself (which could occur during the crushing) and the original aggregate's strength. From, the observations, it is recommended that the fine aggregate should better be replaced with the recycled less than 60% in the consideration of compressive strength.

Poon et al. (2004) studied Influence of moisture states of natural and recycled aggregates on the compressive strength of concrete, and concluded that the concrete mixtures prepared with the incorporation of recycled aggregates, the air dried (AD) aggregate concretes exhibited the highest compressive strength. The surface dried density (SSD) recycled aggregates seemed to impose the largest negative effect on the concrete strength, which might be attributed to “bleeding” of excess water in the pre-wetted aggregates in the fresh concrete. Based on the results of his study, aggregates in the AD state and contain not more than 50% recycled aggregate should be optimum for normal strength recycled aggregate concrete production.

Khatib et al (2005) found that the absorbed water in the recycled aggregate may have helped with internal curing by providing a source of water to react with the cement. The relative compressive strength of recycled aggregate concrete decreases with the increase of relative water absorption of aggregate and the relative compressive strength can also be significantly affected by the *w/c* and curing condition.

Rahal et al (2007) when relative water absorption of aggregate is below 1.8%, the compressive strength of recycled aggregate concrete maintains more than 80% of that of the control concrete with natural aggregates, whereas the compressive strength of recycled aggregate concrete having relative water absorption of aggregate above 5.5% drops significantly, by as much as approximately 40% of that of the control concrete with natural aggregates. Insufficient hydration and a weak interface-zone formed between different components of the concrete matrix owing to a large amount of old cement paste on the surface of recycled aggregates, which can be the cause of a poor development of the compressive strength of concrete. Figure 2.3 shows that higher strength can be achieved by reducing the water to cement ratio in recycled concrete aggregate.

Khaldoun Rahal et al (2007) conducted an experimental study on some of the mechanical properties of recycled aggregate concrete (RAC) as compared to those of the conventional normal aggregate concrete (NAC). Various mix proportions and results for compressive strength are as shown in table 2.3. and table 2.4.

Table 2.3 Different Mix Proportions by Rahal (2007)

Concrete mix proportions (kg/m ³)					
Class	K200	K250	K300	K400	K500
Target 28-day cube strength (MPa)	20	25	30	40	50
Cement (Type I)	360	380	400	420	460
Water (+ liquid super plasticizer)	234	190	192	181	184
<i>w/c</i>	0.65	0.50	0.48	0.43	0.40
Natural sand	705	705	705	705	705
Coarse aggregate (9 mm)	500	500	500	500	500
Coarse aggregate (12 mm)	340	340	340	340	340
Coarse aggregate (19 mm)	260	260	260	260	260

Table 2.4 Different Compressive strengths by Rahal (2007)

Average results from cube compression tests (MPa)

Measured property	Type	No. of tests	Concrete class				
			K200	K250	K300	K400	K500
Strength at 1 day	RAC	3	4.3	5.60	6.30	8.97	10.1
	NAC	3	5.6	7.33	8.77	10.2	13.7
Strength at 3 days	RAC	3	10.7	13.4	16.4	18.5	21.5
	NAC	3	12.5	16.3	18.9	23.4	29.2
Strength at 7 days	RAC	3	15.0	18.9	22.7	26.5	27.8
	NAC	3	17.0	21.2	24.7	32.5	37.3
Strength at 14 days	RAC	3	18.0	22.5	27.2	35.2	41.5
	NAC	3	19.9	25.9	31.2	41.1	46.5
Strength at 28 days	RAC	10	20.3	29.2	32.2	39.4	46.5
	NAC	10	22.7	32.3	36.0	46.0	53.5
Strength at 56 days	RAC	3	21.6	30.7	33.4	42.7	51.2
	NAC	3	23.3	33.3	37.0	48.3	57.6
Standard deviation of 28 days strength	RAC	10	0.53	0.96	0.77	0.85	1.48
	NAC	10	0.95	0.80	0.84	0.99	1.00
Coefficient of variation of 28-day strength (%)	RAC	10	2.61	3.27	2.41	2.16	3.17
	NAC	10	4.18	2.47	2.33	2.14	1.87

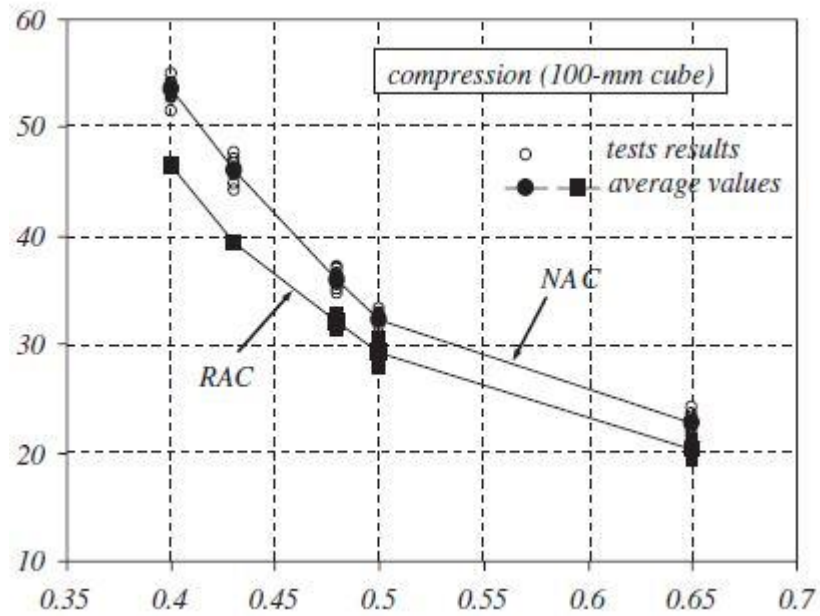


Figure 2.3: 28 days compressive strength versus w/c ratio (Rahal 2007)

Henry et al (2011) analysed Compressive strength development from 7 to 91 days for all series is shown in Fig.3.4. The control series has the highest strength level at 7 days but, from 7 to 28 days, the strength development is higher for the W/B = 0.3, W/B = 0.375, and W/B = 0.45 with blast furnace slag series, regardless of aggregate type. In the

case of the $W/B = 0.3$ and $W/B = 0.45$ with blast furnace slag, the strength level is comparable to the control by 28 days, but for $W/B = 0.375$ the strength level is still lower than the control even though the strength development is higher. Finally, from 28 to 91 days the strength development follows a similar rate as the control series. For the $W/B = 0.45$ series, the strength development is similar to the control from 7 to 91 days, albeit at a much lower level.

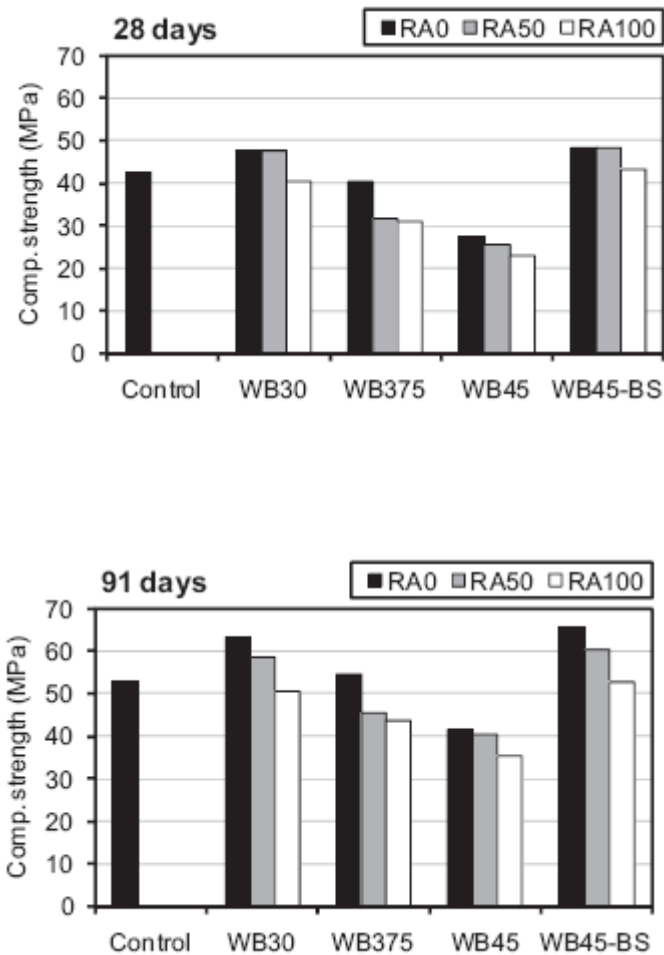


Fig 2.4 Compressive strength development from 7 to 91 days by Henry (2011)

2.4 STEEL SLAG CONCRETE (SSC)

Hisham Qasrawi (2013) concluded the results that with the use of the RCA resulted in reduction of the compressive strength as shown below in Fig 2.5. and mix proportions are considered as earlier in table 2.1 for workability considerations. This reduction increases by the increase in the percentage of RCA in the mix. Similar results are shown by Limbachiya et al. (2004) From the fig shown below, it can be also concluded that higher strength concretes, which has the lower w/c ratios, suffered more reduction in strength. This finding is similar to Chen et al. (2003) who found that at lower w/c ratios, the compressive strength of recycled concrete is much lower than that of normal concrete but at higher water/cement ratios, the compressive strength of recycled concrete becomes closer to that of normal concrete.

Further it can be seen that with the use of SSA as partial replacement of natural aggregate, resulted in increase in compressive strength depending on the used replacement ratio and on the w/c ratio. The increase in strength can reach a value of about 20% from the original value when the whole natural aggregate is replaced by SSA. Higher strength of concrete containing steel slag aggregates can be attributed to the higher angularity of steel slag aggregates which enhances the interaction between the slag aggregate and the cementitious matrix.

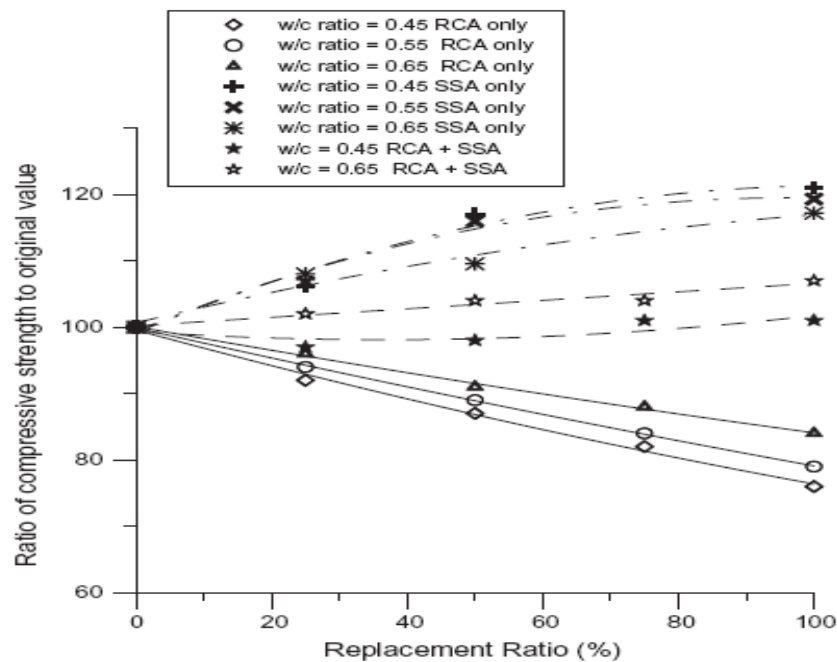


Fig 2.5 compressive strength w.r.t RCA replacement ratio by Qasrawi (2013)

From Fig 2.5. it can be seen that when slag is introduced as 67%-replacement of RAC, the strength of the mixes containing RCA is enhanced .

Alizadeh et al. (CMI report 1996) carried out a research to evaluate the effect of steel slag on hardened concrete. Experimental results indicated that steel slag aggregate concretes achieved higher values of compressive, flexural and flexural strength and modulus of elasticity, compared to natural aggregate concretes.

Kamal et al. (2002) presented a study on using blast furnace steel slag, which was crushed and screened to the required sizes, as coarse aggregate in concrete. The results show that the properties of hardened concrete, such as compressive, flexural and bond strength are higher for concrete containing steel slag when compared with those containing natural aggregate. Also the use of steel slag enhanced the elastic properties: There was an increase in the modulus of elasticity and a decrease in Poisson's ratio.

Shekarchi et al. (2004) conducted a comprehensive research on the utilization of steel slag as aggregate in concrete. They concluded that the use of air-cooled steel slag with low amorphous silica content and high amount of ferric oxides is unsuitable to be employed in blended cement. On the other hand, utilization of steel slag as aggregate is advantageous when compared with normal aggregate concrete mixes.

Maslehuddin et al. (2003) presented a comparative study of steel slag aggregate and crushed limestone concretes; where, only part of the coarse aggregates is replaced by slag aggregates. The study concluded that the compressive strength of steel slag aggregate concrete is marginally better than that of crushed limestone aggregate concrete. Moreover, the improvement in the flexural strength steel slag concrete is not significant.

Manso et al. (2006) presented a study in which electric arc furnace slag has been used to obtain concrete of better quality. The study shows that steel slag can be used to enhance concrete properties.

2.5 EFFECT ON COMPRESSIVE STRENGTH USING GROUND ASH AS PARTIAL REPLACEMENT OF NATURAL AGGREGATE

Somna et al. (2012) compared compressive strength and percentage of compressive strength of concrete to CON concrete. The compressive strength of recycled aggregate concrete without GBA (RB00) was lower than that of CON concrete at all tested ages. It is due to the use of recycled coarse aggregate which is weaker than natural coarse aggregate (crushed limestone) because the attached mortar on the surface of recycled coarse aggregate had higher porosity and greater weakness than natural coarse aggregate (crushed limestone) resulting in decreasing of the compressive strength of concrete. Additionally, the bond between new cement paste and recycled coarse aggregate was also obstructed by the residual impurities on the surface of the recycled coarse aggregate. For recycled aggregate concrete with GBA, the compressive strength decreased with the increasing GBA replacement. Ref table 2.5 ,and fig 2.6

Table 2.5 : Compressive strength of concrete by Radonjanin

Samples	Compressive strength (MPa) (%)				
	7 days	28 days	60 days	90 days	180 days
CON	37.6 (100)	44.4 (100)	49.1 (100)	52.8 (100)	53.1 (100)
RB00	34.1 (91)	41.0 (92)	46.7 (95)	50.7 (96)	51.3 (97)
RB20	34.5 (92)	41.2 (93)	47.1 (96)	51.3 (97)	51.9 (98)
RB35	32.3 (86)	38.6 (87)	43.4 (88)	46.9 (89)	47.5 (89)
RB50	29.0 (77)	35.1 (79)	40.4 (82)	43.8 (83)	44.4 (84)

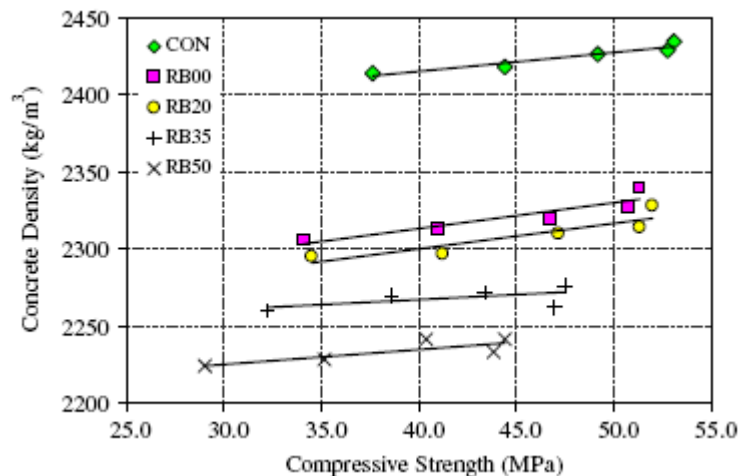


Fig 2.6 Density of concretes Radonjanin (2012)

Radonjanin et al. (2013) compared the compressive strength for different concrete types mix proportions are shown in table 2.6. The results of compressive strength testing of referent RAC concretes of this concrete group are high values of compressive strength. Concluded a rapid strength development in the period up to 7 days, slower strength gain after 28 days. However, there are small differences depending on the type of highly reactive mineral admixture applied. The results of compressive strength testing of GRAC composites with fly ash, in comparison to referent RAC concrete A are shown in Fig. 2.7 , there are significant differences between the referent concrete and all concretes with fly ash, but that there are also significant differences in strength values within the group of concretes containing fly ash, depending on the presence of super plasticizer and highly reactive mineral admixtures. Referent concrete had fast strength development in the initial period, while all concretes with high content of fly ash showed a tendency towards a significant increase in strength after 28 days.

Table 2.6 : Different mix proportions by Radonjanin for different admixtures

Mix proportions of referent RAC (A) and GRAC (B, C, D and E).

Concrete type	Cement m_c (kg/m ³)	Water $m_{w,tot}$ (kg/m ³)	Aggregate m_a (kg/m ³)		Mineral admixture m_{mad} (kg/m ³)	
			$m_w + m_{w,add}^a$	NA ^b 0/4	RCA ^c 4/8 8/16	Fly ash FA
A	350	200 + 19.1	845	845	-	-
A-SF	315	200 + 19.0	838	838	-	-
A-MK	315	200 + 19.0	840	840	-	-
B-FA	175	240 + 17.3	761	762	175	-
B-LS	175	200 + 18.9	835	835	-	175
C-FA	175	200 + 18.3	808	809	175	-
D-FASF	175	200 + 18.3	808	809	140	-
D-LSSF	175	200 + 18.7	829	830	-	140
E-FAMK	175	200 + 18.3	810	810	140	-
E-LSMK	175	200 + 18.8	832	833	-	140

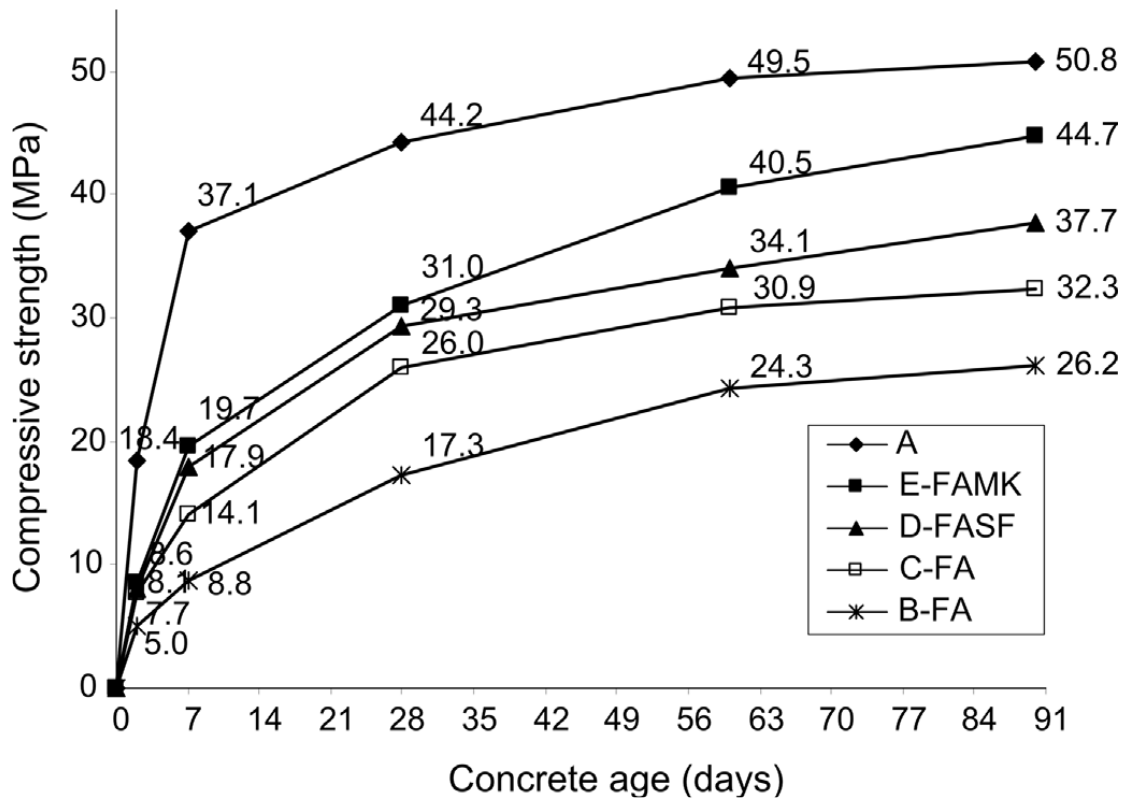


Fig 2.7 compressive strength behavior by Radonjanin (2012)

2.6 CLOSING REMARKS

A review of recent literature on compressive strength behaviour of natural coarse aggregate and recycled coarse aggregate concrete has been presented on the basis of which the need of the present investigation has been identified.

CHAPTER 3

EXPERIMENTAL PROGRAMME

3.1 INTRODUCTION

The details of experiment programme in terms of material properties, test set-up for measuring different parameters are the testing procedure discussed in this chapter.

3.2. EXPERIMENTAL DETAILS

The experimental program showing details about the materials and different tests for compressive strength is shown in Fig. 3.1.

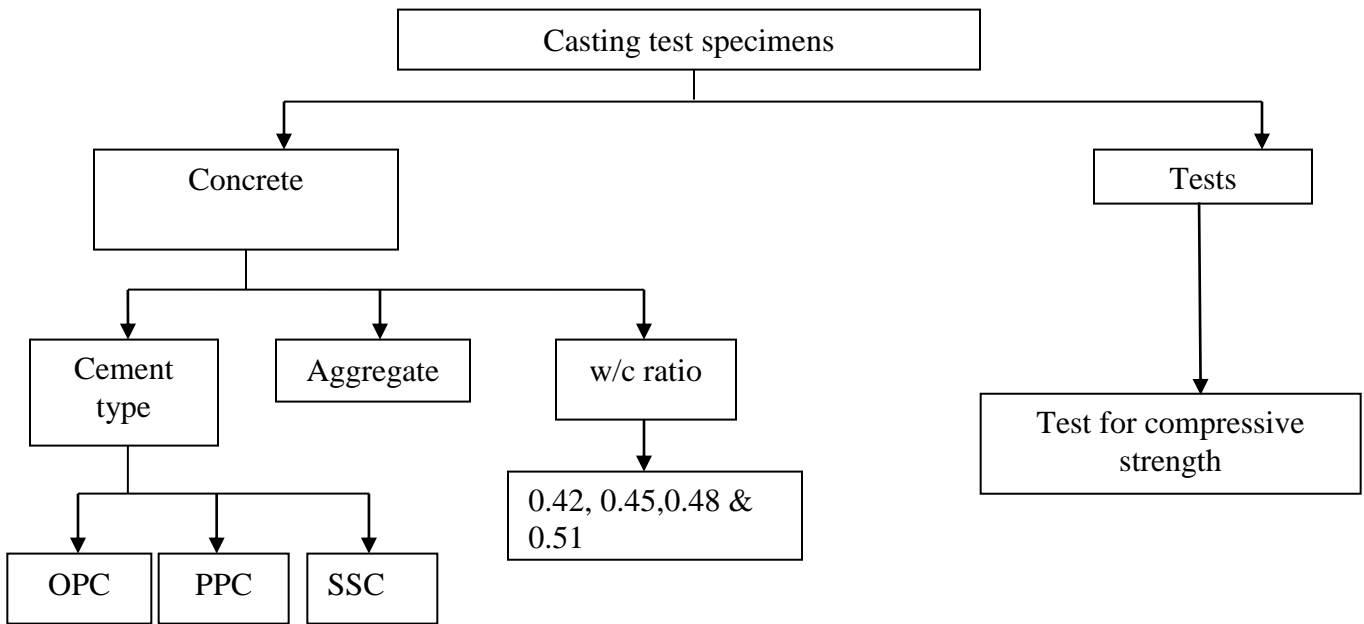


Fig. 3.1: Experimental details for compressive strength

3.3 MATERIAL PROPERTIES

Cement, fine aggregates, coarse aggregates, recycled coarse aggregate, super-plasticizer and water is used for present investigation. The properties of these materials are discussed in the following sections.

Cement

It is mixed with water and materials such as sand, gravel, and crushed stone to make concrete. The cement and water form a paste that binds the other materials together as the concrete hardens. Three different types of cement used were

- 1) Ordinary portland cement (OPC) satisfying Indian standards IS: 8112-1989.
- 2) Portland pozzolana cement (PPC) having 20% pozzolana (fly ash) content, satisfying Indian standards IS: 1489 (Part I) – 1991.
- 3) Steel slag cement

3.3.1. Ordinary Portland Cement (OPC)

Ordinary Portland cement “Ultratech” (grade-43) was used in the investigation. The physical properties of the cement were tested in laboratory as per the IS Standard specification and results are presented in Table 3.1. Chemical composition of the cement was supplied by the manufacturer and is presented in the Table 3.2. Compressive strength of OPC at 3 days, 7 days and 28 days of curing are represented in Table 3.3

Table-3.1 Physical Properties of OPC

S.NO	Characteristics	Result	Requirement as per IS:8112-1989
1	Normal consistency	28%	-
2	Initial setting time	48 min	Min 30
3	Final setting time	165 min	Max 600
4	Specific gravity	3.15	-
5	Soundness	1	Max 10

Table 3.2 Chemical properties of ordinary Portland cement

S.NO	Oxide composition	Values
1.	CaO	62.1%
2	SiO ₂	21.14%
3	Al ₂ O ₃	5.23%
4	Fe ₂ O ₃	4.42%
5	MgO	1.14%
6	SO ₃	2.3 %
7	LOI	1.5%

Table 3.3 Compressive Strength of OPC (Grade-43)

S.NO	Day of curing	Compressive Strength(MPa)
1	3 days	11.3
2	7 Days	23.5
3	28 days	43.8

3.3.2. Portland Pozzolonic cement (PPC)

Portland Pozzolana cement “Ultratech” (PPC) is used for the present investigation. The cement is of uniform color i.e. grey with a light greenish shade and is free from any hard lumps. There are four major compounds present in all the cement. The variation in percentage composition of compounds influences the properties of cement. Portland Pozzolana Cement is kind of blended cement which is produced by intergrading of OPC clinker along with gypsum and pozzolonic materials in certain proportions. Pozzolana is a natural or artificial material containing silica in a reactive form. The chemical properties of cement are given in Table 3.4 and the physical properties of the cement are shown in Table 3.5. All the tests are carried out in accordance with procedure laid down in IS: 1489(part-1)1991. Table 3.6 shows the compressive strength of cubes at 3 days, 7 days and 28 days after curing.

Table 3.4 Chemical composition of PPC

S.NO	Oxide composition	Values
1.	CaO	47.72%
2	SiO ₂	28.82%
3	Al ₂ O ₃	9.31%
4	Fe ₂ O ₃	4.60%
5	MgO	1.48%
6	SO ₃	2.10 %
7	LOI	2.7%

Table 3.5 Physical properties of PPC

S.NO	Characteristic	result	Standard values
1	Normal consistency	34%	-
2	Initial setting time	51 min	Should not be less than 30 minutes
3	Final setting time	205 min	Should not be more than 600 minutes
4	Soundness	<1	
5	Specific gravity	2.97	-

Table 3.6 Compressive strength of PPC (cement sand ratio is 1:3)

S.NO	Day of curing	Compressive strength(MPa)
1	3 Days	10.7
2	7 Days	19.2
3	28 Days	38.0

3.3.3 Slag Cement (SSC)

The term "slag cement" is a very general term that can be used to include many types of materials and combinations. In recent years, "slag cement" has been commonly used to refer to either combinations of Portland cement and ground slag or to the ground slag alone. In the present investigation slag cement "Ultratech Premium" was used. It is also known as ground granulated blast-furnace slag (GGBFS). GGBFS has been often used for civil engineering structure, but it has rarely been used for reinforced concrete because of slow strength growth.

The slag cement used in the present study has the chemical composition provided by the manufacturer as listed in Table 3.7. The physical properties of the cement are presented in Table 3.8 and compressive strength of the 70.4 mm cubes at 3 days 7 days and 28 days are presented in Table 3.9.

Table-3.7 Chemical composition of Slag Cement

Contents	Oxide compound
SiO ₂	33.64 %
Al ₂ O ₃	14.33 %
Fe ₂ O ₃	0.16 %
CaO	42.93 %
MgO	6.38 %
Na ₂ O	0.20 %
K ₂ O	0.34 %
TiO ₂	0.61 %
P ₂ O ₅	0.01 %
MnO	0.36 %

Table 3.8: Physical properties of Slag cement

Properties	Observed value
Specific surface area	350 to 500 m ² /Kg.
Initial setting time	500 minutes.
Final setting time	1000 minutes.
Soundness	< 1
Specific gravity	2.85 to 2.95

Table-3.9 Compressive strength of slag cement

S.NO	Days of curing	Compressive strength (MPa)
1	3 days	15
2	7 days	25.2
3	28 days	34.6

3.3.4 Coarse aggregates

Coarse aggregates of size 20mm and 10mm of quartzite origin were used in the ratio of 2:1. The grading of 20mm and 10mm in the above proportion is presented in Table 3.10 and Table 3.11. The specific gravities of 20mm and 10mm were found to be 2.68 and 2.64.

Table 3.10: Gradation of 20mm aggregates

Sr.No.	Sieve Size (mm)	Percentage weight retained	Percentage passing	Cumulative percentage retained
1	80	0	100.00	0.00
2	40	0	100.00	0.00
3	20	0.055	98.15	1.83
4	10	2.895	1.72	98.26
5	4.75	0.041	0.36	99.62
6	2.36	0	0.00	100
7	1.18	0	0.00	100
8	600	0	0.00	100
9	300	0	0.00	100
10	150	0	0.00	100
11	PAN	0.011	-	
			SUM	199.69

$$\begin{aligned} \text{Fineness modulus of coarse aggregates} &= \frac{\Sigma C + 500}{100} \\ &= \frac{199.69 + 500}{100} \\ &= 6.99 \end{aligned}$$

Table 3.11: Gradation of 10mm aggregates

Sr.No	Sieve size (mm)	Material retained	Percentage retained	Percentage passing	Cumulative percentage retained
1	80	0.00	0.00	100.00	0.00
2	40	0.00	0.00	100.00	0.00
3	20	0.005	0.249	99.73	0.249
4	10	0.485	24.23	75.5	24.479
5	4.75	1.25	62.46	13.04	86.93
6	2.36	0.00	0.00	0.00	100
7	1.18	0.00	0.00	0.00	100
8	600	0.00	0.00	0.00	100
9	300	0.00	0.00	0.00	100
10	150	0.00	0.00	0.00	100
11	PAN	0.261	13.04	-	-
				SUM	111.658

$$\begin{aligned} \text{Fineness modulus of coarse aggregates} &= \frac{\Sigma C + 500}{100} \\ &= \frac{500 + 111.658}{100} \\ &= 6.11 \end{aligned}$$

3.3.5 Fine aggregates

The material which passes through 4.75 mm sieve is termed as fine aggregate. Usually natural sand is used as a fine aggregate at places where natural sand is not available crushed stone is used as a fine aggregate. The sand used for the experimental works procured and conformed to grading zone II. The sieve analysis of fine aggregates is shown in Table 3.12. The physical properties are provided in Table 3.13.

Table 3.12: Gradation of fine aggregates

Sieve size (mm)	Material retained	Percentage retained	Percentage passing	Cumulative percentage
80	0	0.00	100.00	0.00
40	0	0.00	100.00	0.00
20	0	0.00	100.00	0.00
10	0	0.00	100.00	0.00
4.75	5	0.50	99.50	0.50
2.36	59	5.90	93.60	6.40
1.18	136	13.60	80.00	20.00
600	243	24.30	55.70	44.30
300	415	41.50	14.20	85.80
150	122	12.20	2.00	98.00
PAN	20	2.00		
SUM	1000		SUM	255.00

$$\text{Fineness modulus of coarse aggregates} = \frac{\Sigma C + 500}{100}$$

$$\text{Fineness modulus of aggregates} = 2.55$$

Table 3.13: Physical properties of fine aggregates

Sr. No.	Characteristics	Value
1.	Type	Natural sand
2.	Specific Gravity	2.58
3.	Fineness Modulus	2.55
4.	Grading Zone	Type III

3.3.6 Mixing water

Tap water from laboratory of deep ground water source was used in the experimental work.

3.3.7. Admixture

Conplast SP430, the admixture supplied by Fosroc India Pvt. Limited is used in our investigations. It is a highly effective super plasticizer for concrete and mortar. It meets the requirements for super plasticizer according to BS 5075 Part 3, ASTM C-494 Type A and Type F and IS: 9103-1999 (amended 2003). The dosage of the super plasticizer is fixed based on the requirements for workability. The technical data related to the super plasticizer used is provided in Table 3.14. This data is supplied by the manufacturers.

Table 3.14: Technical data of admixture

Sr. No.	Characteristics	Value
1.	Colour	Brown
2.	Specific gravity	1.20
3.	Air entrainment	Minimum 1%
4.	pH	7 to 8

3.3.8 Recycled Coarse Aggregate

Large amount of tested concrete specimens e.g. cubes, cylinders, beams etc. were lying in the concrete laboratory of Thapar University. These specimens were used as a source of RCA concrete. To make RCA, the specimens without reinforcement were manually broken down into small pieces and then crushed using jaw crusher as shown in Fig. 3.2 (a) & (b). The crushed pieces of concrete were then separated into two fractions depending on their size. The larger fraction, passing through 20 mm sieve but retained on 10 mm sieve was designated RCA20 – 10 mm, while the smaller fraction passing through 10 mm sieve but retained on 4.75 mm was designated RCA10 - 4.75. The fraction passing through 4.75 mm sieve was discarded. While making RCA concrete, the two different sizes of RCA were mixed in a suitable proportion so that the gradation curve of the combined RCA concrete was similar to that of the natural coarse aggregate.



(a) Waste concrete used for producing RCA (b) RCA obtained from the jawcrusher

Figure 3.2: (a) Waste concrete used for producing RCA (b) RCA obtained from the jaw crusher

Gradation of Coarse recycled concrete aggregate and Natural aggregate

While making recycled coarse aggregate concrete, the size fractions of recycled coarse aggregate 20 - 10 and RCA 10 - 4.75 were mixed by the method of equivalent mix proportion so that the gradation curve of the combined recycled coarse aggregate was similar to that of the natural coarse aggregate. The final mix ratio for recycled coarse aggregate was achieved as 70% of RCA 20-10 mm and 30% of RCA 10-4.75 mm. The mix proportion of different size fraction of RCA was decided by hit and trial method. Table 3.15 and 3.16 shows the sieve analysis results of the natural coarse aggregates and recycled coarse aggregate respectively. It may be seen in Table 3.16 that the recycled coarse aggregate satisfies the IS 383:2007 specified gradation criteria for 20mm sized aggregates. The recycled coarse aggregate gradation curves in Fig. 3.3 are seen to have a close resemblance to the NA gradation curves and hence the size distribution of the recycled coarse aggregate particles is acceptable. The physical properties of coarse aggregates (both natural and recycled) used are provided in Table 3.17.

Table 3.15: Gradation of natural coarse aggregate

Sieve size (mm)	% passing Required [IS383:1970]	Weight retained (kg)	Cumulative % weight Retained	%passing for RCA
20	100	0	0	100
12.5	90-100	1.040	12.4	85.7
10	40-85	3.50	47.4	58.3
4.75	0-10	4.77	95.1	3.5

Table 3.16: Gradation of recycled coarse aggregate

Sieve size (mm)	% passing Required [IS383:1970]	Weight retained (kg)	Cumulative % weight Retained	%passing for RCA
20	100	0	0	100
12.5	90-100	1.040	12.4	85.7
10	40-85	3.50	47.4	58.3
4.75	0-10	4.77	95.1	3.5

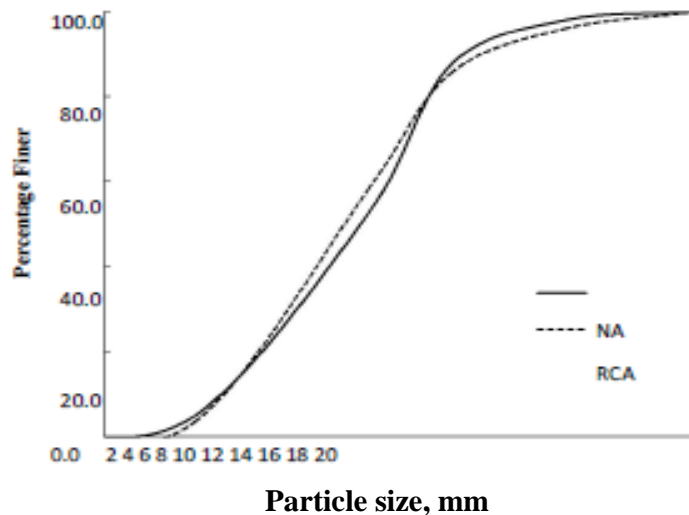


Figure 3.3: Gradation curve of coarse aggregate

Table 3.17: Physical properties of the recycled and natural coarse aggregate

Properties	Natural Aggregate	Recycled Coarse Aggregate
Specific gravity	2.34	2.6
Water absorption (%)	1.6	2.4
Fineness modulus (%)	6.7	7.1

3.4 MIX DESIGN

Concrete mix has been designed using the IS code 10262:2009 and also referred the Thesis work already done by one of the former student Shilpa . All the mixes are designed by keeping the water content constant. The desired workability of the mix is kept at 50-60 mm slump. To achieve the required workability of concrete mix, water reducing admixture i.e. super plasticizer, namely canplast SP-430 is added to the matrix at a desired dosage rate. Concrete mixture proportion and super plasticizer dosage rate is presented in Table 3.18. The mix proportion of corresponding mixes for each water-cement ratio is prepared by replacing natural aggregate by recycled coarse aggregate. In this, mixture proportions for the natural coarse aggregate and the recycled coarse aggregate concretes were nominally kept the same, except for replacement of NCA with recycled coarse aggregate, depending upon the desired recycled coarse aggregate replacement percentage.

The recycled coarse aggregate replacement percentage is defined as the weight ratio of recycled coarse aggregate to the total coarse aggregates in the concrete mixture and depending upon the selected replacement percentage, direct substitution of NCA with an equal weight of recycled coarse aggregate particles is carried out. The following four weight combinations of NCA and recycled coarse aggregate are adopted: 100 % NCA (control mixture), 60 % NCA + 30 % recycled coarse aggregate, 30 % NCA +60 % RCA, 10 % NCA +90 % RCA. The concrete mixture proportions and the corresponding mix designations are presented in Table 3.19. In concrete batching, first the natural coarse aggregates and RCA are added in the mixer, subsequently, fine aggregates and cement are added to the mixer the ingredients are dry mixed in the mixer for 2 minutes. Then half of water is added and again mixed for 1 minute. After this, the rest of the water along with the quantity of required super plasticizer is added and mixed for another 2 minutes. The mixture is now ready to be poured in the moulds.

Table 3.18 Mix proportion for controlled sample

w/c ratio	Cement (kg/m³)	Fine aggregate (kg/m³)	Natural aggregate (kg/m³)	Water (kg/m³)	Superplasticizer (% by weight of cement)
0.42	486	640	1256	206	1.4%
0.45	453	651	1274	206	1.2%
0.48	426	657	1291	206	1.0%
0.51	400	664	1303	206	0.5%

Table 3.19 Mix proportion for mixes different replacements of NA and RCA

Designation	w/c Ratio	Replacement (%)	Cement (kg/m³)	Fine aggregate (kg/m³)	Natural aggregate (kg/m³)	Recycled aggregate (kg/m³)	Water (kg/m³)
A1-0	0.42	0	486	640	1256	-	206
A1-30		30	486	640	879	376	206
A1-60		60	486	640	376	879	206
A1-90		90	486	640	124	1131	206
A2-0	0.45	0	453	651	1274	-	206
A2-30		30	453	651	891	382	206
A2-60		60	453	651	382	891	206
A2-90		90	453	651	131	1152	206
A3-0	0.48	0	426	657	1291	-	206
A3-30		30	426	657	903	388	206
A3-60		60	426	657	388	903	206
A3-90		90	426	657	129	1162	206
A4-0	0.51	0	400	663	1303	-	206
A4-30		30	400	663	912	391	206
A4-60		60	400	663	391	912	206
A4-90		90	400	663	130	1173	206

3.5 TEST SET UP FOR SLUMP VALUE

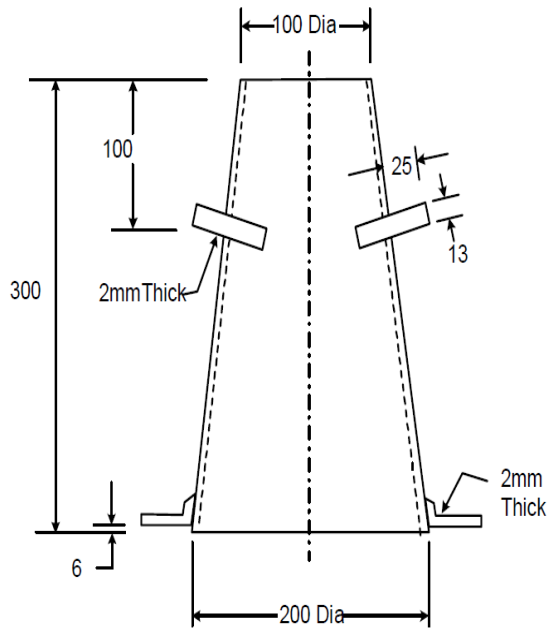
Flowability, deformability, flow characteristics and the stability of RCA were determined by slump flow. The slump flow test apparatus for concrete is shown in Fig. 3.4. These tests are briefly discussed as following :

Equipment used

- (a) Mould in the shape of a truncated cone with internal base diameter of 200 mm and internal top diameter of 100 mm. The height of the cone was 300 mm.
- (b) 800 mm square base plate, marked with a circle marking the central location for the slump cone and another concentric circle of 500 mm diameter.
- (c) Trowel
- (d) Scoop
- (e) Ruler
- (f) Stop watch

Procedure

About 6 liters of concrete was needed to perform the test. The slump cone and the base plate were moistened. Then the slump cone was placed on the base plate and was held down firmly. The fresh self-compacting concrete was poured into the cone and the excess concrete was struck off level with the trowel. After this, the cone was raised vertically and the concrete was allowed to flow out freely. The final diameter of the concrete was measured in two perpendicular directions and the average of the two diameters was taken as slump flow in mm.



(a) Apparatus



(b) Slump measurement

Fig. 3.4: Slump flow test

3.6. CASTING OF SPECIMENS

In this section casting procedure for compressive strength test and pull out strength test are Discussed

3.6.1 Casting for Compressive Strength test

150mm cube is used to study the compressive strength of various mixes. The cubes are filled with fresh concrete using vibrating table. Immediately after casting cubes, the specimens are covered with gunny bags to prevent water evaporation. Three cubes are casted for each parameter. The compressive strength test is carried out for 7 days and 28 days. Therefore, six identical specimens are casted for each concrete mix. The cubes after casting are shown in Figure 3.5.



Figure 3.5: Casting of cubes

3.7 TESTING OF SPECIMENS

In this section test setup for both the tests (compressive strength test and pull out strength test) are discussed.

3.7.1 Test setup for Compressive Strength test

As shown in Figure 3.6 and fig 3.7, three identical specimens are crushed at 7days and three identical specimens are crushed at 28 days. The compressive strength is calculated by dividing the failure load by average cross sectional area.

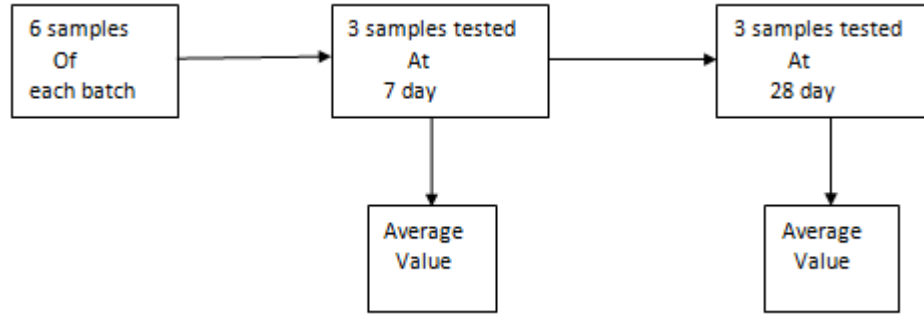


Fig: 3.6. Compressive Strength test chart



Figure 3.7: concrete cube specimens

The compressive strength testing machine of capacity 3000 KN is used for determining the maximum compressive loads carried by concrete cubes. The compressive strength test machine which used in all tests is shown in Figure 3.8 At the test age the specimens are taken out of the curing tank and kept outside for 10 minutes. As shown in fig 3.9 one specimen is placed on the steel platen of the machine such that the specimen is tested perpendicular to the casting position. Then the test is carried out at the loading rate of 5 KN/s specified IS: 516–1959.



Figure 3.8: Compressive strength test machine



Figure 3.9: Cube Samples under machine

3.8 CLOSING REMARKS

The experimental programme described in this chapter includes the significant material properties and specifications of the ingredients of concrete, the testing procedure. The specimen details and the test set up have been discussed.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In the first part of this chapter, the effect of replacement ratio of recycled coarse aggregate on workability of concrete by using OPC, PPC and SSC is discussed. In the second part the effect of replacement ratio of recycled coarse aggregate on compressive strength of concrete by using OPC is discussed. The effect is studied at a range of w/c ratios. The third consists of discussion the effect of replacement ratio of recycled coarse aggregate on compressive strength of concrete by using PPC is discussed w.r.t different water cement ratios. The fourth part consists of discussion the effect of replacement ratio of recycled coarse aggregate on compressive strength of concrete by using steel slag based cement is discussed w.r.t different water cement ratios.

4.2. WORKABILITY

4.2.1 Effect of water cement ratio and RCA replacement ratio :

During mixing it is observed that as we increase the replacement ratio of recycled aggregate, the workability decreases. This decrease in workability was then controlled by addition of extra dose of super plasticizer as presented in Table 4.1. The decrease in workability with the addition of RCA can be due to the adhered cement mortar attached with recycled aggregates. Similar trend was observed by Henry et al. (2011) and Qasrawi et al. (2013). Trends for dose of super plasticizer requirement w.r.t different replacement and w/c ratios is as shown in bar graph (fig 4.1 to 4.3).

Table 4.1 Dose of super plasticizer for mixes with different replacements and w/c ratio

Designation	w/c Ratio	Replacement (%)	Cement (kg/m³)	Water (kg/m³)	OPC	PPC	SSC
A1-0	0.42	0	486	206	6.8	8.7	10.7
A1-30		30	486	206	6.9	8.8	10.8
A1-60		60	486	206	7	8.9	10.9
A1-90		90	486	206	7.1	9	11
A2-0	0.45	0	453	206	4.6	6.8	8.6
A2-30		30	453	206	4.7	6.9	8.7
A2-60		60	453	206	4.8	7	8.8
A2-90		90	453	206	4.9	7.1	8.9
A3-0	0.48	0	426	206	4.2	5.5	7.2
A3-30		30	426	206	4.3	5.6	7.3
A3-60		60	426	206	4.4	5.7	7.4
A3-90		90	426	206	4.5	5.8	7.5
A4-0	0.51	0	400	206	2	3.2	4.4
A4-30		30	400	206	2.1	3.3	4.5
A4-60		60	400	206	2.2	3.4	4.6
A4-90		90	400	206	2.3	3.5	4.7

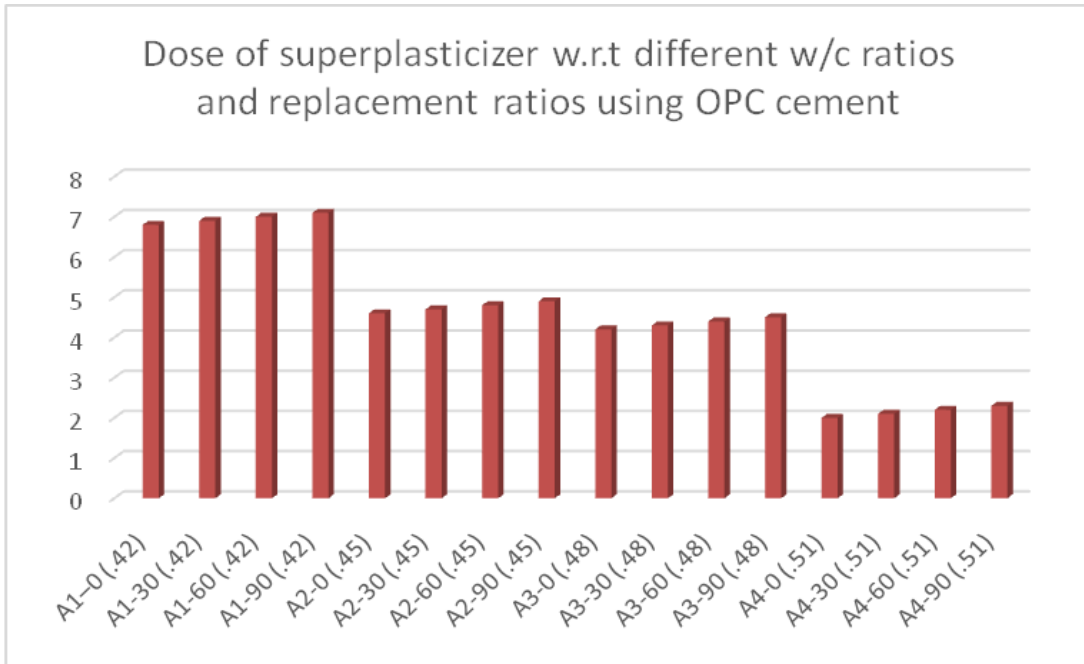


Fig: 4.1 Dose of superplasticizer w.r.t different w/c ratios and replacement ratios using OPC

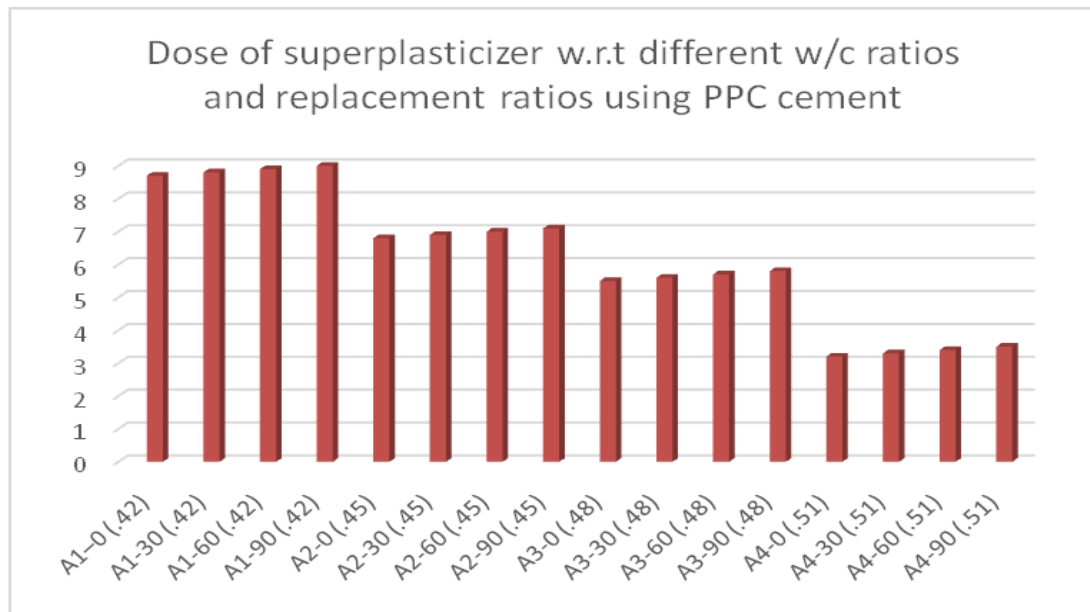


Fig: 4.2 Dose of superplasticizer w.r.t different w/c ratios and replacement ratios using PPC

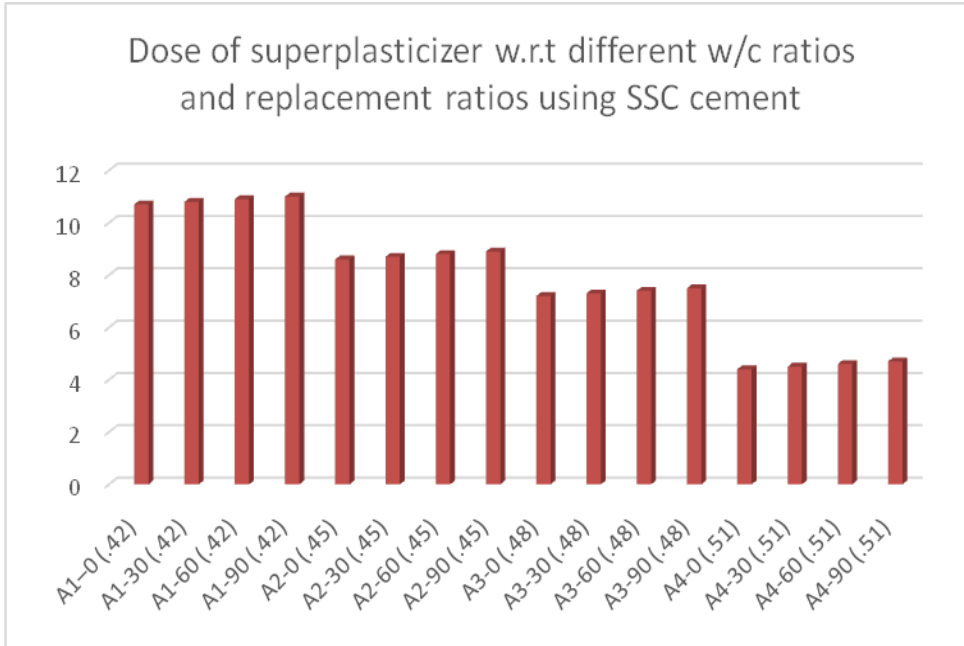


Fig: 4.3 Dose of superplasticizer w.r.t different w/c ratios and replacement ratios using SSC

4.2.2 Effect of cement type

Moreover the workability also decreases with change in type of cement. It is observed that for all w/c ratios, workability is very low in case of SSC as compared to PPC and OPC. This may be due to the ball bearing effect of flyash with recycled aggregates as compared with slag. Additional quantity of super plasticizer is added for the different recycled coarse aggregate replacement percentage in the concrete mixture and for different w/c ratios and different type of cements to maintain the selected slump value i.e 50-60 mm as presented in Table 4.1. Trends for dose of super plasticizer requirement w.r.t different replacement w/c ratios and different type of cements is as shown in bar graph (fig 4.4 to 4.7).

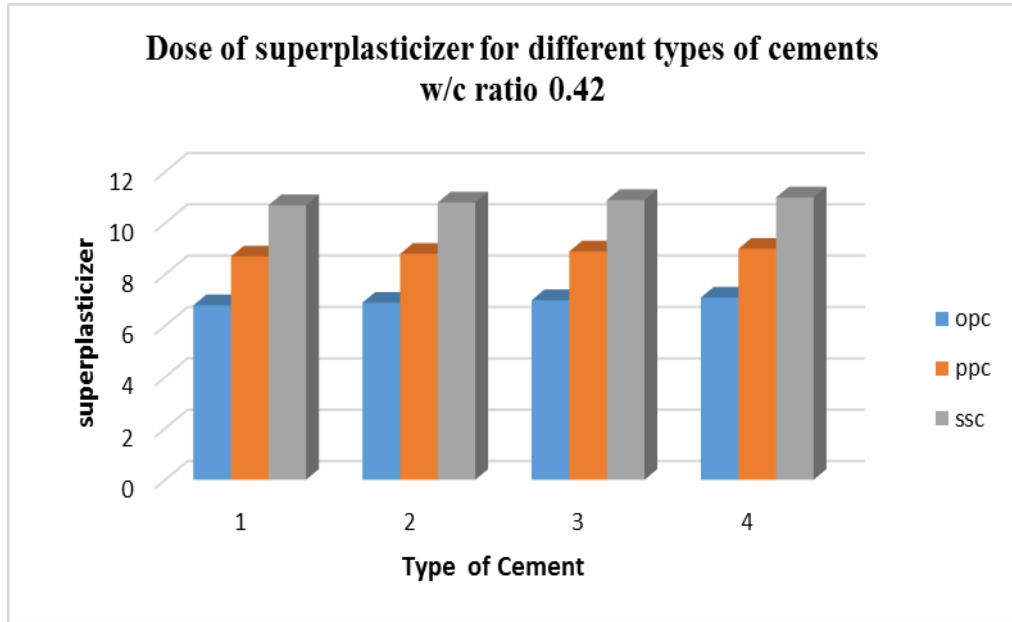


Fig: 4.4 Dose of superplasticizer for different types of cements w/c ratio 0.42

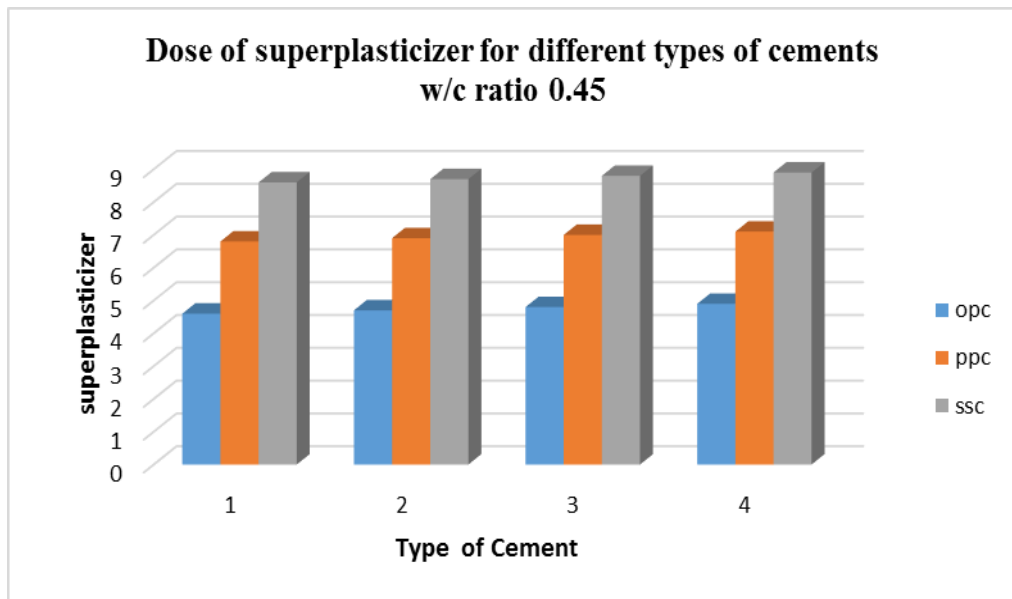


Fig: 4.5 Dose of superplasticizer for different types of cements w/c ratio 0.45

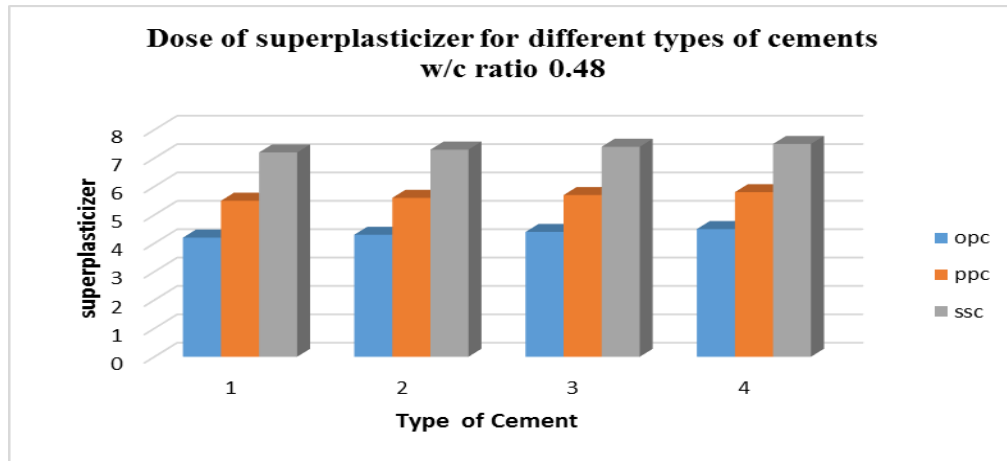


Fig: 4.6 Dose of superplasticizer for different types of cements w/c ratio 0.48

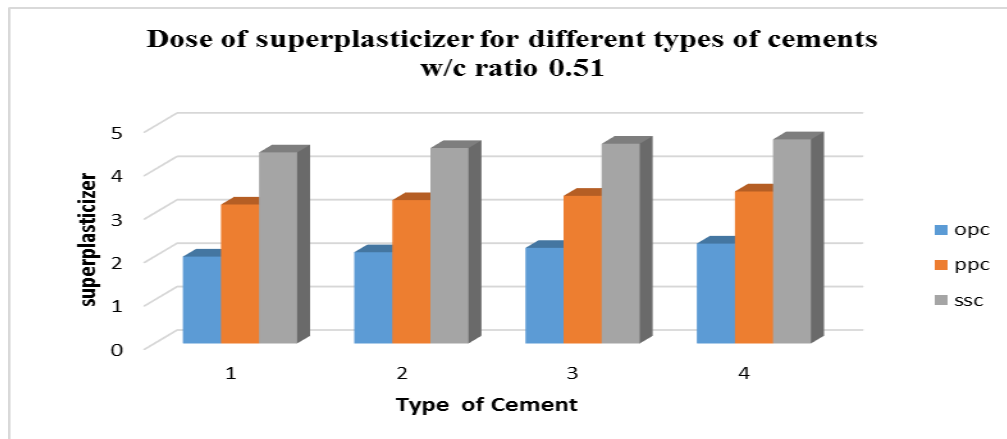


Fig: 4.7 Dose of superplasticizer for different types of cements w/c ratio 0.51

4.3. COMPRESSIVE STRENGTH

Three cubes (150mm) from each batch of concrete mix are casted and cured for 7 and 28 days in order to determine compressive strength of RCA concrete. All specimens are cast in a single mix and direct weight to weight replacement of natural coarse aggregate is carried out with recycled coarse aggregate at a replacement ratio of 0, 30, 60, and 90 %. The mixes are casted at water-cement ratio of 0.42, 0.45, 0.48 and 0.51. This corresponds to range of strength varying from low strength concrete to moderate strength concrete. Table 4.2 to 4.4 shows the value of compressive strength of cube tested for different types of cement at 7 and 28 days. The results obtained are discussed in the following sections:

Table 4.2. Cube compressive strength 7 and 28 days using OPC

Designation/Specimen ID	w/c Ratio	Replacement (%)	Compressive Strength	
			7 days (MPa)	28 days (MPa)
A1-0	0.42	0	38.82	47.84
A1-30		30	35.2	42.1
A1-60		60	34.2	43.5
A1-90		90	33.6	38.2
A2-0	0.45	0	37.72	45.72
A2-30		30	35.2	43.68
A2-60		60	32.8	41.4
A2-90		90	31.4	39.95
A3-0	0.48	0	31.42	40.72
A3-30		30	29.7	38.68
A3-60		60	28.8	37.6
A3-90		90	27.9	35.45
A4-0	0.51	0	31.28	38.84
A4-30		30	29.84	36.45
A4-60		60	27.98	35.3
A4-90		90	27.48	33.95

4.3.1 Effect of recycled coarse aggregate on compressive strength using OPC

As can be seen from Figure 4.8 - 4.11, for all water-cement ratios, the 28 days compressive strength decreases as the percentage of replacement increases. Maximum decrease in compressive strength is 20% and average decrease is 10%. However the same trend is at 7 days strength but with lesser decrease in strength. Similar trend is studied by Rahal et al. (2007) and Xiao et al. (2012) for 28 days compressive strength.

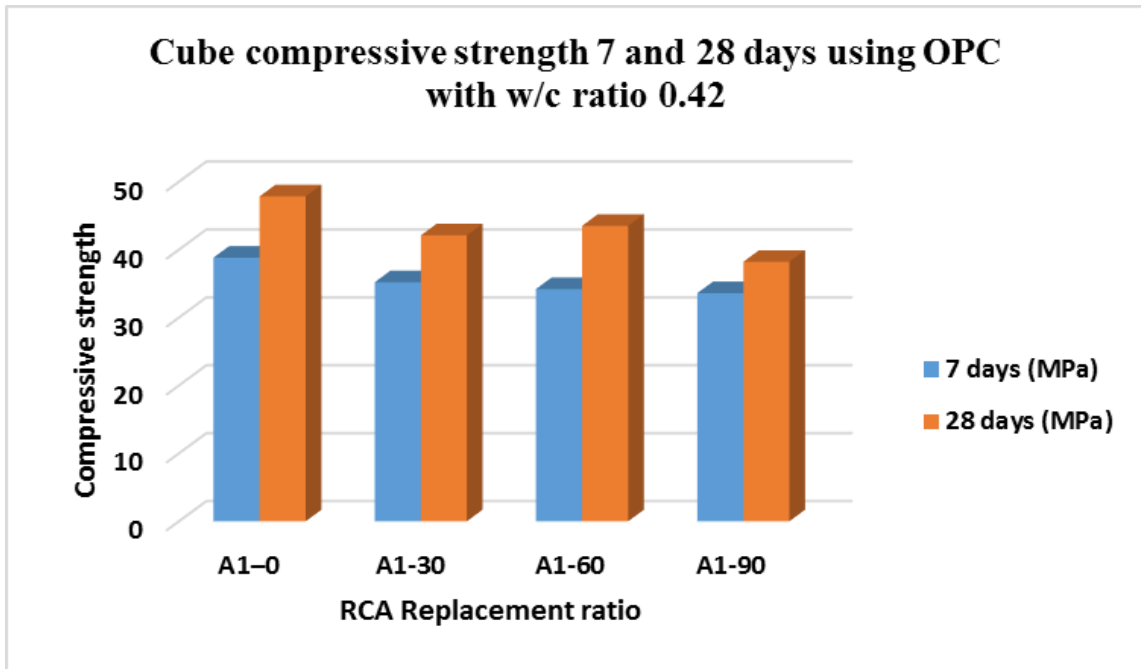


Fig: 4.8 Cube compressive strength 7 and 28 days using OPC with w/c ratio 0.42

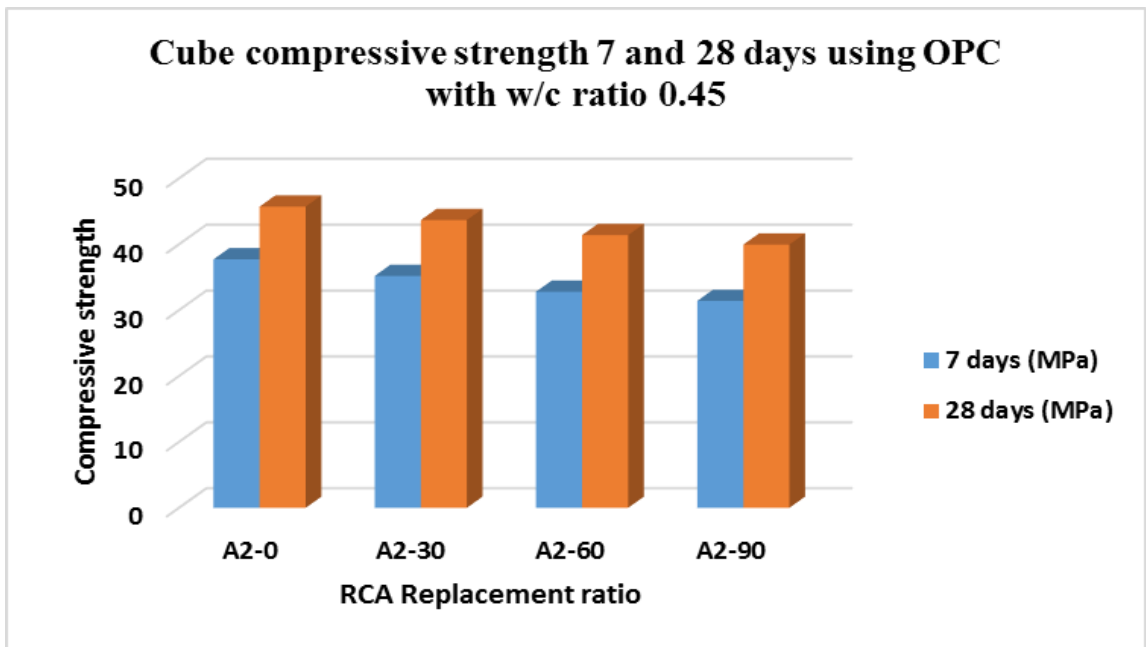


Fig: 4.9 Cube compressive strength 7 and 28 days using OPC with w/c ratio 0.45

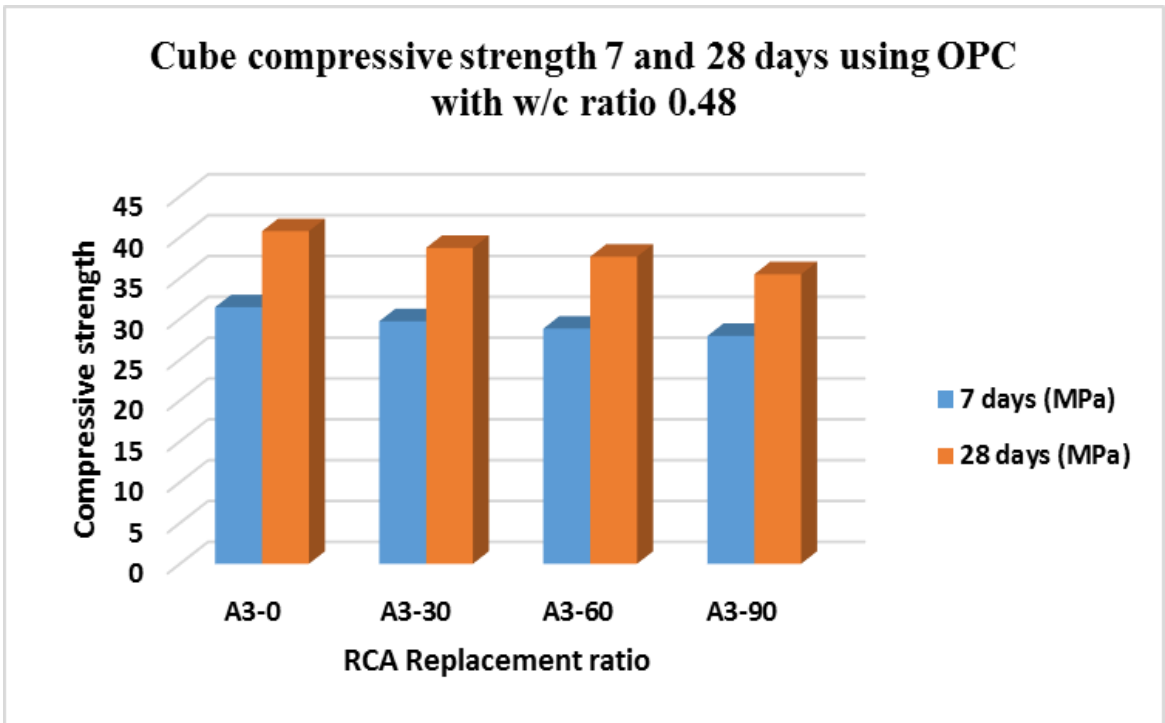


Fig: 4.10 Cube compressive strength 7 and 28 days using OPC with w/c ratio 0.48

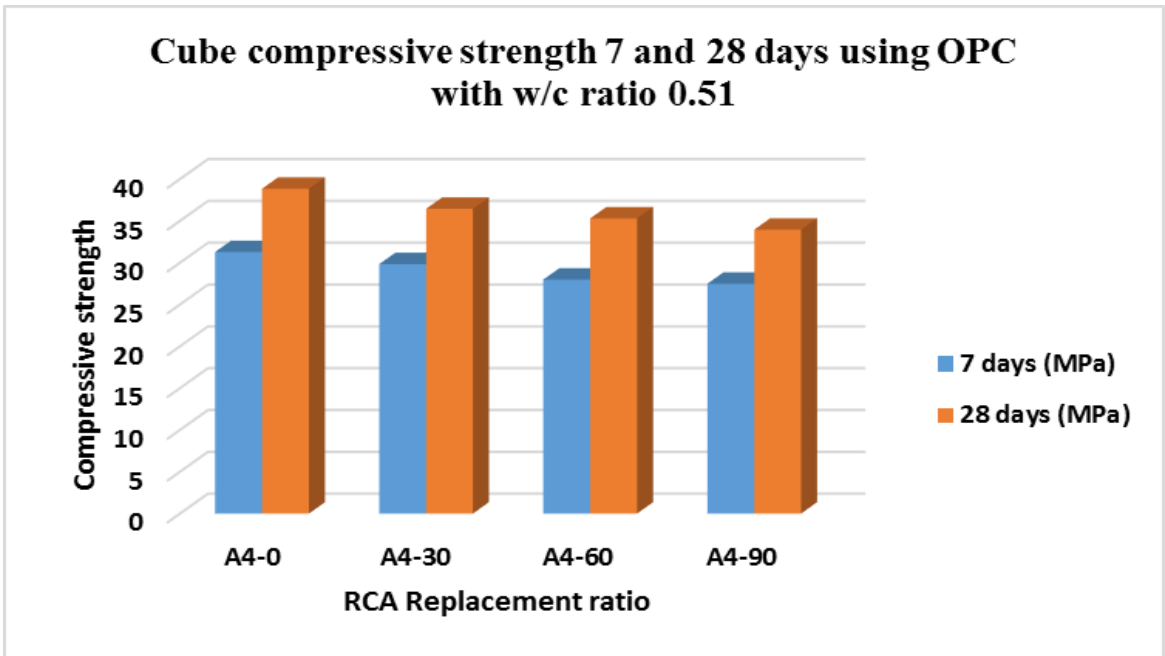


Fig: 4.11 Cube compressive strength 7 and 28 days using OPC with w/c ratio 0.51

4.3.2 Effect of recycled coarse aggregate on compressive strength using PPC

As can be seen from Figure 4.12 - 4.15, for all water-cement ratios, the 28 days compressive strength decreases as the percentage of replacement increases. Maximum decrease in compressive strength is 12% and average decrease is 10%. Somana et al . (2012) and Radonjanin et al .(2013) concluded that with the addition of ground ash / fly ash by 20 % by wt of binder content there is an increase in compressive strength. Similar trend is observed in our test results by using PPC cement , as flyash is mixed in cement itself at standard norms.

Table 4.3. Cube compressive strength 7 and 28 days using PPC

Designation/Specimen ID	w/c Ratio	Replacement (%)	Compressive Strength	
			7 days (MPa)	28 days (MPa)
A1-0	0.42	0	36.1	48.54
A1-30		30	34.8	46.1
A1-60		60	33.95	45.8
A1-90		90	32.4	43.2
A2-0	0.45	0	32.72	46.6
A2-30		30	29.7	44.4
A2-60		60	28.8	44.26
A2-90		90	27.4	41.48
A3-0	0.48	0	28.82	42.98
A3-30		30	27.78	40.78
A3-60		60	27.32	38.86
A3-90		90	26.93	38.65
A4-0	0.51	0	26.36	39.8
A4-30		30	25.45	37.4
A4-60		60	24.98	36.8
A4-90		90	24.5	34.95

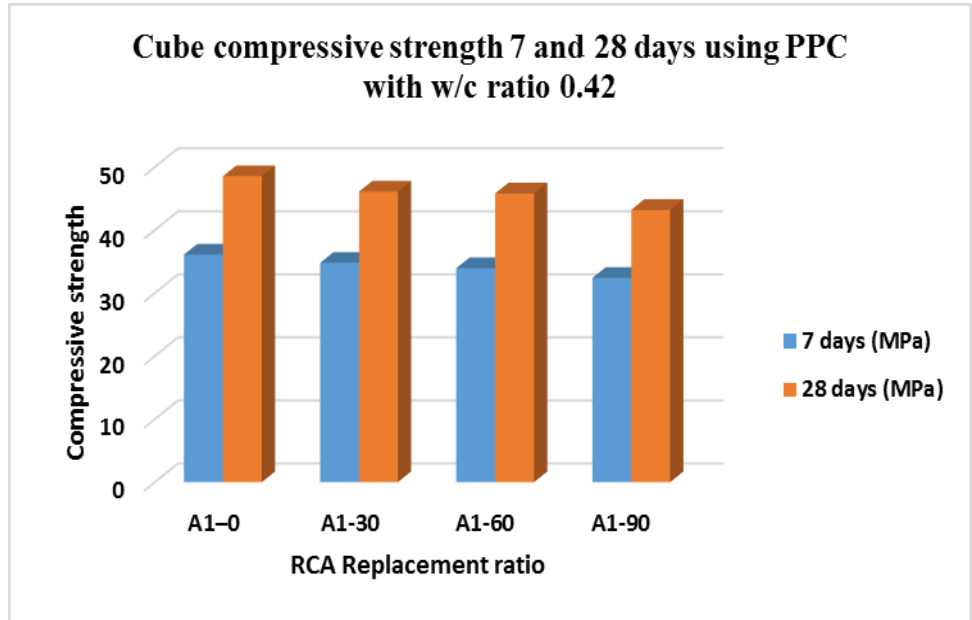


Fig: 4.12 Cube compressive strength 7 and 28 days using PPC with w/c ratio 0.42

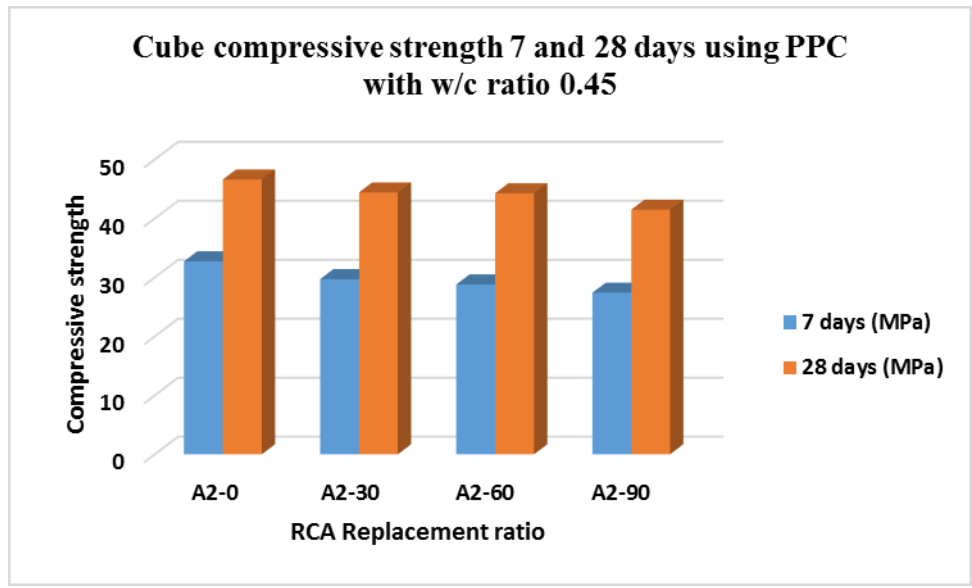


Fig: 4.13 Cube compressive strength 7 and 28 days using PPC with w/c ratio 0.45

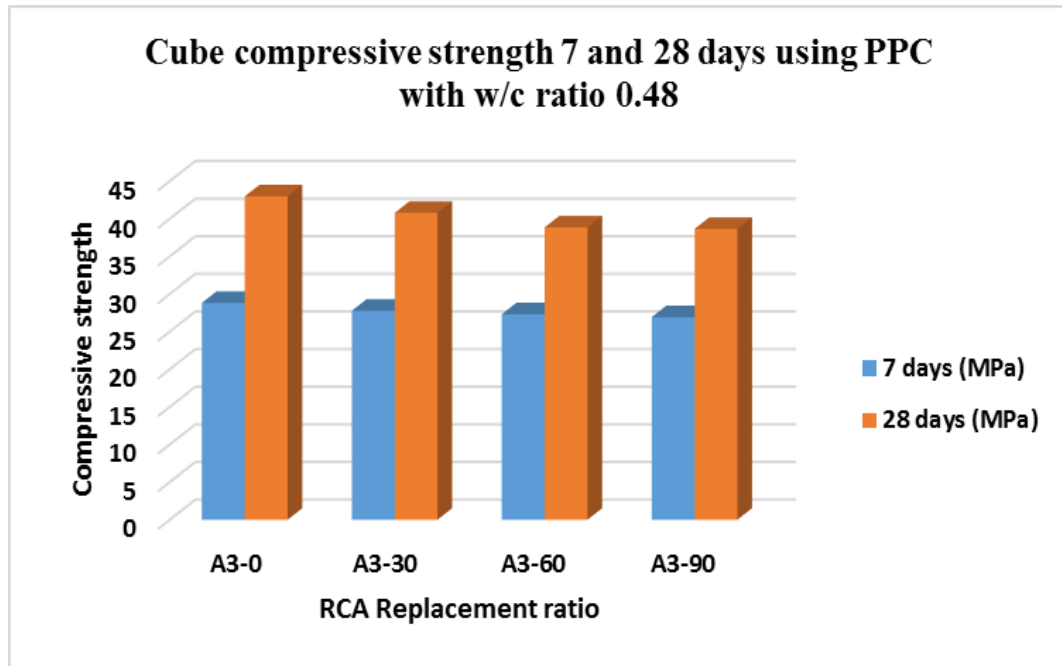


Fig: 4.14 Cube compressive strength 7 and 28 days using PPC with w/c ratio 0.48

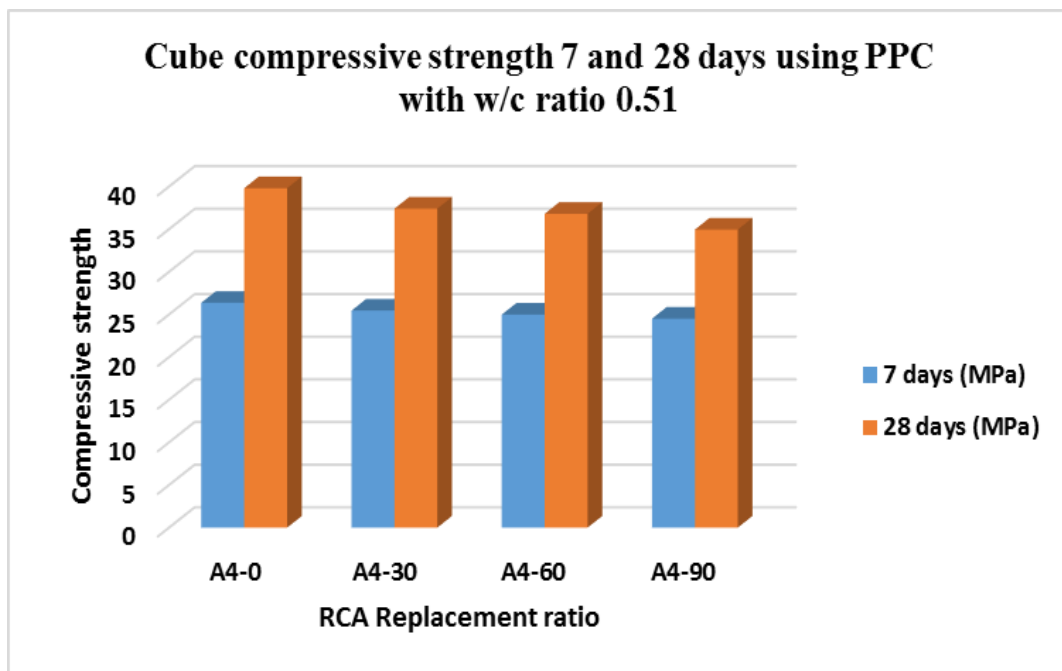


Fig: 4.15 Cube compressive strength 7 and 28 days using PPC with w/c ratio 0.51

4.3.3 Effect of recycled coarse aggregate on compressive strength using SSC

As can be seen from Figure 4.16 - 4.19, for all water-cement ratios, the 28 days compressive strength decreases as the percentage of replacement increases. Maximum decrease in compressive strength is 15% and average decrease is 12%. Qasrawi et al . (2013) concluded that with the addition of steel slag as partial replacement of aggregate results in an increase in compressive strength. Similar trend is observed in our test results by using SSC cement , as steel slag is mixed in cement itself at standard norms.

Table 4.4. Cube compressive strength 7 and 28 days using SSC

Designation/Specimen ID	w/c Ratio	Replacement (%)	Compressive Strength	
			7 days (MPa)	28 days (MPa)
A1-0	0.42	0	38.2	47.98
A1-30		30	35.4	45.2
A1-60		60	34.38	44.26
A1-90		90	33.88	39.42
A2-0	0.45	0	34.2	45.42
A2-30		30	32.4	43.88
A2-60		60	32.6	43.4
A2-90		90	31.34	41.45
A3-0	0.48	0	30.92	41.42
A3-30		30	28.95	40.68
A3-60		60	28.68	38.85
A3-90		90	27.18	36.78
A4-0	0.51	0	30.86	39.64
A4-30		30	28.95	36.28
A4-60		60	27.48	35.8
A4-90		90	26.85	34.78

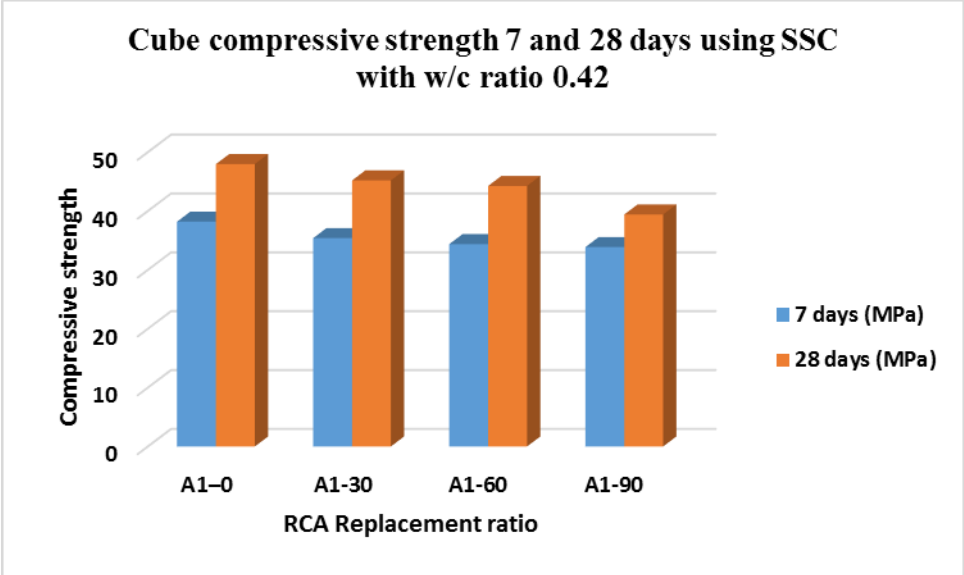


Fig: 4.16 Cube compressive strength 7 and 28 days using SSC with w/c ratio 0.42

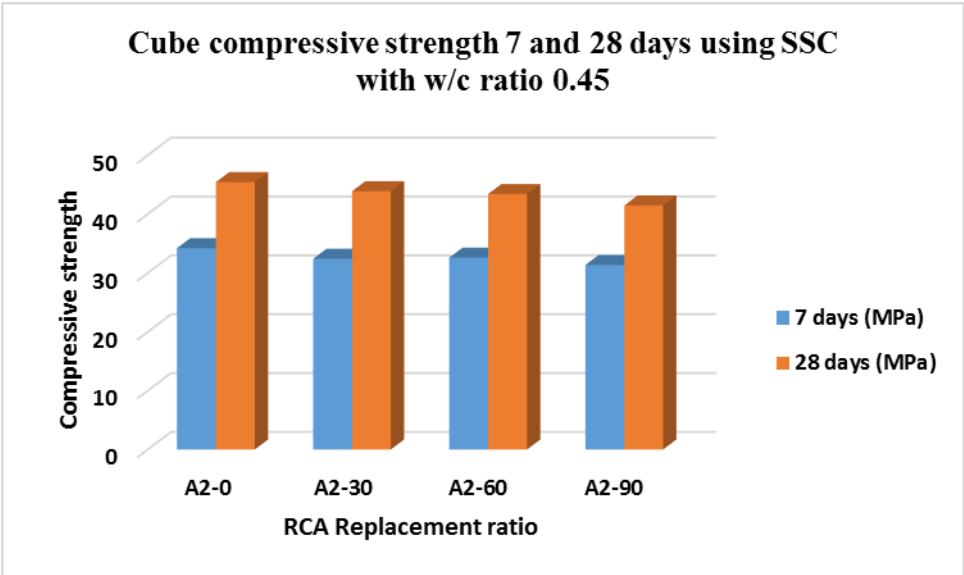


Fig: 4.17 Cube compressive strength 7 and 28 days using SSC with w/c ratio 0.45

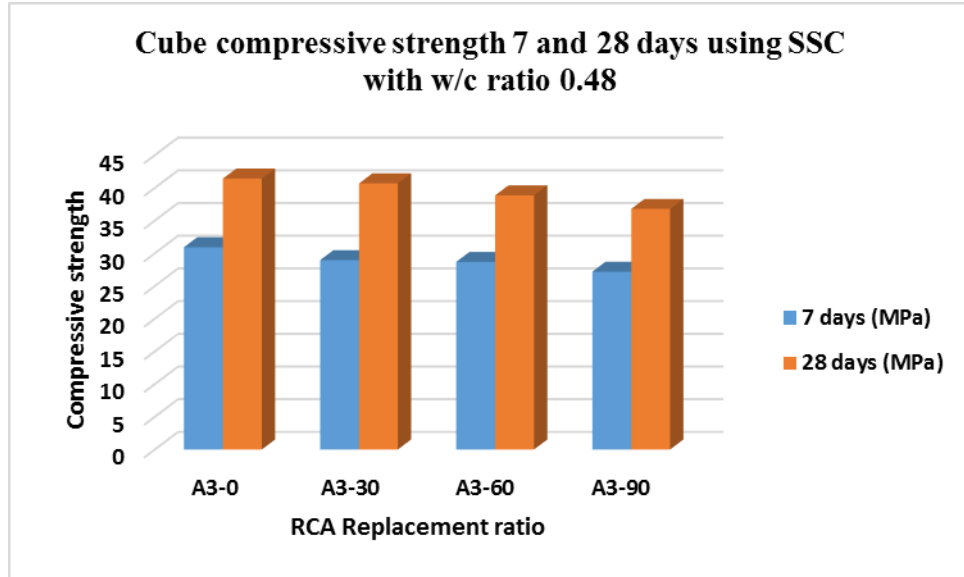


Fig: 4.18 Cube compressive strength 7 and 28 days using SSC with w/c ratio 0.48

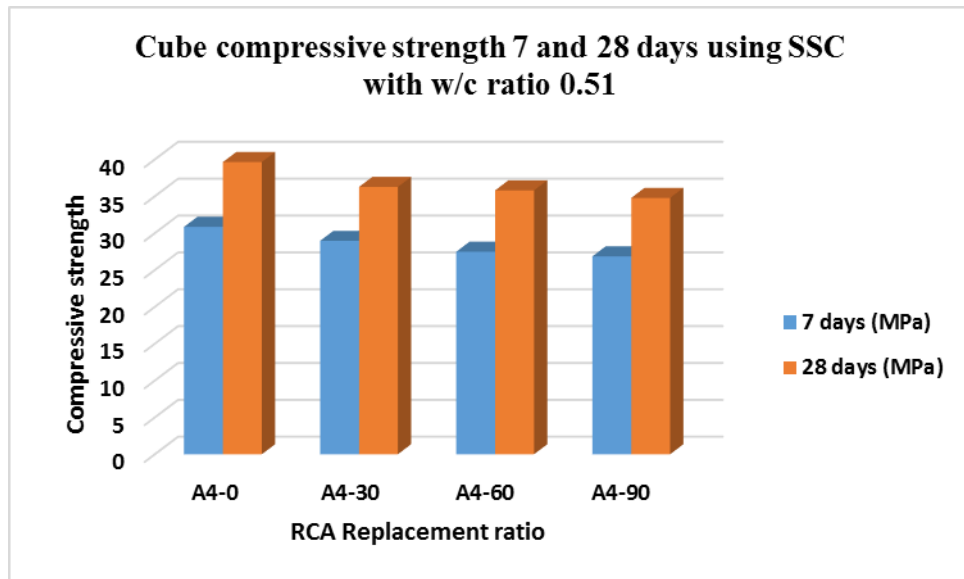


Fig: 4.19 Cube compressive strength 7 and 28 days using SSC with w/c ratio 0.51

4.4 EFFECT OF RECYCLED COARSE AGGREGATE IN COMPRESSIVE STRENGTH USING DIFFERENT TYPE OF CEMENT :

The results obtained are shown in table 4.5 and are discussed in the following sections

4.4.1 Effect of recycled coarse aggregate on increase / decrease in compressive strength using OPC & PPC :

Table 4.5 shows the value of increase / decrease in compressive strength cement OPC and PPC at 7 and 28 days. The results obtained are discussed in the following sections and the same can be seen from Figure 4.20 - 4.23 .It is noticed that as compared to OPC & PPC the 28 days strength of PPC is better than the corresponding strength of OPC for all w/c ratios & all %age replacements of RCA. However similar trend is not observed at 7 days . The 7 days strength of OPC is better than that that of PPC. This is due to the pozzolanic reaction of flyash and calcium hydroxide filled in voids of concrete and produced the addition in compressive strength. In addition the products could reduce the average pore diameter and pore size distribution resulting in denser concrete.

The effect of using PPC Cement Maximum at water cement ratio 0.42 the same can be observed from table no 4.5. The performance of OPC & PPC concrete is almost same at all percentage replacement levels that shows the type of cement does not have much effect when compared with % age of RCA.

Table 4.5. Increase / decrease in Cube compressive strength 7 and 28 days using OPC & PPC

Designation/Specimen ID	w/c Ratio	Replacement (%)	% age increase / decrease in compressive Strength	
			7 days (MPa) decrease	28 days (MPa) increase
A1-0	0.42	0	-7.01	1.46
A1-30		30	-1.14	9.50
A1-60		60	-0.73	5.29
A1-90		90	-3.57	13.09
A2-0	0.45	0	-13.26	1.92
A2-30		30	-15.63	1.65
A2-60		60	-12.20	6.91
A2-90		90	-12.74	3.83
A3-0	0.48	0	-8.27	5.55
A3-30		30	-6.46	5.43
A3-60		60	-5.14	3.35
A3-90		90	-3.48	9.03
A4-0	0.51	0	-15.73	2.47
A4-30		30	-14.71	2.61
A4-60		60	-10.72	4.25
A4-90		90	-10.84	2.95

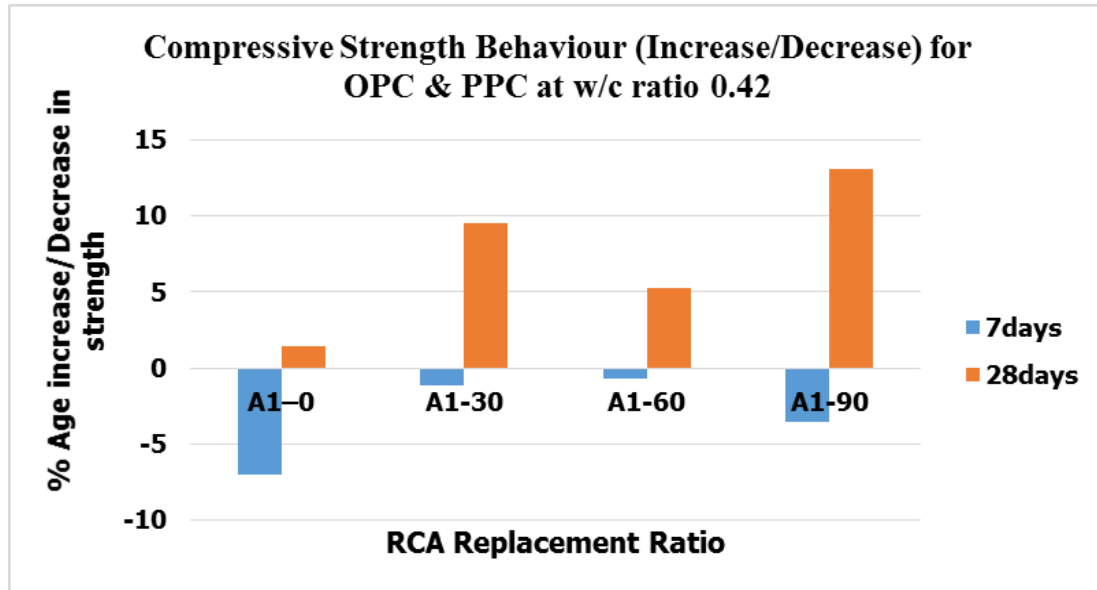


Fig: 4.20 Effect of recycled coarse aggregate on increase / decrease in compressive strength using OPC & PPC at w/c ratio 0.42

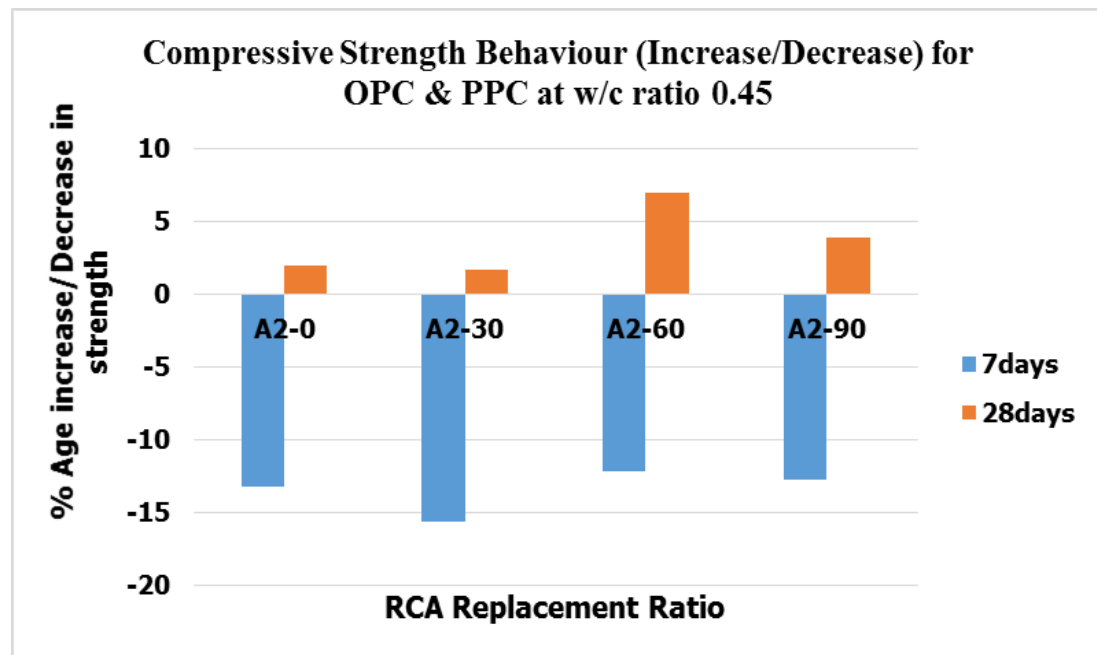


Fig: 4.21 Effect of recycled coarse aggregate on increase / decrease in compressive strength using OPC & PPC at w/c ratio 0.45

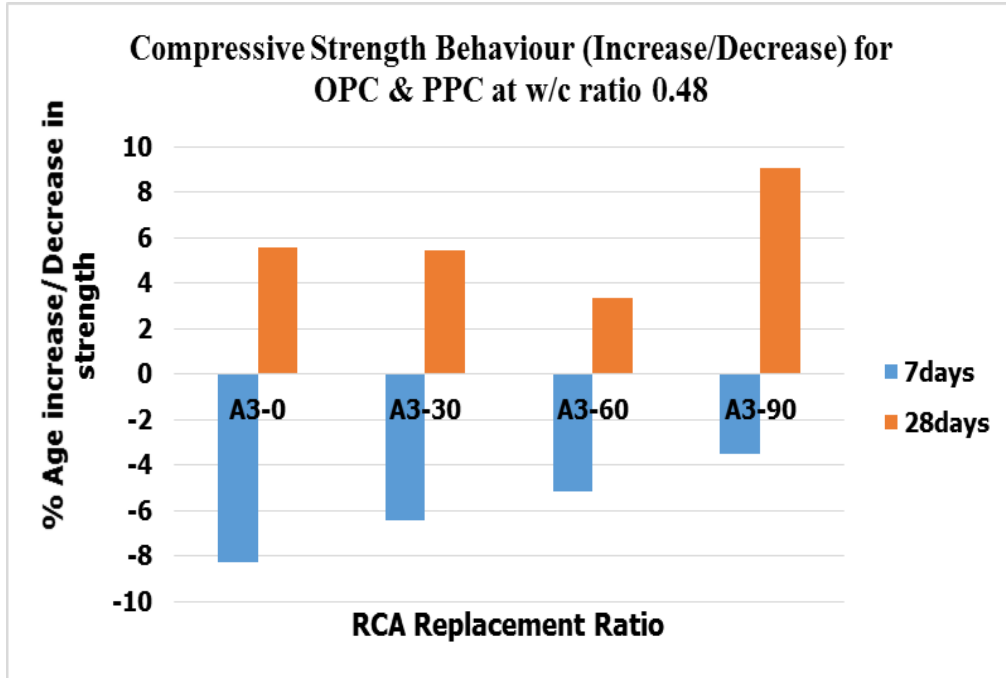


Fig: 4.22 Effect of recycled coarse aggregate on increase / decrease in compressive strength using OPC & PPC at w/c ratio 0.48

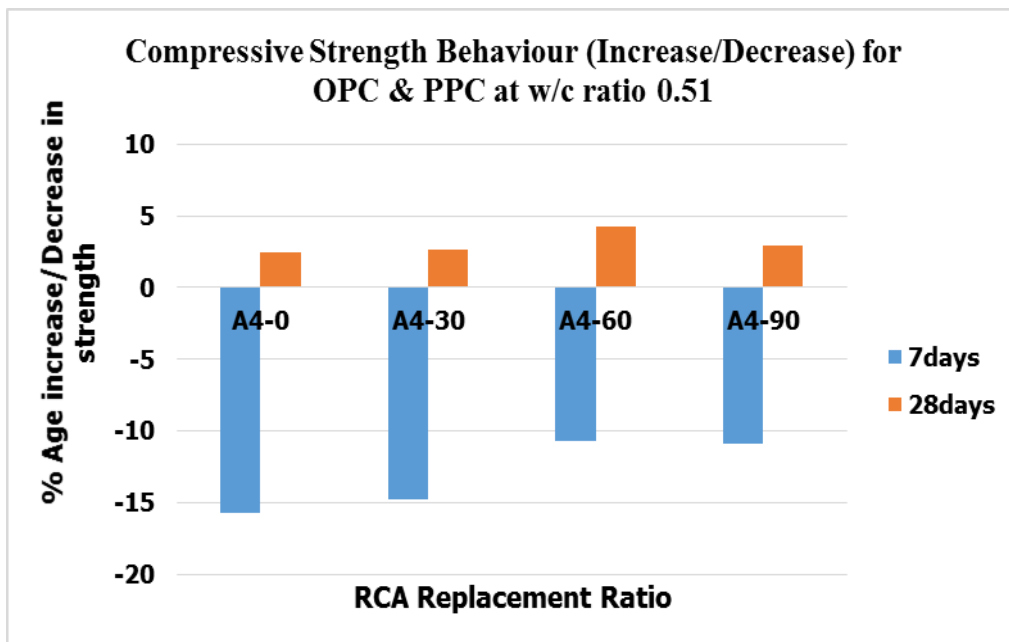


Fig: 4.23 Effect of recycled coarse aggregate on increase / decrease in compressive strength using OPC & PPC at w/c ratio 0.51

4.4.2 Effect of recycled coarse aggregate on increase / decrease in compressive strength using OPC & SSC :

Table 4.6 shows the value of increase / decrease in compressive strength cement OPC and SSC at 7 and 28 days. The results obtained are discussed in the following sections and the same can be seen from Figure 4.24 - 4.27 .It is noticed that as compared to OPC & SSC the 28 days strength of SSC is better than the corresponding strength of OPC for all w/c ratios & all %age replacements of RCA. However similar trend is not observed at 7 days . The similar trend is observed with using PPC cement , use of SSC leads to higher strength at 28 days although % age increase in strength is marginal & as can be observed from table 4.6 for 7 days of strength OPC is better than that that of SSC. This is also due to the pozzolanic reaction of ground ash / ground slag and calcium hydroxide filled in voids of concrete and produced the addition in compressive strength at later ages as discussed earlier in case of PPC. However the performance of PPC concrete is more better than that of SSC concrete.

It can therefore be concluded that the performance of PPC cement out of three types of cement at all percentage replacement levels at all w/c ratios is best .

Table 4.6. Increase / decrease in Cube compressive strength 7 and 28 days using OPC & SSC

Designation/Specimen ID	w/c Ratio	Replacement (%)	% age increase / decrease in compressive Strength	
			7 days (MPa) decrease	28 days (MPa) increase
A1-0	0.42	0	-1.60	0.29
A1-30		30	0.57	7.36
A1-60		60	0.53	1.75
A1-90		90	0.83	3.19
A2-0	0.45	0	-9.33	-0.66
A2-30		30	-7.95	0.46
A2-60		60	-0.61	4.83
A2-90		90	-0.19	3.75
A3-0	0.48	0	-1.59	1.72
A3-30		30	-2.53	5.17
A3-60		60	-0.42	3.32
A3-90		90	-2.58	3.75
A4-0	0.51	0	-1.34	2.06
A4-30		30	-2.98	-0.47
A4-60		60	-1.79	1.42
A4-90		90	-2.29	2.44

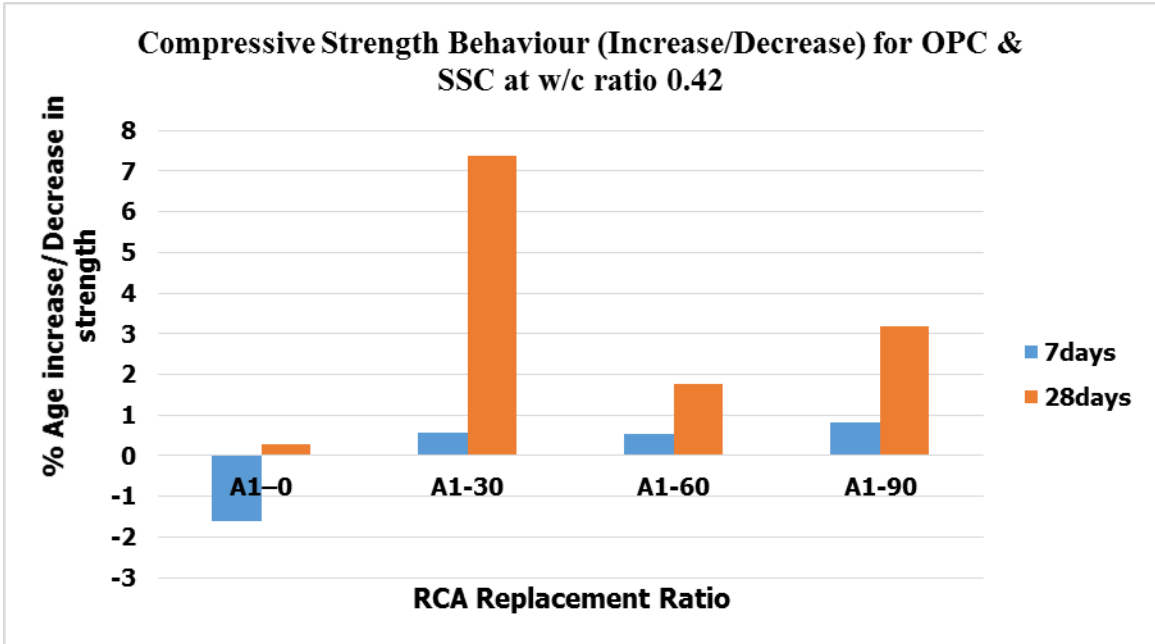


Fig: 4.24 Effect of recycled coarse aggregate on increase / decrease in compressive strength using OPC & SSC at w/c ratio 0.42

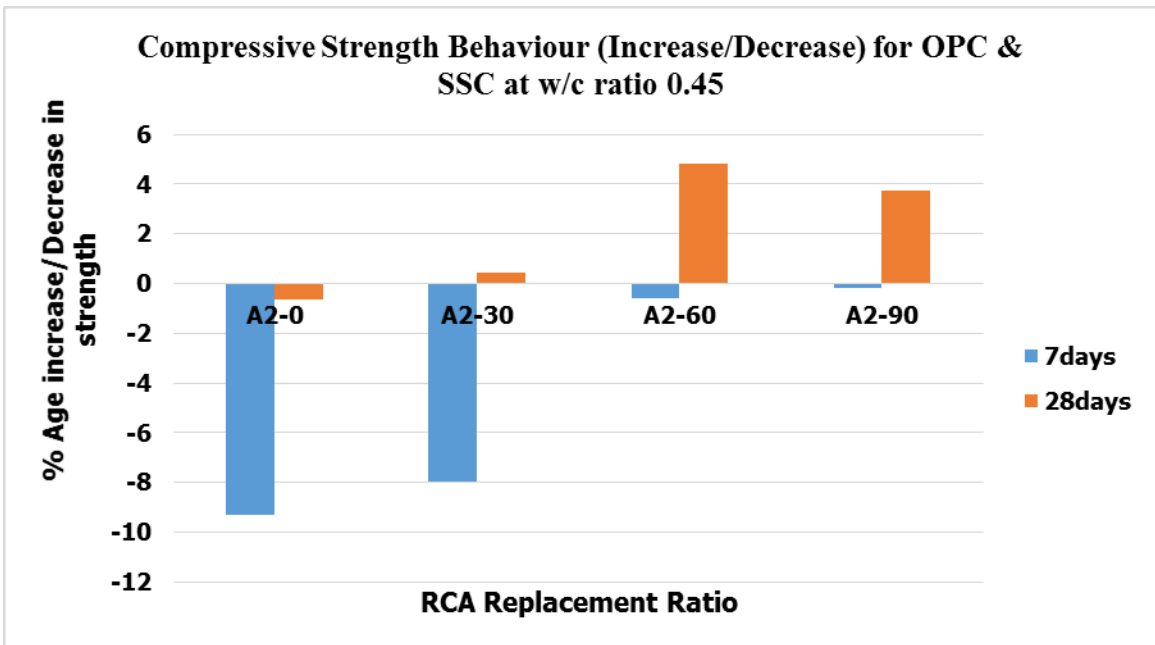


Fig: 4.25 Effect of recycled coarse aggregate on increase / decrease in compressive strength using OPC & SSC at w/c ratio 0.45

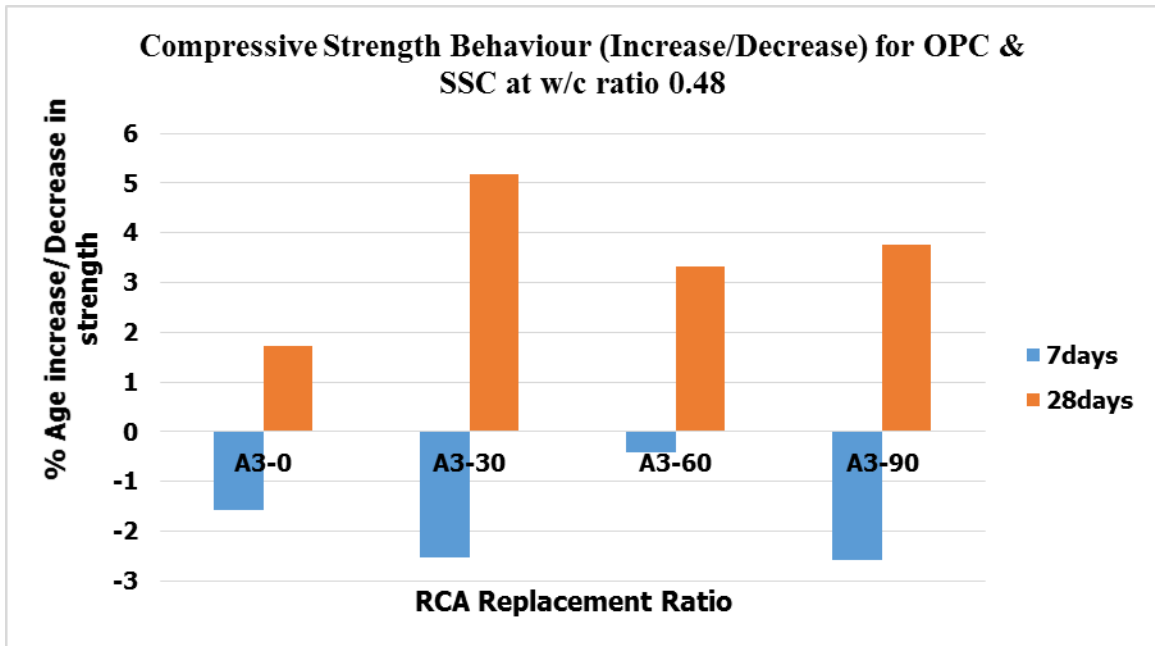


Fig: 4.26 Effect of recycled coarse aggregate on increase / decrease in compressive strength using OPC & SSC at w/c ratio 0.48

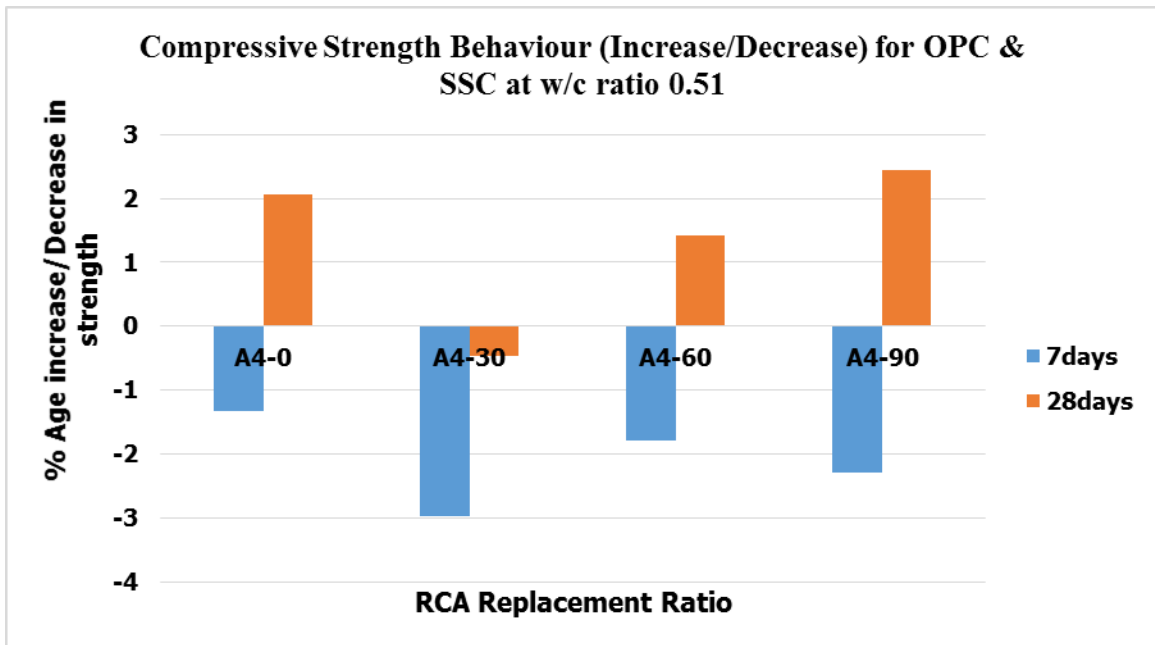


Fig: 4.27 Effect of recycled coarse aggregate on increase / decrease in compressive strength using OPC & SSC at w/c ratio 0.51

CHAPTER 5

CONCLUSIONS

5.1 INTRODUCTION

The reuse of recycled materials derived from construction and demolition waste is growing all over the world. The main scope of the work is to prepare the concrete by using different type of cement with replacing the natural aggregate with recycle concrete aggregates by (0%, 30%, 60% and 90%). The compressive strength of concrete after 7 days and 28 days and workability are compared for recycled concrete aggregate concrete and natural aggregate concrete. The major observations from this experimental work are as follows:

5.2 MAIN CONCLUSION OF STUDY

1. RAC requires more water for the same workability than normal concrete, the same can be controlled by addition of superplasticizers.
2. The use of RCA as coarse aggregate in concrete mixes resulted in a marginal decrease in the strength depending on the replacement ratio and the grade of concrete.
3. As compared to OPC & PPC the 28 days strength of PPC is better than the corresponding strength of OPC for all w/c ratios & all percentage replacements of RCA.
4. The performance of SSC & PPC concrete is almost same at all percentage replacement levels that shows the type of cement does not have much effect when compared with percentage of RCA.
5. SSC cement performs in decrease in workability and there is marginal increase in strength.
6. Considering all the mixes it can be said that PPC at 90% replacement level of RCA is giving the most economical and sustainable mix.

REFERENCES

- Agg Regain 2001, Recycled aggregate for use as capping in housing development, <[http://. www.aggregain.org.uk / casesstudy_detail.asp?projectID=44](http://www.aggregain.org.uk/casesstudy_detail.asp?projectID=44)>
- Ajdukiewicz, A. and Kliszczewicz, A. “Influence of Recycled Aggregates on Mechanical Properties of HS/HPC”. *Cement and Concrete Composites*, Vol. 24, 2002, pp. 269 – 279.
- Alizadeh R, Chini M, Ghods P, Hoseini M, Montazer Sh, Shekarchi M. Utilization of electric arc furnace slag as aggregates in concrete – environmental issue. Tehran: CMI Report; 1996.
- Bakoss P.S.L and Ravindrarajah R Sri 1999 ,recycled construction and demolition materials for use in road works and other local <http://www.ipwea.org.au/upload/final_scoping_report.pdf>
- Building innovation and construction Technology,1999, recycled hits, new high,<<http://www.cmit.csiro.au/innovation/1999-02.html>>
- Butler L., 2012, “Evaluation of Recycled Concrete Aggregate Performance in Structural Concrete”, thesis, The University of Waterloo, Canada, Viewed April 2013
- Davinel,2000,impulsion, <<http://www.nottongham.ac.uk/~evzard/cost2d-1.html#25>>
- DG/TJ08-2018-2007. Technical Code for Application of Recycled Concrete (in Chinese). 2007
- Hansen TC, Bøegh E. “Elasticity and drying shrinkage of recycled-aggregate concrete”. *ACI Material Journal* 1985;82(5) pp648–52.

- Hisham Qasrawi,2013 The use of steel slag aggregate to enhance the mechanical properties of recycled aggregate concrete and retain the environment pp 298-304
- Hong Kong Housing Department ,Use of recycled aggregate, <[http://. www. housing authority.gov.hk/en/buisnesspartners/ura/0,,00.html#10473,](http://www.housingauthority.gov.hk/en/businesspartners/ura/0,,00.html#10473)”
- IS 10262-2009, Recommended guidelines for concrete mix design,”Indian Standard Institution, New Delhi.
- IS 8112 (1989) (Reaffirmed 2005) 43 Grade ordinary Portland cement-specification. Bureau of Indian Standards, New Delhi, p 8
- Kamal M, Gailan AH, Haatan A, Hameed H. Aggregate made from industrial unprocessed slag. In: Proceeding of the 6th international conference on concrete technology for developing countries, Amman, Jordan, 2002.
- Katz A. Treatments for the improvement of recycled aggregate. J Mater Civil Eng 2004;16(6) pp 597–603
- Khatib, J.M., 2005. Properties of Concrete Incorporating Fine Recycled Aggregate.Cement and Concrete Research, V. 35, pp.763-69.
- Kishore, Revande (1998) –“Recycled Aggregate Concrete- A prospective structural grade concrete”All India seminar on Concrete for infrastructure development,CID-98,pp 303-315
- Lam L, Wong YL, Poon CS. Degree of hydration and gel/space ratio of high volume fly ash /cement systems Cement Concrete Resources 2000;30(5)pp747–56.
- Limbachiya M.C. , Leelawat T and Dhir R.K , 2000 , Use of recycled concrete aggregate in high strength concrete , Materials and structures, vol 33, Nov 2000,p574-580

- Manso J, González J, Polanco J. Electric furnace arc slag in concrete. *J Mater Civ Eng ASCE* 2004 pp:639–45.
- Manso J, Polanco J, Losañez M, González J. Durability of concrete made with EAF slag as aggregate. *Cement Concrete Composites* 2006;28(6) pp:528–34.
- Maslehuddin M, Alfarabi M, Shammem M, Ibrahim M, Barry M. Comparison of properties of steel slag and crushed limestone aggregate concretes *Construction and Building Materials* (17) 2003 pp:105–12.
- Michael Henry, German Pardo, Tsugio Nishimura and Yoshitaka Kato (2011) Balancing Durability and environmental impact in concrete combining low grade recycled aggregates and mineral admixtures “ resources conversation and recycling 55(2011) pp1060-1069
- Neville, A.M., 1995. “Properties of Concrete” UK: Longman. p844.
- Poon, C. S., Kou S. C., Lam, L., 2007. “Influence of Recycled Aggregate on Slump and Bleeding of Fresh Concrete”. *Materials and Structures*, V. 40(No. 9), pp981-88.
- Poon, C.S. et al., 2004. “Influence of Moisture States of Natural and Recycled Aggregates on the Slump and Compressive Strength of Concrete”. *Cement and Concrete Research*, V 34, pp31-36.
- Qasrawi H, Marie I. Towards better understanding of concrete containing recycled concrete aggregate. *Adv Mater Sci Eng* (8) 2013 Article ID 636034.
- Qasrawi H, Marie I, Tantawi H. The use of concrete rubbles as coarse aggregate in concrete. In: 5th Jordanian civil engineering conference, JAE, Jordan, January 2012. pp. 281–87.

- Rahal, K., 2007. “Mechanical Properties of Concrete with Recycled Coarse Aggregate. Building and Environment”, V. 42, pp 407-15.
- Rakshvir M., Barai S. V., 2006, “Recycled aggregates-based concrete”. Waste Management & Research, Vol. 24, No. 3, 225-233,
- Rao A., Experimental Investigation on Use of Recycled Aggregates in Mortar and concrete. Thesis submitted to the Department of Civil Engineering, Indian Institute of Technology Kanpur(2005)
- Rao MC, Bhattacharyya SK, Barai SV. Influence of field recycled coarse aggregate on properties of concrete. Material Structure 2011;44(1) pp205–20.
- RILEM. “Specifications for concrete with recycled aggregates”. Mater Structure, 1994, 27: 557–559.
- S. Hasaba, M. Kawamura, K. Torik, K. Takemoto, Drying shrinkage and durability of the concrete made of recycled concrete aggregate, Transactions of the Japan Concrete Institute 3 (1981) pp 55–60
- Shekarchi M, Alizadeh R, Chini M, Ghods P, Hoseini M, Montazer Sh. Study on electric arc furnace slag properties to be used as aggregates in concrete. InCANMET/ACI international conference on recent advances in concretetechnology, Bucharest, Romania, June, 2003.
- Shekarchi M, Soltani M, Alizadeh R, Chini M, Ghods P, Hoseini M, Montazer Sh. Study of the mechanical properties of heavyweight preplaced aggregate concrete using electric arc furnace slag ssa aggregate. In: International conference on concrete engineering and technology, Malaysia, 2004.

- T.C. Hansen, H. Narud, Strength of recycled concrete made from crushed concrete coarse aggregate, *Concrete International—Design and Construction* 5 (1) (January 1983) pp79–83.
- Vlastimir Radonjanin , Mirjana Malesev, Snezana Marinkovic , Ali Emhemd Saed Al Maly 2013 “Green recycled aggregate concrete”*Construction and Building Materials* 47 (2013) pp1503–1511
- Xiao J, Li J, Zhang C. Mechanical properties of recycled aggregate concrete under uniaxial loading. *Cement Concrete Resources* 2005;35(6)pp 1187–94.
- Xiao J, Wengui Li, Yuhui Fan, Xiao Haung (1996-2011). An overview of study on recycled aggregate concrete in china *Construction and Building Materials* 31 (2012) pp364–383
- Xu Y. Z., Shi J G. “Analyses and evaluation of the behaviour of recycled aggregate and recycled concrete” (in Chinese). *Chinese Concrete Journal*, 2006, 7: 41–46.
- Yong PC, Teo DCL. Utilization of recycled aggregate as coarse aggregate in concrete. *UNIMAS E-Journal Civil Engg* 2009(1) pp1–6.
- www.ies.org.sg
- www.science direct.com