EFFECT OF UNPROCESSED AND PROCESSED RECYCLED AGGREGATE ON THE COMPRESSIVE STRENGTH OF HIGH STRENGTH CONCRETE

A

PROJECT REPORT

Submitted in partial fulfilment of the requirements for the award of the degree of

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Under the supervision of

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to

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

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HIMACHAL PRADESH, INDIA

May, 2019

STUDENT'S DECLERATION

I hereby declare that the work presented in the Project report entitled "**EFFECT OF UN-PROCESSED AND PROCESSED RECYCLED AGGREGATE ON THE COMPRESSIVE STRENGTH OF HIGH STRENGTH CONCRETE"** submitted for the fulfilment of the requirements for the degree of Bachelor of Technology in Civil Engineering at **Jaypee University of Information Technology, Waknaghat** is an authentic record of my work carried out under the supervision of **Mr. Kaushal Kumar.** This work has not been submitted elsewhere for the reward of any other degree. I am fully responsible for the contents of my project report.

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CERTIFICATE

This is to certify that the work which is being presented in the project report titled "**EFFECT OF UNPROCESSED AND PROCESSED RECYCLED AGGREGATE ON THE COMPRESSIVE STRENGTH OF HIGH STRENGTH CONCRETE"** in fulfilment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **Aditya Sharma (151637) & Ashish Verma (151672)** during a period from August, 2018 to May, 2019 under the supervision of **Mr. Kaushal Kumar,** Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

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PREFACE AND ACKNOWLEDGEMENT

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ABSTRACT

The growing industrialization and rapid infrastructural development has resulted in the increased demand of concrete and especially high strength concrete. With greater than before demand for concrete the enormous quantity of natural aggregate is required for making concrete. This in turn has resulted in the depletion of the natural sources of course aggregates. Also large amounts of construction and demolition wastes are generated per year and dumping of these creates huge problem to the environment like presence of inert and non biodegradable materials, emission of carbon dioxide and scarcity of land fill areas. Also, roadside dumping causes problem to the traffic flow causing additional workload to the local administration. Thus, to tackle the above mentioned problems, the introduction of recycled aggregate comes into the picture.

The study has been done in three phases: (i) using natural aggregate in making high strength concrete, (ii) use of un-processed recycled aggregate (UPRA) at 20%, 40% & 50% replacement with natural aggregate and studying its effect in attaining the required compressive strength, (iii) use of processed recycled aggregate (PRA) at 20%, 40% & 50% replacement with natural aggregate and studying its effect in attaining the required compressive strength. The processing of PRA was done using "straight forward mechanical grinding approach" in which the aggregates to be processed were introduced in Los Angeles abrasion machine to get rid of the adhered mortar. Effect of different revolutions (200, 500 & 700 revolutions) on concrete boulders to produce the required compressive strength were studied for each replacement percentage (20%, 40% & 50%). Two-stage mixing approach was adopted for a homogenous mix.

In conclusion, processed recycled aggregate with 500 and 700 revolutions at 20% replacement with natural aggregate gave the desired compressive strength compared to 200 revolutions. Also, in general, compressive strength attained with PRA 500 and 700 revolutions results were closest to the desired compressive strength i.e. 50MPa in 28days. Results obtained from 500 and 700 revolutions were almost same so we adopted 500 revolutions as the most suitable processed recycled aggregate.

However, on the other hand desired compressive strength of 50MPa at 28 days was not attained using UPRA.

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Symbols	**Meaning**
MPa	mega Pascal (unit of pressure) = N/mm^2
mm	millimetre
cm	centimetre
%	percentage
ml	millilitre
g	grams
m	meter
μ	micron
pH	phenolphthalein
&	and

ABBREVIATIONS

Abbreviations	Meaning
w/c	Ratio of Water to cement Content
RCA	Recycled concrete aggregate
HSC	High Strength Concrete
ASTM	American Standard for Testing and Materials
NA	Natural Aggregate
RA	Recycled aggregate
CPCB	Central pollution control board
C&D	Construction and demolition waste
OPC	Ordinary Portland cement
PRA	Processed recycled aggregates
ITZ	Interfacial transition zone
CTM	Compression testing machine
FM	Fineness modulus
IS	Indian standards
SP	Special publications

NAC	Natural aggregate concrete
SEN	Scanning electron microscope
CSH	Calcium silicate hydrate
UPRA	Unprocessed recycled aggregate
RVS	Revolutions
IST	Initial setting time
FST	Final setting time
C	Cement
W	Water
FA	Fine aggregate
P	Normal consistency of cement
TIFAC	Technology information forecasting and assessment council
Acc.	According
Approx.	Approximate

CHAPTER 1

INTRODUCTION

1.1 General

The environmental concerns is of great importance like sustainable use of natural resources for the production of natural aggregate, increased carbon emission resulting in global warming, presence of inert and non biodegradable waste. As a result, saving of natural resources and using waste demolished waste becomes important. Also due to rapid urbanisation increased industrialisation has caused serious problems to the environment. According to Wai et al. 2012, construction industry is one of the highest consumers of natural resources and also an enormous construction and demolished waste producer. Among all the construction and demolition waste, concrete has the major contribution with 40% according to (CPCB) Delhi, India survey 2012.

Therefore, keeping in mind the environmental safety & sustainable construction methods efforts are made to use the recycled aggregate obtained from construction and demolished (C&D) waste in making high strength concrete. To ensure sustainable and safe construction practice the use of RCA i.e. recycled concrete aggregate is recommended. Also it will ensure the less usage of natural resources.

1.2 Construction and Demolition (C&D) waste scenario of India

Due to increased population and rapid urbanisation the extent of construction has been boosted, reaching its peak. Therefore, demanding for more houses for people to live, more offices to work in, more factories to produce goods etc. This results in the increased probability of the generation of construction and demolition waste.

Generation of construction and demolition waste can be due to construction, demolition, renovation activities and natural disasters like tsunami, earthquake, war, cyclones taking place. According to the waste management world, 2012 around 12 million to 14.7 million tonnes per annum of total quantum of waste is generated from the construction industry in India per year and out of which 7 to 8 million are concrete and bricks waste. Table 1.1 shows the quantity of construction and demolition waste generated in India per annum in India.

Table 1.1 Quantity of waste generated per annum in India*

C&D waste constituents	Quantity(million tonnes per annum)
Soil, sand and gravel	4.20 to 5.14
Bricks and masonry	3.60 to 4.0
Concrete	2.40 to 3.67
Metal	0.60 to 0.73
Bitumen	0.25 to 0.30
Wood	0.25 to 0.30

(*Source: Technology Information, Forecasting and Assessment Council (TIFAC), Department of Science and Technology, Government of India)

1.3 Utilization of recycled aggregate in concrete

It is beneficial to use recycled aggregate in concrete as a substitute for natural aggregate as it helps in the conservation of natural resources and saves money too. However, issues like high water absorption due to adhered mortar, the characteristics of parent rock, origin of C&D waste, how old the demolish structure is, water content, type of cement, chlorine content are the dependent factors for the performance of concrete. As these factors are not easy to predict this becomes the major weakness of using C&D waste in concrete. Hence, researchers have utilized RA as a partial replacement of natural aggregate in concrete. There are also some drawbacks in RCA like limited slump, low mechanical strength, high water absorption, sorptivity, chlorine- ion penetration, dry shrinkage, abrasion loss, creep etc.

Therefore, RA is usually used in low grade concretes and as filling materials. Literature review confirms that it is the adhered mortar that affects the efficiency of the concrete in fresh and hardened state. The use of RA in high strength concrete is very rare due to the problem associated with recycled aggregates. The researchers who have used RA in high strength concrete have used unprocessed recycled aggregates, due to which the use of recycled aggregate was limited. Few researchers used normal mixing approach for the introduction of PRA also but the results were not satisfactory. Some researchers used unprocessed RA by using two staged mixing approach and the RA dosage was limited to 30% only. [Limbachiya (2000), Tam (2005), Dhir and Paine (2010), Kou and Poon (2012).

1.4 Necessity for the present work

It is very well known that concrete can easily be mould, has good fire resisting property, and is readily available making it an important building material. A concrete is said to be a good quality concrete if it has high durability, high mechanical strength and reasonably good workability.

From the previous data collected, tonnes of concrete are produced every year for the construction purpose in which roughly 70%-80% of the concrete is comprised of coarse aggregate [Dhir and Paine (2010)]. Hence, it creates a necessity to choose an alternative for coarse aggregate as it will ensure sustainable use of natural aggregate. Therefore, recycled aggregate can be used as a replacement for coarse aggregate. Although the use of recycled aggregate is gaining popularity, its application is limited to minor and temporary works due to the variation in the characteristics of recycled aggregate, variation in the source of recycled aggregate and the adhered mortar.

Very few researchers have used recycled aggregate to produce high strength concrete. Among those few researches the recycled aggregate used were unprocessed. As a result the replacement level was very less.

From the past researchers it was noticeable that the cement used was OPC. However, it is very well known that about 75%-85% of the cements used are blended cement like PPC and PSC. It was also reported in the previous research papers that the usage of minerals and chemical admixtures readily improve performance of high strength concrete containing recycled aggregate. Also it is observed that the combine method of using two stage mixing and processing techniques i.e. straight forward mechanical grinding approach were used rarely. Therefore, in our present research straight forward mechanical grinding approach and two stage mixing approach were used together to produce high strength concrete containing recycled aggregates.

1.5 Research objectives

The present research is being done to utilise maximum possible percentage of RA in RCA to form a high strength concrete using a suitable chemical admixture and also to find the process of obtaining recycled aggregate. Initially the aim is to make high strength concrete using 100% natural aggregates (NA) for the comparison purpose and then moving on to increase the replacement level of NA by UPRA/PRA by 20%, 40%, 50% to find the optimum replacement level.

For reaching the goal of making high strength concrete two-stage mixing approach will be followed and processed recycled aggregate will be used using straight forward mechanical grinding technique.

1.6 Research methodologies

To utilize the maximum quantity of recycled aggregates to produce high strength concrete the existing problem related to RA and RCA were thoroughly studied to understand the basic scenario of both RA and RCA. Next step was the available techniques of processing and mixing investigation for the improvement of the performance of RCA.

Due to insufficient information on recycled aggregate the quantity of RA varies from source to source. Therefore, various factors are controlling the final quality of RA. Hence, based on the study of literature review a process technique called “straight forward mechanical grinding technique” and “two-stage mixing approach” has been used to overcome the difficulty usually encountered by RA and RCA in the production of high strength concrete.

In the present study the work has been carried out in two phases:

- Influence of un-processed and processed RA on the properties of RCA
- Influence of mixing approaches on the properties of RCA

The mix proportion of M50 grade has been kept constant in both phases. However, the new mix is prepared each time by replacing NA with UPRA/PRA at different proportion. The percentage replacement of NA with UPRA/PRA varies from 0% to 50%.

In the first phase, the adhered mortar will be removed using straight forward mechanical grinding technique to improve the quality of RA. Once the adhered mortar is removed dosage can be increased accordingly.

In the second phase, two stage mixing technique is used to improve the performance of recycled aggregate in concrete mix.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The use of recycled aggregate is gaining popularity and has become common in recent years. Researchers have used RA in high as well as in low grade concrete application. However, the quality of RA varies from source to source which makes it necessary for the further research in the area of high strength concrete. Also not much of the research has been done in making high strength concrete using RA.

The literature review presented in this chapter will give necessary information about C&D waste, recycled aggregate (RA) and recycled aggregate concrete (RAC). It will also discuss about the previous research that has been done in this field.

2.2 Previous researches

Neville (1) concluded that interfacial transition zone (ITZ) between cement paste and aggregates play a vital role in determining the mechanical performance and thus the strength. ITZ will ultimately decide the behaviour of the concrete. This is so because interfacial transition zone is a region with high water to cement ratio and thus high porosity, making it the weakest part of the concrete paste. Hence, strengthening of this region will decide the ultimate strength of the concrete mix.

Tam (2) studied that quality and performance of recycled aggregate is generally lower than that of natural aggregate. This is the main reason why is it is used as a partial replacement rather than 100% replacement.

Khaldoun (3) through an experimental program studied the mechanical properties of RAC and compared it to that of NA with SP and found that the compressive strength of RAC was about 90% of that of NAC and exhibited similar behaviour with respect to the rate of strength development and workability.

Topcu (4) reported that the specific gravity of RA was lower and the water absorption ratio was much higher than that of normal crushed aggregates. It was concluded that concrete with more than 50% RA experienced workability problem.

Amon (5) concluded that the compressive strength of RA increases by addition of silica fumes solution and by ultrasonic cleaning up to 15% and 7% respectively.

Otsuki (6) reported that the resistance of recycled aggregate concrete to chlorine ion penetration and carbonation were slightly inferior to those of natural aggregate (NA). The reason he claimed was due to the adhered mortar to RA. This adhered mortar leads to weak interfacial zone.

Fong & Jaime (7) reported that slump loss of concrete will be fast for recycled aggregate concrete without pre-wetting of RA.

Niro (8) concluded that it was impossible to make RCA concrete stronger than 35 MPa when w/c ratio was between 0.45-0.50 and a compressive strength of 60MPa was achieved when w/c ratio was 0.35.

Dhir (9)stated with 30% replacement of NA with RA there were no significant adverse effects on RAC cube strength and for higher replacement level minor alterations were necessary in mix design.

Limbachiya (10) concluded that it was possible to make high strength concrete with compressive strength 50MPa or more with 30% replacement level of NA with RA. With further increase in replacement resulted in gradual reduction in compressive strength.

2.3 Previously used processing techniques of RA

Jishen Qiu (11): In this particular research to process the recycled aggregates microbial carbonate precipitation was done. There was increase in the amount of microbial carbonate precipitation with increase in the temperature, bacterial concentration or calcium concentration and its peak was at *pH*=9.5. There was constant check on controlling the culturing and precipitation conditions to ensure efficient microbial precipitation on recycled aggregate concrete. The results showed that there was decrease in the water absorption of processed recycled aggregate. However, their effects on the mechanical properties were not studied.

Sallenhan and Mahyuddin (12): According to their research, acid treatment was the way to produce good quality recycled aggregate. Hence, to study the effect, low concentration acid of different molarities was used as acid solvent at different age of treatment (soaking) on properties of RCA. The influence of the treated/processed recycled aggregate was studied on the properties of the concrete. The results showed significant improvement in physical and mechanical properties of concrete due to the use of acid of different molarities by removing adhered mortar to the aggregate. Also removal of significant amount of the adhered mortar resulted in better bond between the aggregate and the cement paste ensuring good strength. However, there are various other factors that need more consideration, on which the efficiency of this method depends.

Valerie and Tegguer (13): To produce a good quality recycled aggregate they used polymer treatment. Various tests were conducted to observe the water absorption and fragmentation resistance of recycled concrete aggregate to understand the efficiency of the usage of polymer. The results were pretty good as there was low water absorption and high fragmentation resistance.

Valerie and Tegguer (14): To produce high quality recycled aggregate they used polymer treatment method. On the basis of experimental studies carried out on RCA and RA it was found that with use of appropriate polymer, lower water absorption and better fragmentation resistance were achieved.

Anna (15): To achieve good quality RA they did surface modification of recycled aggregate by bacterial treatment. The results were quite satisfying as there was less water absorption of the aggregates. The results much more evident in case of the poor quality recycled aggregates i.e. aggregates achieved from poor quality concrete. However, the mechanical behaviour of concrete was not studied.

Akbarnezhad (16): For the processing of RA they used the microwave treatment method. The heat produced by the microwave was used to partially remove the adhered mortar. The mechanical properties of concrete were studied with use of un-treated and microwave treated RCA. Normal mixing approach was used.

Abbas (17): They used chemical- mechanical beneficiation. In this the RA were exposed to sodium sulphate solution and mechanical stress created through subjecting RA to free and thaw action to separate adhered mortar from RA.

Tam (18): They pre-soaked the recycled aggregate in 0.1M acidic solutions for 24 hours. They proposed that water absorption after treatment reduced. However, the only drawback of this technique was it increased chlorine and sulphate content of the aggregates. Three different acidic solutions were considered i.e. HCl, H_2SO_4 and H_3PO_4.

Wan (19): They used two processing methods i.e. PVA polymer solution method and MS-lyophobic active agent method. In these methods RA was dipped for 48 hours in 1% PVA polymer solution and MS lyophobic active agent and then dried at 50^0C. After cooling to room temperature it was ready to use as it reduced pores and holes to great extent thus, improving its strength and performance.

How- Ji (20): They used washed recycled aggregate with water/cement ratio of 0.5. Results showed that building rubble had transformed into a useful recycled aggregate through proper processing. Using of un-washed RA greatly affected its strength. This was counterbalanced with washed recycled aggregate.

Shima (21): They used thermal mechanical RCA treatment technique known as "heating and rubbing". In this technique the RA is heated at 300^0C in a vertical furnace to render the adhered mortar brittle due to dehydration. Finally, the adhered mortar was removed by feeding into rubbing equipment.

2.4 Previously used mixing approach in RCA

The following three mixing approaches have been adopted by the researchers in the past:

(a) **Single stage mixing approach**: This is the conventional method followed by most of the researchers in the past by either using processed recycled aggregate or un-processed recycled aggregate. In this method the mixing is done in single step as in case of the conventional way of mixing.
(b) **Two stage mixing:** In this method the mixing is done in two stages i.e. stage I and stage II. The mixing time for both stages i.e. I&II were 180 seconds and 120 seconds respectively with the time gap of 60seconds for material loading in between. In stage I processed RCA, cement, sand; water and super plasticizer are added one by one. The addition of material is kept in proportion with the percentage of processed recycled aggregate. The remaining materials including natural aggregates are added, thus, completing the entire process.
(c) **Three stage mixing:** In this method of mixing the materials are added in three stages i.e. stage I, stage II, stage III.

Following researchers have done the research work:

Kou and Poon (22): In this particular study recycled aggregates were generated from fresh concrete waste and were replaced with natural coarse granite at 0%, 15%, 30% & 50%. The w/c ratio was kept at 0.35 and 0.50. Normal mixing approach and two stage mixing approach was used and the results from the respective approaches were compared. The results, as expected, the physical properties of concrete like density, strength and static modulus of elasticity of the concrete having recycled aggregate, generated from fresh concrete waste was reduced. Also, with the introduction of RA generated from fresh concrete waste the water absorption, chloride ion permeability and dry shrinkage increased. It was also concluded that two stage mixing improved the strength of the concrete mix when the w/c ratio was 0.35. Hence, it was concluded that the new concrete could be used as non structural concrete.

Wengui (23): It is quite evident that ITZ plays an important role in the mechanical properties of the concrete. This paper discusses the effect of different mixing approaches on the ITZ. For studying ITZ, Scanning Electron Microscopy i.e. SEM and nano indication was used. It was observed that with the adoption of two stage mixing the properties of newly formed ITZ were sufficiently improved by reduction in the voids and the consumption of CH. Also with the adoption of this particular mixing approach the ITZ was much denser and homogenous than that when normal mixing approach was adopted. Hence, it implies that with usage of two stage mixing approach it resulted in enhanced hydration resulting in the formation of CSH gel providing sufficient strength to the mix.

Deyu Kong (24): They used a special method called triple mixing approach for coating the surface of the recycled aggregates with pozzolans to further enhance the microstructure of the ITZ (interfacial transition zone). The effect of this method was studied on the chloride ion penetration resistance and compressive strength. It was concluded that CH was sufficiently used up by the coated pozzalanic material from the pores of the adhered mortar to form a hydration product called CSH gel i.e. calcium silicate hydrate to give sufficient strength to the concrete mix containing recycled aggregate coated with pozalanic material. However, the only down fall of this particular method was it was difficult to perform in actual field.

Li Yamura (25): To produce recycled aggregate two stage crushing procedure was adopted. The comparison of 7 and 28 days compressive and flexural strength was done on two types of techniques in which in first technique, stone was first enveloped with pozzolanic powder and in the second technique stone was enveloped with Portland cement. It was found that the new technique gave better results as strength and flexural results showed positive results. With the help of scanning electron microscopy (SEM) it was observed the interfacial transitional zone was sufficiently improved.

Sanchez and Gutierrez (26): In this particular research paper Los Angeles abrasion value of the recycled aggregate was determined to understand its performance in recycled concrete aggregate. The recycled aggregate is a mixture of natural/virgin aggregates and the adhered mortar. The results were quite obvious as the extent of adhered mortar was directly proportional to absorption and the Los Angeles abrasion value. In simple words, with increase in the adhered mortar, absorption and Los Angeles abrasion value increases. Hence, adhered mortar affects the bonding between the aggregate and the cement in the mix.

Tam and Tam (27): This research paper discusses about new mixing approach in which silica fumes and cement were mixed in certain amount with recycled aggregate in the pre-mix. According to the results the results were way better than the conventional procedure of mixing. This is so because with the usage of silica fumes and cement in the premix stage filled up weak areas in the RA resulting in strong interfacial bond. Thus, improving the overall strength of the concrete.

Tam (28): They compared the traditional mixing procedure with two stage mixing procedure at different proportion of RA. Results were better for two stage mixing.

Tam (29): To improve the compressive strength of RCA they proposed the method called two stages mixing. Their experimental work concluded that there was improvement in compressive strength of concrete due to strong ITZ and reduction in pores.

Otsuki (30): They concluded that the ITZ was strengthened by using double mixing method. Adverse effects due to the use of recycled aggregates were minimised by the use of double mixing method.

2.5 Conclusions of the literature review

Based on the literature review it was quite evident that it is the adhered mortar that is causing the problems. If somehow we get rid of this adhered mortar, we can achieve high strength concrete using recycled aggregates**.** As a result various processing and mixing techniques were discussed in the literature review to improve the quality of the concrete mix using recycled aggregate. However, it was observed that most of the researchers had utilised unprocessed recycled aggregate in the making of high strength concrete and the percentage replacement of natural aggregate with recycled aggregate was very less, about 20% to 30%. Hence, to check the feasibility of the mentioned percentage replacement i.e. 20 % to 30%, will be taken care of in the present study and checked whether or not is it possible to increase the proportion of RA in the concrete mix to make high strength concrete. From the literature it was found that although straight forward mechanical grinding technique is simple, suitable and gave improved quality recycled aggregate, it was not used by a lot of researchers. Also, two stage mixing approach was found to be way better than the normal mixing approach when recycled aggregate were introduced in the mix.

Additionally, most of the researchers have used mineral and chemical admixtures to improve the quality of high strength concrete having recycled aggregate and were successful in doing so. One critical observation from the literature was that none of the researchers had used mechanical grinding processing technique and two stage mixing approach jointly with the usage of chemical and mineral admixtures.

Thus, we will be using processed recycled aggregates with two stage mixing technique and compare its results with that of un-processed recycled aggregates to understand its effect on compressive strength and check whether or not is it possible to attain more replacement level using unprocessed and processed recycled aggregate . Table 2.1 summaries the performance of RCA according to previous researches.

Table2.1 Summarization of the previous year researches on the performance of RCA

Source	Replacement ratio	Property	Conclusions
Acker et al.(1998)	100% replacement of NA with RA	Cube strength*	17.2% lower
Ahmad and Struble et al. (1995)	100% replacement with RA	Cube strength*	33% lower
Bretschneider et al. (2004)	100% replacement with RA	Modulus of elasticity*	11.9% lower
		Flexural strength*	8.1% lower
	75% replacement	Modulus of elasticity*	4.0% lower
	50% replacement	Modulus of elasticity*	5.8% lower
Frondistou-yannas et al.(1997)	100% replacement with RA	Cube strength*	4% to 14% lower
		Modulus of elasticity*	40% lower
Grubl et al. (2004)	100% replacement	Modulus of elasticity*	28.3% lower
	75% replacement		21.9% lower
	50% replacement		23.3% lower
	25% replacement		13.6% lower
Ikeda et al. (1988)	100% replacement	Cube strength*	15% to 40% lower
		Modulus of elasticity*	30%to 50% lower
Khatib et al. (2004)	100% replacement	Density*	7% lower
		Cube strength*	36% lower

		Modulus of elasticity*	20.8% lower
	75% replacement	Density*	6% lower
		Cube strength*	25% lower
		Modulus of elasticity*	16% lower
	50% replacement	Density*	2% lower
		Cube strength*	25% lower
		Modulus of elasticity*	11.6% lower
	25% replacement	Density*	1% lower
		Cube strength*	25% lower
		Modulus of elasticity*	7.1% lower
Roos et al. (2003)	100% replacement	Density*	10% lower
		Cube strength*	34% lower
		Modulus of elasticity*	36.4% lower
Kakizaki et al.(1998)	100% replacement of coarse aggregate and fine aggregate	Cube strength*	15% to 40% lower
		Modulus of elasticity*	30% to 50% lower
Nishibayashi and Yamura et al. (1988)	100% replacement	Cube strength*	15% to 30% lower
		Modulus of elasticity*	15% lower

Note* test were conducted at 28 days

2.6 Objectives

1. To design high strength concrete with natural aggregate i.e. 0% replacement of NA with RA.

2. Observing the variation of compressive strength with (20, 40 & 50) % replacement of un-processed RCA with NA.

3. Studying the variation of compressive strength with different levels of processing (200RVS, 500RVS & 700RVS) for (20, 40 & 50) % replacement for each.

4. To determine the optimum replacement level of NA with RCA.

Hence, this paves the way to our objective of making high strength concrete with unprocessed & processed recycled aggregates at optimum replacement level. Since, none of the previous researchers have used two stage mixing in combination with straight forward mechanical grinding approach and appropriate admixtures, we will be employing them collectively to get desired results. The process of two stage mixing approach and straight forward mechanical grinding approach are discussed in later chapters.

CHAPTER 3

THEORY AND METHODOLOGY

3.1 Introduction

Construction and Demolition occupies huge disposal area and has a potential threat to the environment. To mitigate the problem there is a need to use recycled aggregate as a safe construction material.

This chapter summarizes the materials used in performing the various tests of high strength concrete and the procedure to find out the various mix designs. This chapter also discusses the research methodology which we have adopted to make high strength concrete using UPRA/PRA. Before the cubes were casted with natural and recycled aggregates, essential cement tests were conducted like normal consistency test, setting time test, fineness test, soundness test, specific gravity test, compressive and tensile strength test. After this the main research is divided in three stages namely:

(1) **Stage I** – using natural aggregates i.e. 0% replacement level of NA with UPRA/PRA in making high strength concrete.

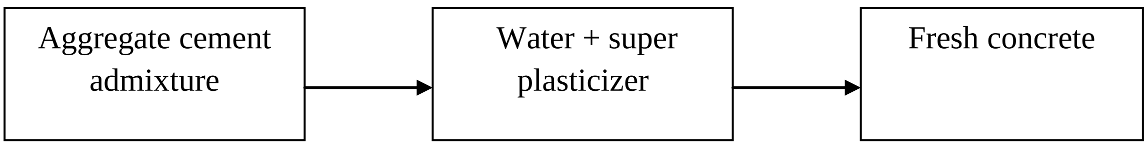

Figure 3.1 Normal Mixing Approach

(2) **Stage II** – using unprocessed recycled aggregate at 20%, 40% and 50% replacement level to understand its effect in making high strength concrete.

(3) **Stage III** – using processed recycled aggregate at 20%, 40% and 50% replacement level. The processing of the recycled aggregate was done by straight forward mechanical grinding technique in which RCA were introduced to Los Angeles abrasion machine and provided with 200RVS, 500RVS and 700RVS to get rid of adhered mortar.

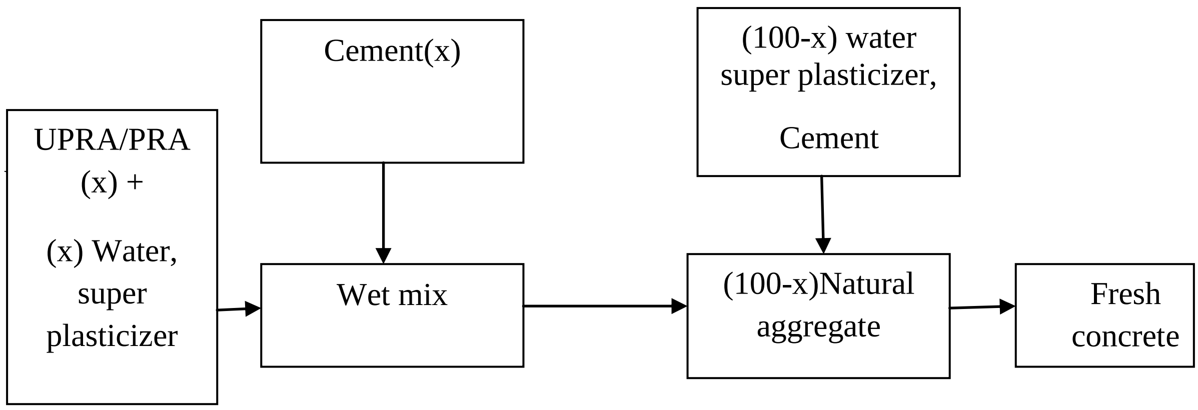

Figure 3.2 Two Stage Mixing Approach using PRA/UPRA

3.2 Materials used

- **Ingredients of HSC**

Table 3.1 shows size/grade of ingredients

Ingredient	Size/ Grade
Cement	OPC 43 Grade
Water	Potable
Fine aggregates	2.36 mm
Coarse aggregates	10 mm
Coarse aggregates	20 mm
Stone dust	Zone II
Plasticizer	Auramix-200

3.2.1 Cement: Type of cement used i.e. 43 grade ordinary Portland cement (OPC), as per IS 12269, manufactured by Ambuja Cement.

3.2.2 Water: Ordinary tap water was used in the production of concrete. Water used for mixing and curing shall be clean and free from excess amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances that may have negative affect to concrete or steel used.

3.2.3 Admixtures Used:

- **Chemical admixture** - Auramix 200 super plasticizer
- **Mineral admixture** – Stone dust

Figure 3.3 Addition of super plasticizer

Figure 3.4 Stone dust passed from 4.75 mm sieve

- **Super plasticizer:** Auramix 200 is a combination of the latest generation super plasticizer, based on a poly carboxylic ether polymer with long lateral chains conforming to the requirements of IS: 9103-1999 was used as a super plasticizer throughout the study.

Table 3.2 Information about the chemical properties of the super plasticizer

S.No	Chemical properties	Stated value	Value obtained	Limits as per IS 9103:1999
1.	Relative density	1.070	1.072	± 0.02 of the value stated by the manufacturer
2.	*pH*	Minimum 6.0	6.65	Minimum 6.00
3.	Dry material content	24.50	24.13	± 5% of the value stated by the manufacturer
4.	Chloride content	Max 0.2	0.026	Within 10% of the value or within 0.2% whichever is greater

- **Super plasticizer: Why it is used and how it works,**

i) Addition of water to improve workability results in weak concrete mix and reducing water content may result in stiffer mix which would be less workable.

ii) So, care should be taken while determining water content. Reducing water content in a concrete mix should be done in such a way so that complete hydration process may take place and sufficient workability is maintained for placement.

iii) Super plasticizers, also known as 'High Range Water Reducers' are used to improve workability of the concrete while not affecting strength of the concrete.

- **Working of Super plasticizer:**

i) Cement particles form flocks and water gets trapped in these flocks.

ii) If this trapped water could be released, it would improve flow ability of concrete.

iii) Super plasticizer does the same. Super plasticizer gets adsorbed by cement particles and forms a thin film around these cement particles.

iv) Now negatively charged particles impart repulsive forces on each other.

v) Hence, there will be deflocculation of the cement particles and entrapped water will be released. This water will improve flow characteristics of the concrete. Super plasticizer allows water reduction this way.

➢ **Stone Dust:** It is free of cost material. It is used as filler. It increases density by filling voids. Stone dust passed from 4.75 mm sieve is used, grading of the stone dust is done confirming to IS 383:1970.

3.2.4 Aggregates: Sizes of coarse aggregates used in this project i.e. 20-mm graded aggregate as per IS: 383 was used for different grades of concrete.

➢ **Grading of fine aggregate – Acc. to IS: 383-1970**

Aggregate used in making concrete consists of aggregate with different sizes and distribution of these sizes is termed as aggregate gradation. Hence, to ensure proper mix design gradation is essential. The sieve analysis of fine aggregates was done in order to find out the zone of the fine aggregates which is required for the calculation of the mix grade designing.

Table 3.3 Sieve Analysis of Fine Aggregate

IS Sieve Size	Wt. Retained	% Retained	Cumulative % Retained	% Passing
10mm	0g	0	0	100
4.75mm	3.1g	0.31	0.31	99.69
2.36mm	34.6g	3.46	3.77	96.23
1.18mm	155.7g	15.57	19.34	80.66
600µ	116.1g	11.65	30.95	69.05
300µ	175.1g	17.52	48.47	51.53
150µ	397.6g	39.76	88.23	11.77
PAN	117.7g	11.77	100	0

Weight of sample: 1000g

Acc. to IS: 383-1970, zone of sand came out to be grading zone II.

3.3 Mix proportions (IS: 10262: 2009)

To attain cost effective concrete mix specific rate of strength proportioning of concrete mixes is done. For a mix proportion of desired grade of concrete the guidelines are followed using Indian Bureau of Standards along with the field experience of project guide.

3.3.1 Mixture Proportioning Procedure

The basic steps involved in the Indian Standard method of concrete mix design can be summarized as follows:

Step 1: Determination of Target Mean Strength or field strength

For calculating target mean strength there is a need to calculate characteristic strength of concrete at 28 days and standard deviation which varies with variation in the grade of concrete. As per **IS: 456-2000**, the value of 'k' is taken 1.65, assuming that characteristic strength is expected to fall not more than 5 percent of test result. And value of's' is also taken from IS 10262-2009 table 1, which is given for each grade of concrete. The value of's' for M50 grade of concrete is 5MPa.

Target Mean Strength is determined as follows**:**

$$ft = fck + k\, s \qquad \ldots\ldots\ldots(1)$$

Where,

ft = target mean compressive strength at 28 days,

fck = characteristics compressive strength at 28 days,

k = a statical value depending upon the accepted portions of low results and the number of tests,

s = assumed standard deviation.

Step 2: Selection of water-cement ratio

The water-cement ratio is chosen from table no.5 of IS: 456-2000, which specify the minimum cement content, maximum water cement ratio and minimum grade of concrete for the different exposure conditions. The value selected is compared with available relations in SP: 23-1982, for the determination of water-cement ratio for the target mean compressive strength at 28 days.

It is noted here that water-cement ratio for the determined target mean compressive strength at 28 days gives lower value than specified maximum value in table 5 of IS: 456-2000. Even curve-E, which is applicable for 43 grade of OPC, in figure 47 of SP: 23-1982, which consider 28 days compressive strength of cement, incorporated in the mix proportions, also gives slightly lesser value of water-cement ratio.

Step 3: Estimation of mixing water

The approximate water content is selected from the table 35 and 38 of SP: 23-1982**,** applicable for normal concrete mix, which considers the aggregate type (whether crushed or uncrushed), maximum size of the aggregate and required slumps as a measure of level of workability.

Step 4: Estimation of air content

Estimate the amount of entrapped air for maximum nominal size of the aggregate from the table. The estimated entrapped air content is taken (2%) from table No. 41 of SP: 23-1982**,** based on nominal maximum size of the aggregate.

Step 5: Determination of cement content

The cement content is calculated from the selected water-cement ratio and estimated water content. The cement content so calculated is compared with the minimum required cement content as per the durability consideration as stipulated in the clause 8.2.4.2 of IS: 456-2000**.** The greater of the two values is adopted. It is noted that the quantity adopted is inclusive of the addition of part supplementary cementitious material to OPC.

Step 6: Estimation of percentage of sand in total aggregates

The percentage of sand in total aggregates depends upon the grading of sand to be incorporated in the mix. The general guideline is obtained from the figure 45 of SP: 23-1982**,** which is based on maximum size of coarse aggregates and the required slump value targeted. It is to be noted that concrete with super plasticizers will have different percentage of sand than concrete without super plasticizer for the same w/c ratio.

It is noted that that the water-cement ratio 0.3-0.35 was kept for the production of M50.

Step 7: Determination of fine and coarse aggregates

With the quantities of cement, super plasticizer, water and percentage of sand in total aggregates already determined, the content of fine aggregates and coarse aggregates is calculated from the following equations and volume of coarse aggregate corresponding to unit volume of total aggregate for different zones of fine aggregate is determined from table given in IS 383:1970 the values given in the table is applicable only for a water cement ratio of 0.5 and based on aggregates in saturated surface dry condition. For every increase or decrease by 0.05 in water cement ratio the values in table will be decreased or increased by 0.01 respectively.

$$v = \left[w + \frac{C}{Sc} + \frac{1}{p} \times \frac{fa}{Sfa}\right] \times \frac{1}{1000} \qquad \textit{For FA} \qquad \ldots\ldots\ldots (2)$$

$$v = \left[w + \frac{C}{Sc} + \frac{1}{1-p} \times \frac{Ca}{Sca}\right] \times \frac{1}{1000} \qquad \textit{For CA} \qquad \ldots\ldots\ldots (3)$$

Where,

v = absolute volume of fresh concrete i.e. gross volume ($1m^3$) minus the volume of entrapped air,

w = mass of water kg/m^3 of the concrete,

c= mass of cement kg/m^3 of the concrete,

Sc= specific gravity of cement,

p= ratio of fine aggregate to total aggregates by absolute volume,

fa = total mass of fine aggregates kg/m^3 of the concrete,

Sfa = specific gravity of saturated surface dry fine aggregates,

Ca = total mass of coarse aggregates kg/m^3 of the concrete,

Sca = specific gravity of saturated surface dry coarse aggregates.

Step 8: Adjustment of the trial mixture proportions

The trial mixture proportions were adjusted according to the following guidelines to achieve targeted slump (as a measure of workability).

(A) Moisture content – as a part of quality control during production of concrete. It is necessary to provide moisture content correction to dry batching. In this project work sand and coarse aggregate are dried in room temperature after sufficient amount of water sprinkled on the aggregate to avoid further absorption of water from the estimated mixing water quantity. The same quality control was maintained for each batch of concrete produced.

(B) Initial slump- If initial slump is not achieved in the desired range, then the mixing water is adjusted so as to maintain water/cement ratio same. With a change in mixing water quantity, sand quantity is also adjusted accordingly.

Step 9: Selection of Optimum mixture proportions

Once trial mixes have adjusted, test specimens i.e. 150 mm cubes are cast from the concrete produced and finally from the strength tests result of the specimens, optimum of proportioning of mixture is suggested.

For the concrete mixtures of grade M50, ratio used was **0.35:1:3.043:1.472:0.01998**

Table 3.4 shows proportion of ingredients

S.no	Material	Ratio
1.	Water	0.35
2.	Cement	1
3.	Coarse aggregate	3.043
4.	Fine aggregate	1.472
5.	Super plasticizer	0.01998

3.4 Experimental Parameter

The experiments performed for this project work are strictly according to Indian Standard Codes.

Table 3.5 Shows the list of ingredients and their corresponding IS Codes

List of Experiments/Ingredients	IS Code
Ordinary Portland Cement 43	IS 8112:1989
Normal Consistency of OPC 43	IS 4031(part 4):1988
Initial/Final setting time of OPC 43	IS 4031(part 5):1988
Fineness of OPC 43	IS 4031(part 1):1996
Soundness of OPC 43	IS 4031(part 3):1988

Compressive strength of OPC 43	IS 4031(part 6):1988
Specific Gravity of OPC 43	IS 4031(part11):1988
Specification of aggregates	IS 2386(part 1):1963
Le-Chatelier apparatus	IS 5514:1996
Slump test apparatus	IS 7320:1974
Compression Testing Machine	IS 14858:2000
Zoning of Sand	IS 383:1970
Vicat's apparatus	IS 5513:1996

3.5 Various tests on cement

3.5.1 Normal Consistency of Cement –

Figure 3.5 Normal Consistency of Cement

Desired consistency is important for the determination of initial and final setting time and the Le Chatelier soundness test. Therefore, a cement paste of standard consistency has to be used, making it necessary to determine for any cement the water content of the paste that will produce the desired consistency. The consistency was determined using Vicat's apparatus having a 10mm diameter plunger fitted into the needle holder. A mould was filled with the trial cement and water mix, whose surface was kept in contact with the plunger. Due to the self weight the plunger penetrated (6mm to 7mm from the bottom) depending on the consistency. The water content of the standard paste was expressed as a percentage by mass of the dry cement.

3.5.2 Setting time of cement –

Figure 3.6 Setting time of cement

To ensure proper transportation, compaction and placing of cement the initial setting time of cement should be sufficient as the concrete once laid should hardened so that the structure can be put to use as early as possible. Hence, IST (initial setting time) is that stage in the hardening of cement after which any cracks appearing do not reunite. The final setting time FST (final setting time) is that stage when the cement has attained sufficient strength and hardness to carry load. Both IST and FST are carried out using Vicat's apparatus. For determining IST round needle of approx. 1.13mm diameter is used. When the paste of sufficient consistency gains enough stiffness so that the needle penetrate no deeper than to a point 5-6mm from the bottom initial set is set to have taken. FST takes place when the needle fitted with a metal attachment hollowed out to leave a circular cutting edge of 5mm in diameter fails to make an impression on the surface of the paste and when needle penetrates to a depth of 0.5mm.

3.5.3 Soundness of Cement –

This test was done to find whether the cement is sound (absence of free lime) or not. If the cement shows expansion after hardening it is called unsound cement which may cause cracks and destruction of structure. This test was done with Le Chaterlier's apparatus. In this test cement paste is filled in a mould placed on a glass plate from both sides and a small weight is placed on a glass sheet. After that mould is kept in hot and cold water and the distance separating the indicator point is measured. For sound cement Limit of expansion is 0-10mm.

Figure3.7 Soundness of cement

3.5.4 Fineness of cement –

Figure 3.8 Fineness of cement

To ensure good quality of cement, it should have less than 10% of weight of cement particle larger than 90 µ. To determine the number of particles greater than 90 µ fineness test is done. Following steps are included

1. 100 gram (w_1) of cement sample is taken such that it is free of lumps.

2. Then pour the above quantity of cement in 90 µ sieve and close it with lid.

3. Either manually or using sieve shaking machine shake it thoroughly for 15 minutes.

4. The residue retained on 90 µ sieve is weighed (w_2).

5. Then the percentage of weight of cement retained on sieve is calculated.

3.5.5 Specific Gravity of cement –

Figure 3.9 Specific Gravity of cement

Based on the moisture content present in the cement i.e. water present in the pours of the cement particles, the specific gravity can either increase or decrease. Usually cement with specific gravity 3.15 is used to make a nominal mix any change in this value may affect the mix design. Hence, it is necessary to perform this test. For the determination of specific gravity of cement kerosene is used as it does not recent with cement.

3.5.6 Compressive strength of cement mortar –

Figure 3.10 Compressive strength of cement mortar

This test is conducted to determine the ability of material to take on the compressive loads. Cement mortar cubes were prepared in cube mould of size 7.06 mm x 7.06 mm x 7.06 mm. The readings were taken at 3, 7 and 28 days for each samples prepared. The cement mortar was prepared by mixing cement, sand and water. The quantity of water taken was according to the formula $\{\frac{P}{4} + 3\}$ % weight of cement (P represents the normal consistency of cement). Before placing the mortar mix in the mould, the moulds should be lubricated to ensure easy de-moulding and well defined edges of the corners. After approximately 24 hours the specimen may be taken out and kept in water tub for curing. They will only be taken out at the time of testing i.e. 3, 7 and 28 days. However, before they are tested it is essential to dry them out to get rid of excess surface water. The reading may be taken at 3, 7 and 28 days.

3.5.7 Tensile Strength of cement mortar –

Figure 3.11 Tensile strength of cement mortar

This test is conducted to understand the cohesion of the particles in cement mortar which in turn gives us the idea about its tensile load bearing capacity. For making cement mortar specimens, briquette moulds were used which were lubricated prior to use to ensure easy de-moulding. Water used was taken according to the formula $\{\frac{P}{5} + 2.5\}$ % by weight of cement (p represents the normal consistency of the cement). For this particular test 9 specimens were prepared and kept in mould for approximately 24 hours. After taking out the specimens from the briquette after 24 hours, they were kept for curing in the curing tank and were only taken when required for testing. The average value of tensile strength was taken for 3, 7 and 28 days.

3.6 Stage I:-High strength concrete using normal aggregates

3.6.1 Method Used

- Trial and error method
- Target strength: 50MPa

3.6.2 Important Criteria

1. High strength is achieved if the particle packing is dense with minimum voids. For this high paste volume is essential.

2. A rich mix is used.

3. Mineral and chemical admixtures are used.

4. Concrete was prepared with super plasticizer.

3.6.3 Mix (using Super plasticizer) M50

Table 3.6 shows proportion of key ingredients

Water	Cement	Coarse aggregate	Fine aggregate	Super plasticizer
0.35	1	3.043	1.472	0.01998

Table 3.7 shows quantity of key ingredients

No.	Material	Quantity (kg/m^3)
1	OPC-43	422
2	Water	147.6
3	Fine aggregate	621
`	Coarse aggregate	1284
5	w/c	0.35
6	Super plasticizer	5.064

3.7 Stage II: -High strength concrete using unprocessed recycled aggregates

3.7.1 Using unprocessed recycled aggregate (UPRA)

- The replacement of UPRA with natural aggregate (NA) was done by 20%, 40% & 50%.
- There was sufficient adhered mortar attached to the recycled aggregate unlike processed recycled aggregate in which sufficient amount of mortar was removed.

Two stage mixing approach was adopted.

3.8 Stage III: -High strength concrete using processed recycled aggregates

3.8.1 Using processed recycled aggregate (PRA)

- The replacement method will be same as that of UPRA i.e. by 20%, 40% &50%.
- The processing of RCA was done by introducing demolished concrete boulders of size 150mm to 300mm in Los Angeles abrasion machine.
- The extent of processing was varied by giving 200 revolutions (200RVS) first, at 33 rpm to get rid of adhered mortar.
- After gradation of the aggregates the cubes were casted with this processed recycled aggregate (200RVS) at 20%, 40% & 50% replacement level.
- Then secondly, RCA was processed by giving 500 revolutions (500 RVS) at 33 rpm to get rid of adhered mortar and then after gradation of aggregates cubes were casted with this PRA at 20%, 40% & 50% replacement.
- Same procedure was followed for PRA with 500 RVS.
- The variations of compressive strengths were observed for each.

3.8.2 Mixing approach adopted

Generally, the natural aggregates need not require any further treatment because they have clean surfaces. But in the case of the recycled aggregates, this is not so because of the adherent mortar.

The mixing approach adopted is two stage mixing approach. In this approach the addition and mixing of material is done in two stages i.e. I and II. For stage I and stage II the mixing timing were 180 seconds and 120 seconds respectively and in between two stages the time gap was of 60 seconds.

The addition of the materials to be used in the making of high strength concrete mix was kept equivalent to the percentage addition of processed recycled aggregate / unprocessed recycled aggregate, where "X" represents the partial replacement percentage of natural aggregate with PRA /UPRA illustrated in the table 3.9 which were mixed with the other materials in the stage I. In the II stage the virgin aggregates / natural aggregates were added (100-X) with other materials illustrated in figure 3.10. With the mixing of materials in the first and second stage resulted in the completion of the mixing approach.

The processed recycled aggregate were produced by giving 200 RVS, 500 RVS and 700RVS which were replaced in 20%, 40% and 50% with natural aggregate. Therefore, in stage I, PRA were replaced at X= 20%, 40% & 50% for each 200 RVS, 500RVS and 700RVS as shown in table 3.9 and the same was done for the UPRA except that no revolution were given to these aggregates. In the second stage natural aggregates were added at (100-X) 80%, 60% & 50% as shown in 3.10.

Table 3.8 shows the quantity of materials used in making high strength concrete

Material	OPC-43	Water	Fine aggregate	Coarse aggregate	w/c	Super plasticizer
Quantity(kg/m^3)	422	147.6	621	1284	0.35	5.064

Table 3.9 shows Individual quantities of material required in the stage-I of mixing (180 seconds)

Material	Calculations		
	x=20%	***x=40%***	***x=50%***
PRA/UPRA	$\frac{20}{100} \times 1284 = 256.8$	$\frac{40}{100} \times 1284 = 515.6$	$\frac{50}{100} \times 1284 = 642$
C	$\frac{20}{100} \times 422 = 84.4$	$\frac{40}{100} \times 422 = 168.8$	$\frac{50}{100} \times 422 = 211$
FA	$\frac{20}{100} \times 621 = 124.2$	$\frac{40}{100} \times 621 = 248.4$	$\frac{50}{100} \times 621 = 310.5$
W	$\frac{20}{100} \times 147.6 = 29.52$	$\frac{40}{100} \times 147.6 = 59.04$	$\frac{50}{100} \times 147.6 = 73.8$
SP	$\frac{20}{100} \times 5.064 = 1.01$	$\frac{40}{100} \times 5.064 = 2.025$	$\frac{50}{100} \times 5.06 = 2.532$

Table 3.10 shows individual quantities of material to be added in the stage-II of mixing (120 sec)

Material	**Calculations**		
	100-x=80%	***100-x=60%***	***100-x=50%***
NA	$\frac{80}{100} \times 1284 = 1027.2$	$\frac{60}{100} \times 1284 = 770.4$	$\frac{50}{100} \times 1284 = 642$
C	$\frac{80}{100} \times 422 = 337.6$	$\frac{60}{100} \times 422 = 253.2$	$\frac{50}{100} \times 422 = 211$
FA	$\frac{80}{100} \times 621 = 496.8$	$\frac{60}{100} \times 621 = 372.6$	$\frac{50}{100} \times 621 = 310.5$
W	$\frac{80}{100} \times 147.6 = 118.6$	$\frac{60}{100} \times 147.6 = 88.56$	$\frac{50}{100} \times 147.6 = 73.8$
SP	$\frac{80}{100} \times 5.064 = 4.05$	$\frac{60}{100} \times 5.064 = 3.03$	$\frac{50}{100} \times 5.064 = 2.53$

3.8.3 Reasons behind adopting two stage mixing:

- In stage I the repairing of recycled aggregate takes place by using a cement mortar of reasonably low w/c.

- Because of the mixing taking place in the stage I the cracks, pores, voids and cavities are filled up by the mortar. Thus, improving the weak areas of RA.

- Also, the covering of cement mortar around the surface of RA ensures good bondage.

3.8.4 Strength Gain after 28 Days (significance):

- It is not always the case that concrete would gain its 100% strength within 28 days.
- Strength gain after 28 days can be beneficial with respect to cost of construction.
- If there is considerable increase in strength after 28 days, saving in cost is possible.
- For example, if concrete mix of M30 grade gives strength of 55 MPa after 56 days; the mix can be used instead of M50 grade mix. This will result in cost saving because M50 grade concrete mix would require richer mix.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Test results of cement

- **Fineness of cement**

  FM = $\frac{\text{weight retained on standard sieve of 90 microns (w2)}}{\text{Total weight (w1)}} \times 100$

  = $\frac{2.6}{100} \times 100$= 2.6%

  The fineness modulus (FM) of cement is **2.6%.**

- **Specific gravity of cement**

  Weight of cement, W = 64 g

  Initial reading after kerosene oil is poured, V_1 = 1 ml

  Final reading after 64 g cement is poured, V_2 = 21 ml

  Increase in the volume = Final volume – initial volume

  = $V_2 - V_1$ = 20 m

  Specific gravity of cement = $\frac{W}{V2 - V1} = \frac{64}{20}$ = 3.20

  Thus, specific gravity of the cement is found to be **3.2**

- **Compressive strength of cement mortar**

Table 4.1 shows average compressive strength of 3 specimens in 3, 7 and 28 days

S.No.	**Age of testing (days)**	**Average strength(MPa)**
1	3	20.19
2	7	31.58
3	28	41.01

- **Tensile Strength of cement mortar `**

Table 4.2 Shows average tensile strength of 3 briquette samples in 3, 7 and 28 days

S.No.	Age of testing(days)	Average strength(MPa)
1	7	2.07
2	14	2.37
3	28	3.14

Table 4.3 Test results of cement

Cement	Consistency	Initial Setting Time	Final Setting Time	Soundness	Fineness	Specific gravity
OPC43	28%	110 min	285 min	0.5 mm sound	2.6% fine	3.2

4.2 Stage I: -Results of high strength concrete using normal aggregates

Table 4.4 shows the strength of concrete

S.No.	Days	Strength (MPa)
1	3	22.23
2	7	35.5
3	28	52.26

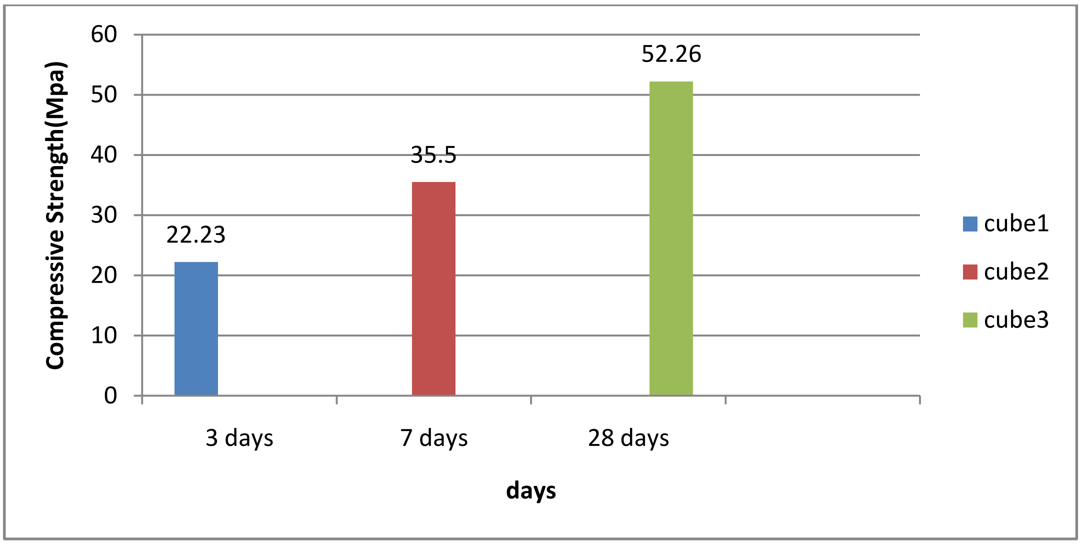

Figure 4.1 Compressive Strength of mix

It is quite evident from the above data that about 38.28% of target strength was achieved in first three days after curing. Similarly, about 60.94% and 89.72% of target strength was achieved for 7 and 28 days respectively after curing.

4.3 Stage II: - Results of high strength concrete using un-processed recycled aggregates

Table 4.5 Compressive strength in (MPa) after partial replacement of NA with UPRA in % after **0 RVS**

Days	***20%***	***40%***	***50%***
7	34	31.33	30
14	34.02	31.67	30.56
28	36.67	32.67	31.33

The target strength was not achieved using partial replacement of unprocessed recycled aggregate. Maximum of 36.67MPa compressive strength was achieved at 28 days with 20% replacement, 32.67MPa with 40% replacement level and 31.33MPa with 50%

replacement. Therefore, with increase in replacement level of UPRA with NA the compressive strength is decreasing.

4.4 Stage III: - Results of high strength concrete using processed recycled aggregates

Table 4.6 Compressive strength in (MPa) after partial replacement of NA with PRA in % after **200 RVS**

Days	***20%***	***40%***	***50%***
7	38.3	35.6	33
14	41.6	39.06	36.1
28	46.3	45	43.67

Even with processed recycled aggregates (200RVS) target strength was not achieved. With 20% replacement 46.3 MPa of compressive strength was achieved at 28 days, 45MPa and 43.6MPa of compressive strength was achieved at 28 days for 40% and 50% replacement respectively.

Table 4.7 Compressive strength in (MPa) after partial replacement of NA with PRA in % after **500 RVS**

Days	***20%***	***40%***	***50%***
7	40.33	37	35.7
14	43.73	39.9	38.8
28	50.87	47.3	46

It was possible to make high strength concrete with PRA (500RVS) with 20% replacement level. 50.87MPa compressive strength was achieved with 20% replacement at 28 days. For 40% and 50% replacement 47.3MPa and 46MPa compressive strength was achieved respectively at 28 days.

Table 4.8 Compressive strength in(MPa) after partial replacement of NA with PRA in % after **700 RVS**

Days	***20%***	***40%***	***50%***
7	40.33	36.33	35
14	43.67	41.33	41
28	51.67	49.55	48.33

Even in this case we managed to make high strength concrete. However, the compressive strength achieved at 20% replacement for 700RVS was marginally higher than that achieved with 500RVS for same replacement level. 48.33MPa and 49.55MPa of compressive strength was achieved at 40% and 50% replacement respectively at 28 days. % natural aggregates.

4.5 Analysis of results

Every presented data in the graphs is the average of three measurements made on the cubes. The degree of processing plays an important role and is very well evident; the variation of compressive strength using unprocessed and processed recycled aggregates is depicted in the graphs below. With increase in the extent of processing the compressive strength is increasing. The graphs show the variation of compressive strength at 7, 14 and 28 days at 20%, 40% and 50% replacement level of UPRA & PRA.

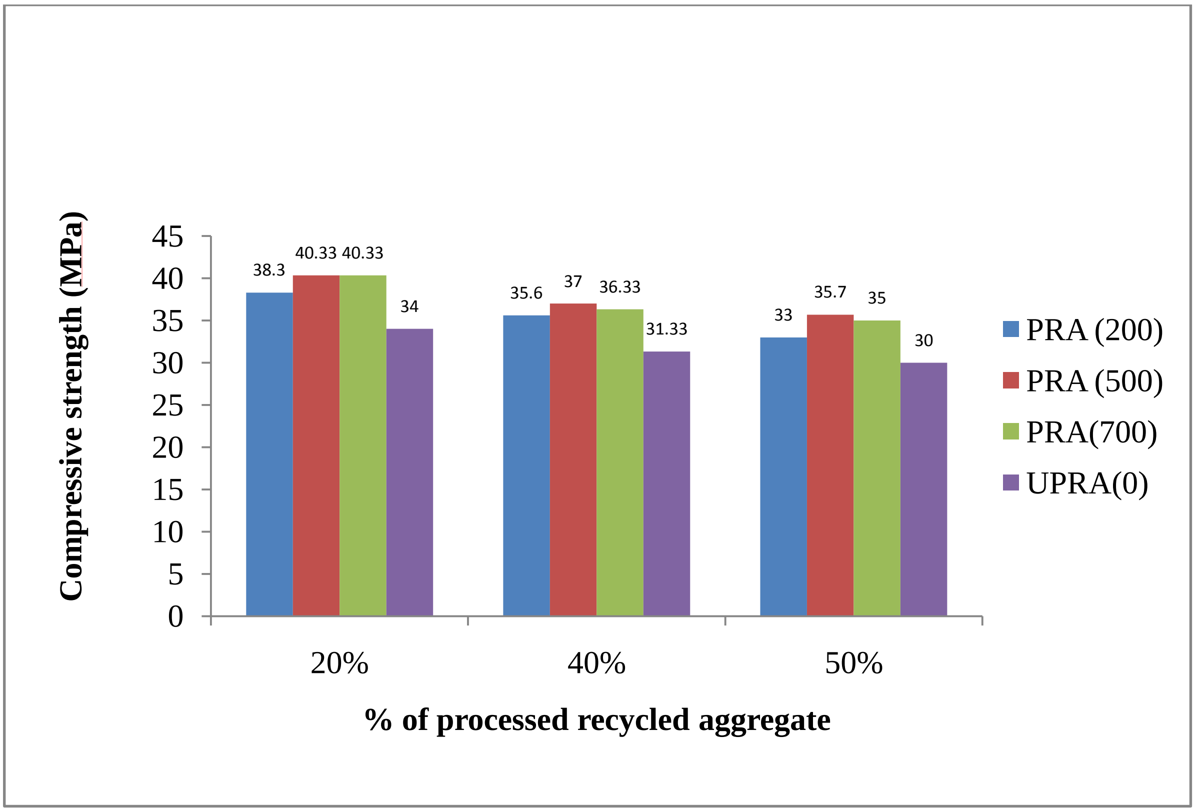

Figure 4.2 shows 7 days compressive strength

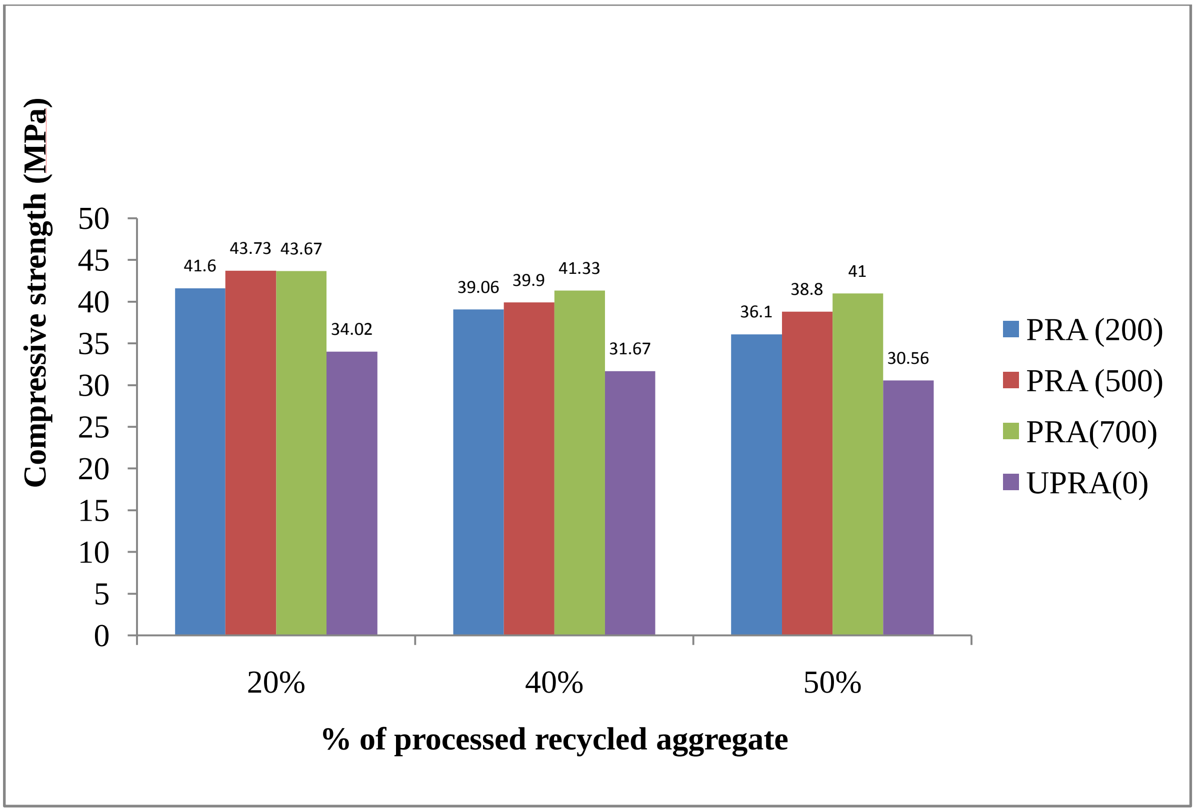

Figure 4.3 shows 14 days compressive strength

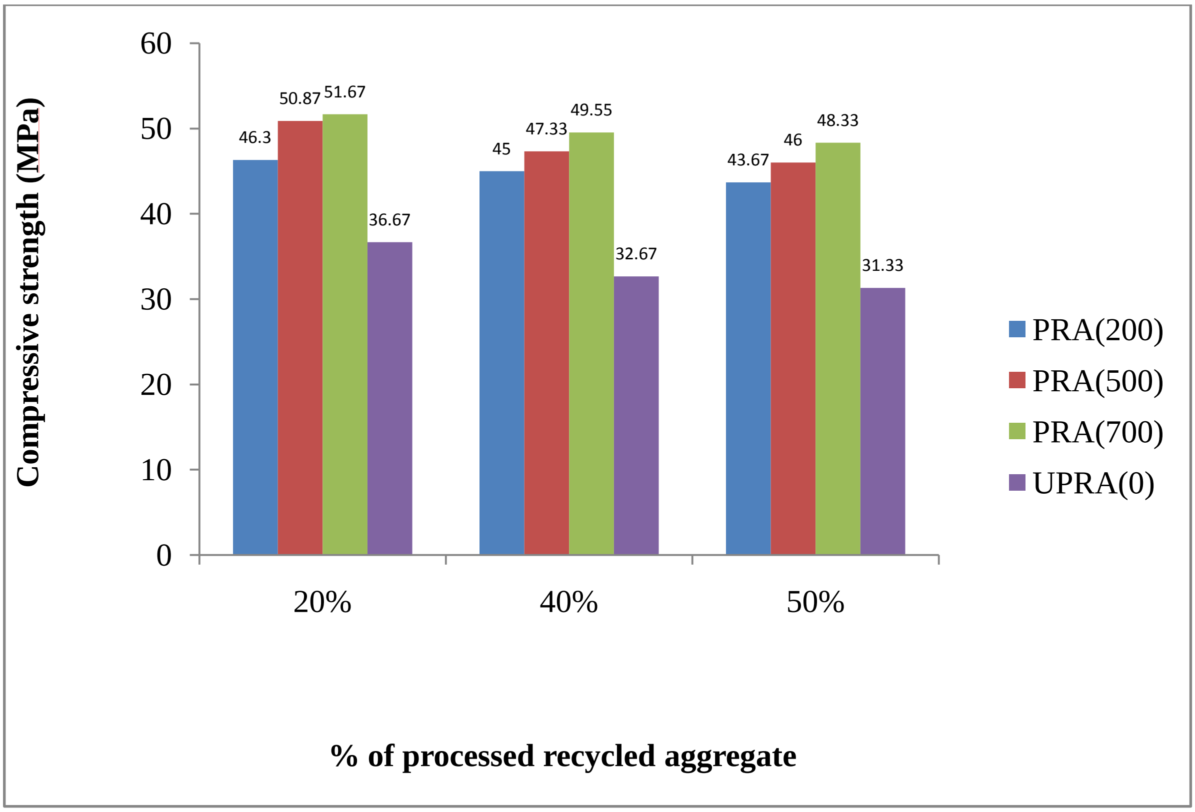

Figure 4.4 shows 28 days compressive strength

4.6 Pictures of casted elements and Production of Processed Recycled Aggregate

Figure 4.5 Cube mould 15x15 cm with oiling

Figure 4.6 Hand mixing

Figure 4.7 Concrete mixture

Figure 4.8 Rod tamping

Figure 4.9 Compaction on Vibration Table

Figure 4.10 Casted elements

Figure 4.11 Curing

Figure 4.12 Broken element on CTM

Figure 4.13 Concrete boulders

Figure 4.14 Processing with Los Angeles abrasion machine

Figure 4.15 RA before water-wash and grading

Figure4.16 Processed RA after water wash

Figure 4.17 Un-processed recycled aggregate

Figure 4.18 Processed RA at 200RVS

Figure 4.19 Processed RA at 500 RVS

Figure 4.20 Processed RA at 700RVS

CHAPTER 5

CONCLUSIONS

The main objective of the research is to utilize the unprocessed and processed recycled aggregate and studying the variation of compressive strength in making high strength concrete. The replacement level of recycled aggregate (unprocessed) is done up to 20%, 40% and 50% and its effect on compressive strength is observed. The same is done for the processed recycled aggregate but the only difference is that the effect of the level of processing is also taken into account in observing its effect on compressive strength. To ensure proper mixing, two stage mixing was adopted. Finally, the results have been optimized to select the most appropriate processed recycled aggregate as well as two stage mixing approach.

5.1 Conclusions

It was concluded that high strength concrete can be made using processed recycled aggregate (PRA) i.e. 500 RVS & 700 RVS in straight forward mechanical grinding approach at 20 % replacement. The 28 days compressive strength results of PRA 500RVS were very similar to PRA 700 RVS but the difference was very small as can be seen from the graph in figure 4.4. Hence, for the convenience purpose PRA with 500 RVS was taken as the most suitable processed recycled aggregate. From the graph in figure 4.4 it is observable that unprocessed recycled aggregate (UPRA) and processed recycled aggregate (PRA) with 200 RVS were unable to give the desired 28 days strength. The possible reasons behind it can be as follows:

- The sufficient amount of adhered mortar was not removed with PRA 200 RVS and too much mortar adhered to UPRA.
- Increase in the number of voids making the mix unsound.
- Weak interfacial transition zone.
- High initial w/c ratio thus, reducing the ultimate strength of concrete.

If the graphs in figures 4.2, 4.3 and 4.4 are closely observed then a general conclusion can be made that the compressive strength is increasing with increase in the degree of processing. However, if 7 days compressive strength is observed (refer to figure 4.2) we see that at 40%

& 50% replacement level, compressive strength obtained from 700RVS is smaller than that obtained from 500RVS. Similarly, in case of 14 days compressive strength at 20% replacement level (refer to figure 4.3) compressive strength obtained from 700RVS is smaller than 500RVS, although the difference is very small. The probable reason as to why compressive strength obtained with 700RVS was lesser than that obtained with 500RVS at 7 and 14 days with 40%,50% and 20% respectively is may be because hydration of cement was slow. On the other hand the compressive strength is decreasing with increase in the replacement of natural aggregate with recycled aggregate.

Also, the compressive strength achieved with partial replacement of natural aggregate with unprocessed / processed recycled aggregates at 7, 14 and 28 days was less than that obtained from the mix containing 100% natural aggregates.

5.2 Recommendations

The following recommendations can be made based on the research;

-with proper processing recycled aggregate can be used to make high strength concrete.

-as stated earlier also, two stage mixing approach and processed recycled aggregate i.e. 500 RVS is recommended to produce high strength concrete as it gave strength more than 50MPa at 28 days.

-20% replacement of natural aggregate with processed recycled aggregate is recommended and suitable to produce high strength concrete according to the research.

5.3 Scope and future work

The source of the recycled aggregate or construction and demolition waste plays an important role in determining the quality of concrete that can be obtained. Hence, further investigation can be made on how the compressive strength is varying using RCA obtained from different C&D waste.

This research was limited to understand the variation of compressive strength with partial replacement of NA with RCA (PRA and UPRA). However, its affect can be understood on other properties of concrete like flexural strength, density of the concrete mix, split tensile strength and alkali silica reaction.

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