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EXPERIMENTAL STUDY ON EFFECTIVE UTILIZATION OF DEMOLITION WASTE IN CONCRETE

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CANDIDATE'S DECLARATION

I, ABHISHEK SINGH, 2K21/STE/02, of M.Tech (Structural Engineering), hereby declare that the project Dissertation titled "Experimental Study on Effective Utilization of Demolition waste in Concrete" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship, or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled "Experimental Study on Effective Utilization of Demolition waste in Concrete" which is submitted by ABHISHEK SINGH, 2K21/STE/02, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

This experimental investigation concentrates on the use of coarse and fine pulverized concrete aggregates in control concrete (CM) mixtures. The intended characteristic strength of the concrete mixture is 25 MPa. The study examines six mixtures: Control Mix (CM) with natural aggregates, six formulations containing 20% total replacement of CRCA and FRCA in CM, namely CM, 20RAC0, 15RAC5, 10RAC10, 5RAC15 and 0RAC20, respectively. Each of the six combinations' fresh and aged qualities are evaluated. For a mixture containing 20% FRCA to obtain the desired slump of 100 ± 10 mm, an increased dosage of Superplasticizer (SP) is required. Control and partially aggregate-replaced concrete were tested for freshness (workability, density), mechanical properties (compressive, flexural strength), and durability (water penetration, permeability test). At each age of curing, the recycled refuse concrete characteristics were typically more severe than those of conventional concrete. However, as the curing time increased, the performance gap between standard and recycled concrete decreased. Moreover, when 20% CRCA and 20% FRCA were substituted for CM, the compressive strength decreased by 7.44% and 12.73%, respectively. As FRCA content increased, similar tendencies were observed in flexural tensile strength, water penetration depth, and permeability. The study demonstrates that RCA can be used in concrete with certain countermeasures to mitigate the negative effects of RAC, thereby assisting in C&D waste management and decreasing construction costs.

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Abbreviations/Symbols	Descriptions
C&D	Construction and Demolition Waste
CM	Control Mix
CNA	Coarse Natural Aggregates
FNA	Fine Natural Aggregates
CRCA	Coarse Recycled Concrete Aggregates
FRCA	Fine Recycled Concrete Aggregates
TRCA	Treated Recycled Concrete Aggregates
RAC	Recycled Aggregate Concrete
RCA	Recycled Concrete Aggregates
w/c	Water to Cement Ratio
XRD	X-ray Diffraction

CHAPTER 1

INTRODUCTION

1.1 GENERAL

In countries with rapid economic growth, the building sector is viewed as essential for nation's development [1]. This sector of economy is deemed to be most stable due to constant influx of investment. To meet this enormous requisite for aggregates, substantial illicit quarrying is done, which depletes the aggregate's natural reserve and is also damaging to the environment.

The excessive production of C&D waste from building deconstruction is an additional effect of the construction industry that exacerbates the worldwide waste problem. Frequent components of C&D trash include sand and gravel, dirt, metal, concrete, bricks and masonry. Recycling C&D trash is essential for lowering carbon footprint and waste output, as it contributes more to the overall waste dilemma than municipal waste [2].

However, due to a lack of reliable data, The global production of C&D trash is significantly underestimated. RCA and RAC manufactured from C&D waste are required sources of additional construction materials for the manufacturing of "green concrete". The majority of variances in RCA's mechanical and physical qualities are governed by the amount and quality of "adhered mortar".

In contrast to control mix (CM) (concrete with standard components), the workability of RAC decreases when coarse natural aggregate (CNA) and FNA are substituted by FRCA and CRCA, respectively. Because attached mortar makes RCA more porous, less dense, and more water-absorbent, this is the case.

However, using high-range water reducer or other method can effectively limit the effectiveness of RAC [3], and RCA can be pre-soaked in water (prior to combining) to help initiate the internal curative process [4]. The amount of mortar that adheres is inversely related to the RCA's size, so the larger the RCA, the less mortar will attach [5]. This explains why the relative quality decline of FRCA is greater than that of CRCA [6].

Studies showed that there was a drop of 5.4% in strength when CNA is replaced by CRCA, a drop of ten percent, as FNA is replaced with FRCA, whereas when both FNA and CNA are replaced by RCA, a drop of 15% was reported. These values further reduced to 3.4%, 8.1% and 13.5% respectively, as the curative period was extended to 56 days. RCA indicated presence of unhydrated cement particles which were responsible for strength at older ages [7]. Moreover, due to its multiphase nature, it is challenging to produce RCA in the correct form and dimension [8].

Previously, several attempts were made to cure RCA, thus reducing the detrimental effects caused by layer of adhered mortar. In these some successful methods were “mechanical and chemical treatment”, “treating of RCA with chemicals” prior to its usage, “use of cementitious materials’ slurry” for strengthening of adherent mortar, increasing cement content, etc.

Hanaa Khaleel et al. [10] compared many CRCA enhancing approaches through study. Researchers discovered that treating CRCA with moderate – acid was advantageous. In addition, moderate acid mitigates the results of acid assaults on the surface of the CRCA more effectively than strong acids [10]. Further it was found out that combination of thermal heating (350^0C) along with short mechanical treatment performed best and helped in lowering the water absorption by 27.4%.

According to Wang et al. [11], treatment of CRCA by soaking in mild acid prior to mechanical abrasion gives optimum strength of RCA. In a second study, CRCA was submerged in sodium silicate solution (10%) followed by coating it with micro-silica, resulting in an improved transition zone of RAC which ultimaltely increases its early strength [12].

FRCA was utilized in a variety of investigations involving various varieties of concrete, such as geosynthetic concrete [13], self-compacting concrete [14], foam concrete [15], etc., with varying degrees of effectiveness. FRCA inclusion in concrete has been observed to decrease its compressive strength, which may be attributed to its high water absorption tendency. The optimal treatment of RCA is known to improve the qualities of RAC, as established by previous studies.

1.2 OBJECTIVES OF THE STUDY

The primary aspirations of the project are:

- To compare the properties of CNA, FNA, CRCA, FRCA.
- To analyse the change in attributes of CRCA upon treatment with mild acid.
- To do a Mix design conforming to M25 grade as control mix.
- Partially replacing both CRCA and FRCA in CM such that the total aggregates replaced remains constant and equal to 20%.
- Testing RAC for Fresh (workability, unit weight), Mechanical (Compressive, Flexural) and Durability (Water penetration test, water permeability test) properties.
- Provide a simple economic study on different samples obtained.

1.3 OVERVIEW OF THESIS

Chapter 1 - deals with the description about an introduction to the topic, its application and significance.

Chapter 2- discusses some of the literature and previous work on damage detection andpiezo sensors.

Chapter 3 – discusses the methodology followed along with details of the experimentaland analytical work carried out.

Chapter 4 - discusses the results and discussion related to use of RCA in concrete construction.

Chapter 5 – deal with the conclusion of the present study.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

The present chapter involves the detailed literature study done to understand in depth about the incorporation of CRCA and FRCA in concrete. Researchers found out that CRCA can be incorporated in concrete production when subjected to mild acid treatment along with brief mechanical treatments. Other studies showed that the use of RCA in RAC production has been found to be successful to a large extent showing minor loss of strength (compared to CM), which can further be improved upon increasing w/c ratio and improved curative ages. A detailed literature review of several researches has been summarized below :

P. Pereira (2012) showed that when CNA is replaced by CRCA, compressive strength dropped by 5.4%, by 10% when NFA is replaced with FDCA, and by 15% when both NFA and NCA are replaced by RCA. These values further reduced to 3.4%, 8.1% and 13.5% respectively, when the curative period was extended to 56 days. The results obtained are clear indicator that the unreacted cement molecules in RCA bestowed to its strength at older ages.

Berredjem et al (2020) found that the mechanism of both stiffened concretes are essentially similar, despite the fact that replacing hundred percent of the naturally occurring aggregate with RCA reduces the strength of RAC. Previously, several attempts were made to cure RCA, thus reducing the detrimental effects caused by layer of adhered mortar. In these some successful methods were “mechanical and chemical treatment”, “treating of RCA with chemicals” prior to its usage, “use of cementitious materials’ slurry” for strengthening of adherent mortar, increasing cement content, etc.

Hanaa Khaleel et al. (2016) compared many CRCA enhancing approaches through study. According to research, treatment of CRCA with moderate – acid was advantageous. In addition, moderate acid mitigates the results of acid assaults on the surface of the CRCA more effectively than strong acids. Thermal heating (350^0 C) in amalgamation with brief mechanical treatment performed best and helped in lowering the water absorption by 27.4%.

Wang et al. (2017) showed that prior to mechanical abrasion, immersion of CRCA in acetic acid, produces RAC that is more durable than CM.

Bui et al. (2018) submerged CRCA in a ten percent sodium silicate suspension and then covered it with micro-silica. The integrated action of both microscopic-silica & sodium silicate showed an improved transition zone of CRCA integrated concrete which ultimately increases its early age strength [12].

H. Donza et al. (2002) in an independent research found out that FRCA addition in CM, decreased concretes' compressive strength predominantly as greater amount of water was required to achieve same degree of wrokability, similar to CM. The increase in compressive strength is attributable to the Infill effect, asymmetrical exterior appearance, internal curative outcome, and angular form of FRCA.

How-JiChen et al. (2003) found out that as the w/c ratio enhanced, the strength of RAC became similar to that of CM. The utilisation of unclean recycled material in concrete will diminish its strength. Recycled concrete's modulus of elasticity was approximately 70 percent of that of conventional concrete.

Susan L.Tigheet al. (2016) studied several techniques for improving the salient features of CRCA were investigated. The study concluded that mild acid is extra effective and safer than aggressive acid and is hence preferred (better than Heat Treatment method).

SallehanIsmail et al. (2013) did a Comparative study on Concrete made with Untreated & Treated Recycled Aggregate. Experiments demonstrated that the application of acid with a low concentration was effective in removing loosely adherent mortar from RCA surfaces. The acid's molarity has a significant effect on the quantity of mortar loss. Using treated RCA generated concrete with greater compressive strength than untreated RCA.

Limbachiya et al. (2003) studied high strength concrete made with RCAIt was found that there was no effect on concrete strength in replacement up to 30%, however the strength started to decrease on account of further addition of RCA.

Miren Etxeberria et al (2016) in their research Considered four unique recycled aggregate concretes consisting of zero percent, twenty five percent, fifty percent and hundred percent RAC, respectively. The compressive strength of concrete including recycled coarse particles at 100 percent is 20 to 25 percent lower than that of CM. Due t non-uniformity of quality control in RCA, the RAC showed a standard deviation of 50% in compressive strengths of RAC compared to CM.

B.M.Vinay Kumar et al. (2018) worked on Concrete mix prepared for strength of grade sixty. Study showed that as FRCA content increased, higher superplasticizer amount was required to achieve same workability. Strength of 20% Fine-RCA mix was found to be 1.18 times the control concrete
whereas the strength of 20% Coarse-RCA mix was 0.98 times the control concrete. The Demolished waste incorporated concrete provided satisfactory performance against sulphate attack but a significant loss in strength was reported on exposure to H_2SO_4.

Rahul Singh et al. (2022) found out that M30 concrete can be made by 100% RCA and 30% RFA or combination of both. Concrete properties are influenced more by age of curing than density of RCA. RCA influences permeability of concrete mostly.

2.2 STUDY GAP

From the literature study, it was concluded that :

1. The majority of existing work was performed on replacement of CRCA in concrete.
2. There were some instances in which FRCA was also incorporated in concrete, but the combined use of both CRCA and FRCA has seldom been done.
3. The combined use of CRCA and FRCA in amalgamation is the scope of our present research.

There have been very few studies reported till date which incorporated both CRCA and FRCA in amalgamation for concrete production.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

A brief overview about procurement of aggregates, their properties and their incorporation in CM is done in this section. The aspirations of the proposed study to analyze the influence of partial replacement of both CRCA and FRCA in concrete by observing its fresh, mechanical and durability properties. Finally, a cost study is also performed to determine the feasibility of their incorporation in construction industry.

3.2 METHODOLOGY

In the past, substantial research was conducted, the unavailability of an accurate calculation of India's RCA generation restricts the usage of RCA. It is mostly the result of the following factors: The Indian Standard IS 383 (1970) did not advocate the implementation of RCA in the industry prior to its 2016 amendment, and there has been no mechanism for segregation, reprocessing, and collecting of RCA [17]. This study investigates the influences of RCA on the mechanical, durability, freshness, and economic properties of concrete to encourage its usage.

Regardless, the utilization of FRCA in concrete is still a matter of debate [8], the problems like greater ratio of surface-present surplus cement fragments and attached mortar compared to CRCA. This study focusses on the use of both CRCA and FRCA in amalgamation, thus keeping the overall aggregate replacement ratio equal to 20%. For the study six different samples were made such that the total aggregate replacement ratio remained constant and equal to 20%. Fig. 3.1 depicts a conceptual depiction of the flowchart of our entire research.

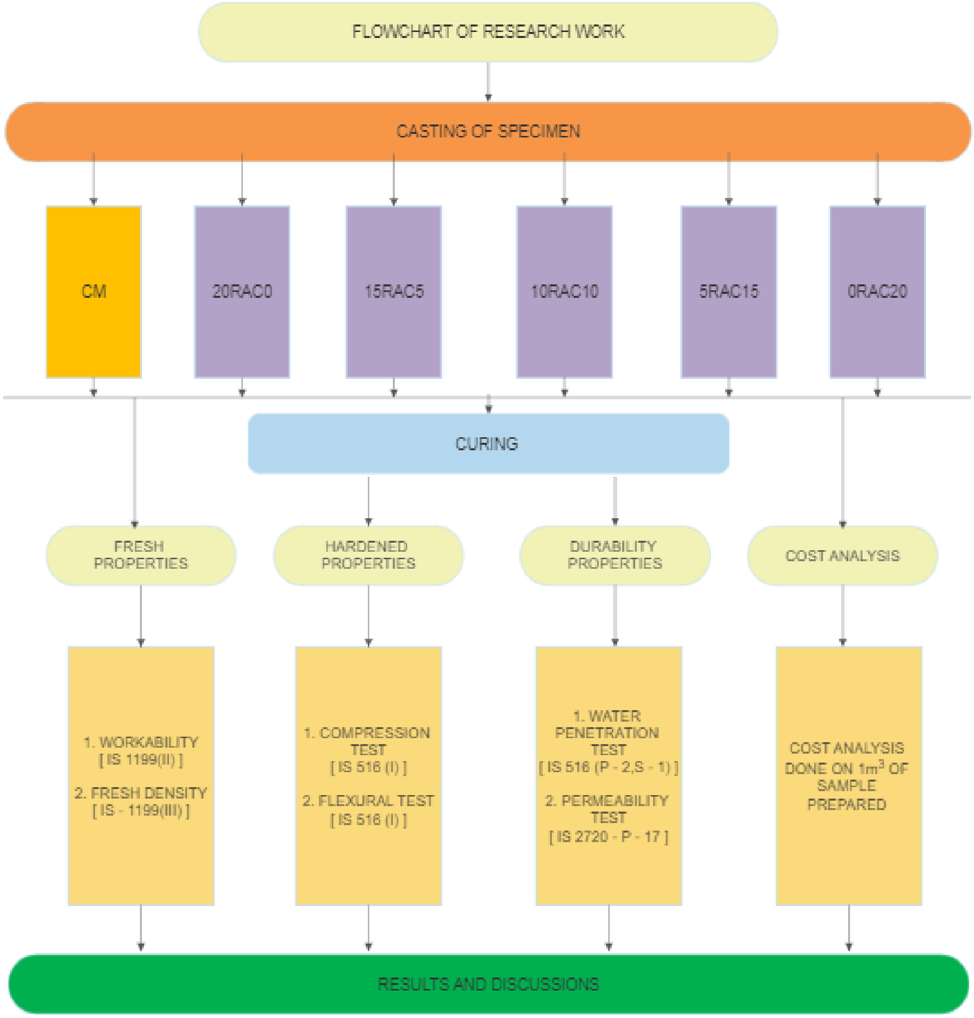


Fig. 3.1. Flowchart of experimental setup

3.3 MATERIAL PROPERTIES

This experimental study required various raw materials, natural or artificial in order to suffice for the experimental work, which is casting of specimens for further testing.

3.3.1 Cement

Conforming to standard IS 8112 [18], Ordinary Portland Cement (OPC) Grade 43 was utilized. The chemical and physical attributes of cement are illustrated in table 3.1, whereas crystallographic state is shown by X-ray diffractogram in fig. 3.2 respectively.

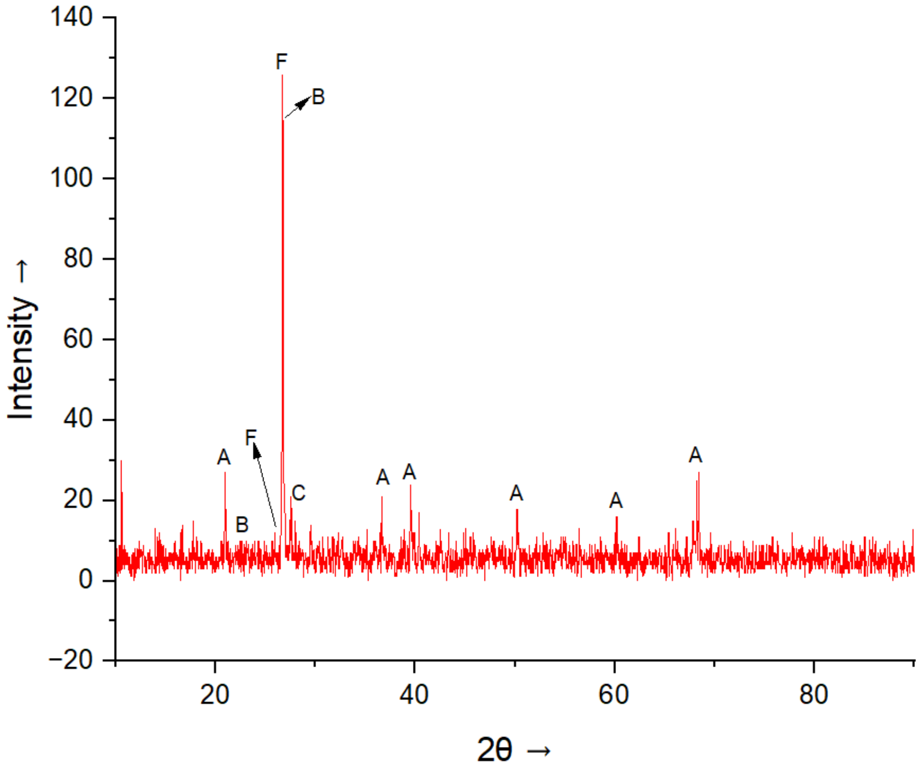


Fig 3.2. X-ray diffractogram of OPC (C-Celite, B-Belite, A-Alite, F-Ferrite)

3.3.2 Natural Aggregates

CNA were manufactured from 10 mm and 20 mm pulverized dolomite, while FNA were acquired from a local business in the vicinity of DTU campus. FNA and CNA both satisfy the requirements of standard IS 383 [19]. Figure 3.4 shows a thematic representation of grading of different aggregates on semilogarithmic graph.

Table 3.1 Properties of Cement

Chemical Attributes		Physical Attributes	
Compound	% Quantity	Properties	Recorded Value (as per IS-8112:1989)
(Lime) CaO	64.32	Fineness	7.6 % (<10)
(Silica) SiO_2	21.54	Consistency	34 % (25-35)
(Alumina) Al_2O_3	4.78	Initial setting time	130min (>30Min)
(Iron Oxide) Fe_2O_3	4.52	Final setting time	450min (<600Min)
(Sulfur) SO_3	1.73	Compressive Strength	49MPa
(Magnesium) MgO	0.45		
(Chloride) Cl	0.12		
(Potassium) K_2O	0.52		

3.3.3 Recycled Concrete Aggregates

East Delhi MCD C&D plant provided us with the RCA required for this study. The location of the aforementioned facility is depicted in Figure 3.3. The RCA waste consisted of Demolished Building Rubble that was pulverized and separated into 10mm Fine Aggregate (FRCA) and 20mm Coarse Aggregate (CRCA), respectively.

(a) (b) (c) (d) (e) (f)

Fig. 3.3. (a) C&D demolition waste facility; (b) Crushing & Segregation unit; (c) C&D unit details; (d) 20mm CRCA sample; (e) 10mm CRCA sample; (f) FRCA

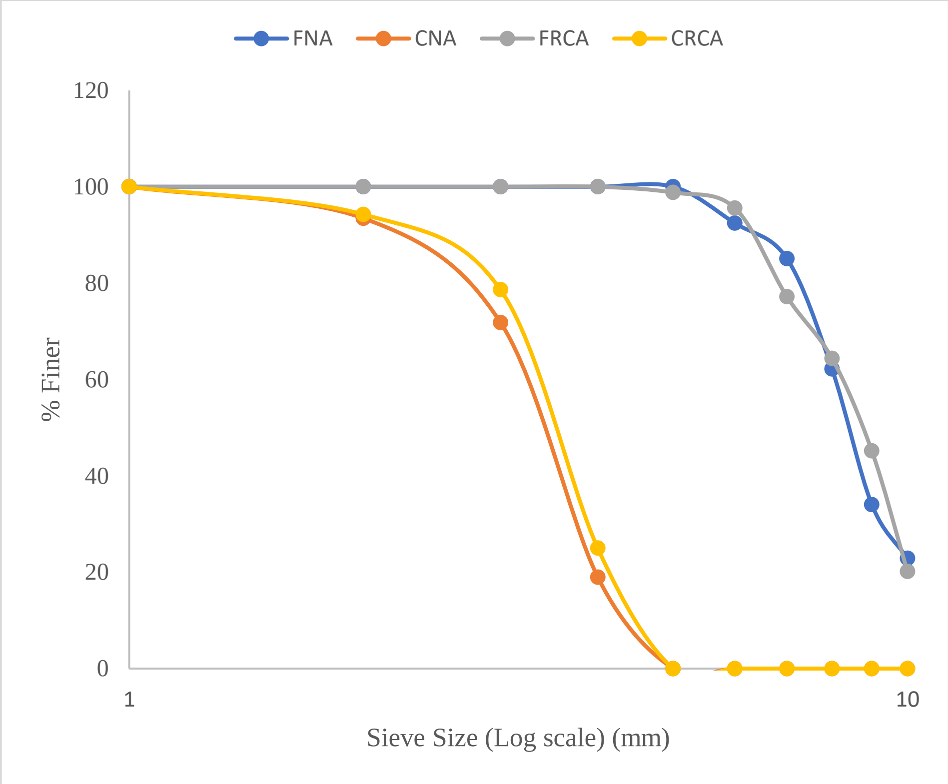


Fig. 3.4 Gradation curve of various aggregates

3.4 EXPERIMENTAL SETUP

For the experimental setup, cubes of 150mm dimensions were casted for compression testing and for measurement of unit weight, whereas for flexural testing beam of 100x100x500 mm are casted considering that maximum nominal size of aggregate is less than 38mm. Slump test was used for determining workability of samples.

3.4.1 Design of Control Mix

CRCA and FRCA are included in this study as partial replacements. The notation for concrete containing a percent CRCA and b percent FRCA replacement is aRACb, thus a sample containing 15 percent CRCA and 5 percent FRCA replacement is 15RCA5.. Six concrete types were incorporated in the present study: CM, 20RAC0, 15RAC5, 10RAC10, and 5RAC15. Control

Mix was designed for a grade of M25 as per the instructions laid down in IS 456 2000 having a w/c proportion of 0.45. [20]. To compensate for FRCA's increased liquid absorption, the 'Water compensation technique' was utilized to treat it. [21]. The aggregate content of each concrete mixture is listed in Table 3.2; nonetheless, each combination comprised of 339 kilograms of cement per m^3 of concrete. Compressive test samples are shown in Figure 3.5.

(a)

(b)

(c)

(d)

Fig. 3.5 (a) Mixing of concrete in mixer; (b) A batch of samples made for compression testing; (c) Curing of samples; (d) Samples made for Flexure testing.

To achieve the desirable slump of 100mm, Fosroc® Auramix 200, a high-performance super plasticizing additive with a specific gravity of 1.07 and a modified polycarboxylate base, was utilised. The dosage was set at 1% (by cement weight). The 'Water Compensation Method' was used to treat FRCA to mitigate for their greater water absorption [21].

Table 3.2 Aggregates per cubic meter of concrete

	Natural Aggregates		Recycled Aggregates	
Sample Designation	Coarse Aggregate [CNA] (Kg)	Fine Aggregate [FNA] (Kg)	Recycled Coarse Aggregates [CRCA] (Kg)	Recycled Fine Aggregate [FRCA] (Kg)
CM	1227.52	667.8	0	0
20RAC0	982.02	667.8	245.50	0
15RAC5	1043.39	634.41	184.13	33.39
10RAC10	1104.77	601.02	122.752	66.78
5RAC15	1166.14	567.63	61.38	100.17
0RAC20	1227.52	534.24	0	133.56

3.4.2 Concrete Property assessment

Conforming to IS 1199 (II), workability was measured using slump test by slump cone [22]. To ascertain the density of the material, fresh concrete was poured into an airtight, sturdy container, compacted using a vibrating table, and then weighed in accordance with IS 1199 (III) [23].

Compressive and flexural strengths of hardened concrete were tested in accordance with IS 516 (I) using 150 mm size cubes on a machine for compressive strength testing and 100 x100x500 mm beams on a machine for bending test (by two-point bending test) [24]. For the compressive strength test, concrete specimens were curated for 7, 28 and 56 days respectively, while for the bending strength test, they were water-curated for 28 and 56 days.

The formula for calculating bending strength is presented in equations (3.1) and (3.2). When the fracture is located at a distance greater than A ≥ L/3 (L in this instance being 500mm), Equation (3.1) is utilized, whereas Equation (3.2) is utilized when 110mm ≤ A ≤ 13.33mm and the test is disregarded if A < 110mm.

$$\sigma_t = \frac{PL}{BD^2} \tag{3.1}$$

$$\sigma_t = \frac{3PA}{BD^2} \tag{3.2}$$

Where, σ_t equals tensile flexural force (MPa)

L = The length of the sample

P = Fracture Load

B = Size of the specimen's width

D = Depth of the beam

A = Distance from the support's perimeter to the fracture

Before being assessed, curing of concrete cubes were done for 28 days in accordance with the IS 516 (part 2, section 1) water penetration test methodology [25]. The specimens were positioned in the centre of a particularly designed impermeable permeability chamber for three days while a confining gauge pressure of 5Kg/cm2 was applied on top surface of specimen. As illustrated in Figure 3.7, the specimens were then sheared with the help of a ribbed bar placed at top to obtain water penetration depth. The permeability coefficient of the sample was then calculated using Equation

(3.3) and the Falling-Head test. Additionally, the greatest penetration depth of each sample, a measure of its durability, was recorded. If the highest penetration exceeds 25 millimetres, the sample does not pass the permeability test. Figure 3.6 displays the water penetration test arrangement.

Fig. 3.6 Concrete Permeability testing equipment

Fig. 3.7 Shearing of specimens to achieve water penetration depth.

$$k = \frac{aL}{AT}\ln\left(\frac{h_1}{h_2}\right) \tag{3.3}$$

Where, k denotes the Coefficient of permeability

a = Standpipe's Surface area

A = Exposed sample’s area

L = Sample’s length

h1 and h2 = Initial and final water level in standpipe

T = Time required for head to reduce from h1 to h2

To assess the crystallographic lattice, chemical content, and physical properties, BRUKER D8 ADVANCE X-Ray Diffractometer (scanning from 10° to 90°, scanning rate = 5°/min, scan step size = 0.02°) was utilized in accordance with ASTM C1365 [26] and illustrated in Fig. 3.8. The sample was ground up and put on a glass fibre filter. The XRD patterns were analyzed using Diffrac Plus software and visualized with Origin. All four different types of aggregates were subjected to XRD examination. The results were then contrasted and discussed.

(a)

(b)

(c)

(d)

Fig. 3.8 (a),(b) X-ray Diffractometer D8 ADVANCE by BRUKER; (c) Raw uncrushed sample of CRCA and CNA; (d) Crushed CRCA and CNA (finer than 90μ) for XRD examination.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 GENERAL

Testing was done on natural aggregates and on recycled concrete aggregates as well as on treated CRCA. Furthermore, compressive strength test, bending strength test, workability test and water penetration cum permeability tests were also performed on the samples. Finally, an economic study was performed on samples obtained and results of all the tests are discussed in the concluding units.

4.1.1 Comparative Examination of Different Aggregates

Table 4.1 investigates the characteristics of several aggregates. Figure 3.4 illustrates the grading of CNA (50 percent - 20mm - 50 percent - 10mm), whereas the grading of FNA exceeds the standards for Grading Zone II of IS 383 [19]. Table 4.1 depicts the many aspects of the aggregate quality. After mild acid exposure for a duration of 24 hours, CRCA had a water absorption value of 6.1%, whereas TRCA had a water absorption value of 4.2%, suggesting a decrease of 30.43 % in water absorption value.

The G_s of natural aggregate and RCA displayed small variations from one another (Table 4.1). CRCA and TCRCA had specific gravities that were 17 percent and 16 percent less than CNA, respectively. In the instance of the FRCA, this percentage was 11.78%. It is suggested that the overall water absorption should not exceed 2 percent [27]. .As demonstrated in Table 4.1, CNA and FNA are the only aggregates which abided by the given recommendation of 2% water absorption.

Due to cleaning of FRCA with water & its drying prior to water absorption test, the water absorption is likely exaggerated. FRCA if left untreated would have resulted in more value of water absorption due to the abundance of more foreign particles.

Various tests, including abrasion, fall, compression, specific gravity etc., were performed in accordance with IS 383 [19] to investigate the mechanical characteristics of aggregates. These tests included abrasion, impact, and compression. Figure 4.1 illustrates the CRCA therapy with a moderate acid (one molecule of acetic acid).

Table 4.1 Characteristics of various aggregates

Properties	Governing Code	Natural Aggregates		Recycled Aggregates		
		CNA	FNA	CRCA	TCRCA	FRCA
Fineness Modulus	IS 383 [19]	6.4	2.7	6.5	6.4	3.2
Water Absorption (%)	IS 2386 (III) [27]	0.65	1.8	6.1	4.2	8.3
Specific Gravity	IS 2386 (III) [27]	2.7	2.63	2.22	2.25	2.32
Moisture Content (%)	IS 2386 (III) [27]	0.2	0.52	0.9	0.56	1.8
Unit Weight (kg/m^3)	IS 2386 (III) [27]	1480	1620	1426	1445	1575
Impact Value (%)	IS 2386 (IV) [28]	18.25	-	31.20	28.78	-
Abrasion Value (%)	IS 2386 (IV) [28]	26.82	-	36.51	33.76	-

(a) (b)

Fig. 4.1 Using a mild acid to treat CRCA.

4.1.2 XRD examination of aggregates

Figures 4.2 and 4.3 depict the XRD findings of several aggregate varieties. Given that quartz (SiO_2) is the most prevalent constituent of river sand, the XRD diffractogram of FNA demonstrates a predominance of quartz (SiO_2) [29]. The magnitudes of the quartz and microcline spike declined as the assemblance of FRCA rose, with the lowest intensities occurring in FRCA.

Although the qualitative character of the XRD data, it appears that a considerable quantity of reacted cement paste attached to FRCA. As the FNA concentration declined, the magnitudes of the belite and portlandite peaks gradually rose, suggesting the existence of a few unreacted cement molecules in the adhered state of mortar. However, the non - availibility of portlandite spike in CRCA indicates that it had transitioned to the calcite or carbonated stage, as miniscule calcite traces (intensity spikes) are present in all RCA’s known form [30].

According to another author [31], portlandite is freed from the hydrated cement paste when RCA is crushed into fine powder for XRD analysis. Portlandite undergoes rapid carbonation when subjected to CO_2 in the atmosphere, resulting in the formation of calcite. Due to the geological origin of the great majority of natural aggregates, CRCA's XRD measurement indicates the presence of a minute dolomite phase. Due to cement reaction, CRCA exhibited a little secondary spike of C-S-H gel (tobermorite).

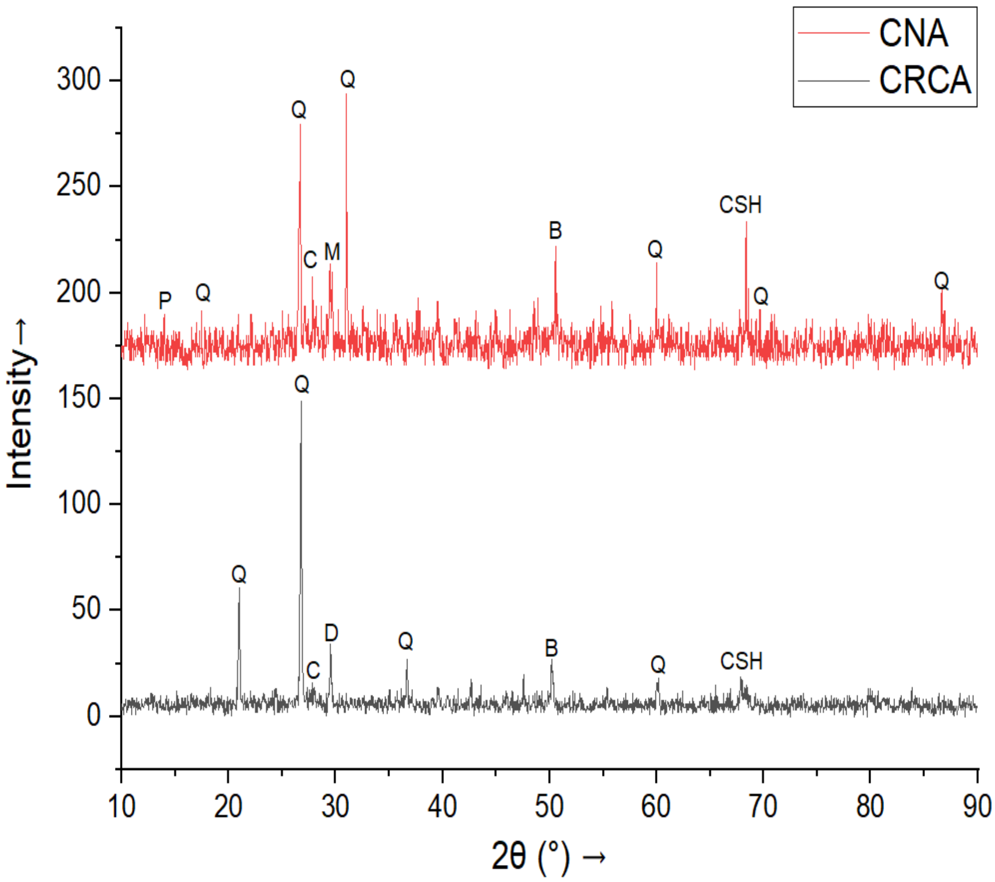


Fig. 4.2 XRD of CNA and CRCA aggregates using Origin© (B-Belite; C-Calcite; D-Dolomite; CSH-Calcium Silicate Hydrate; Q-Quartz; P-Portlandite; M-Microcline)

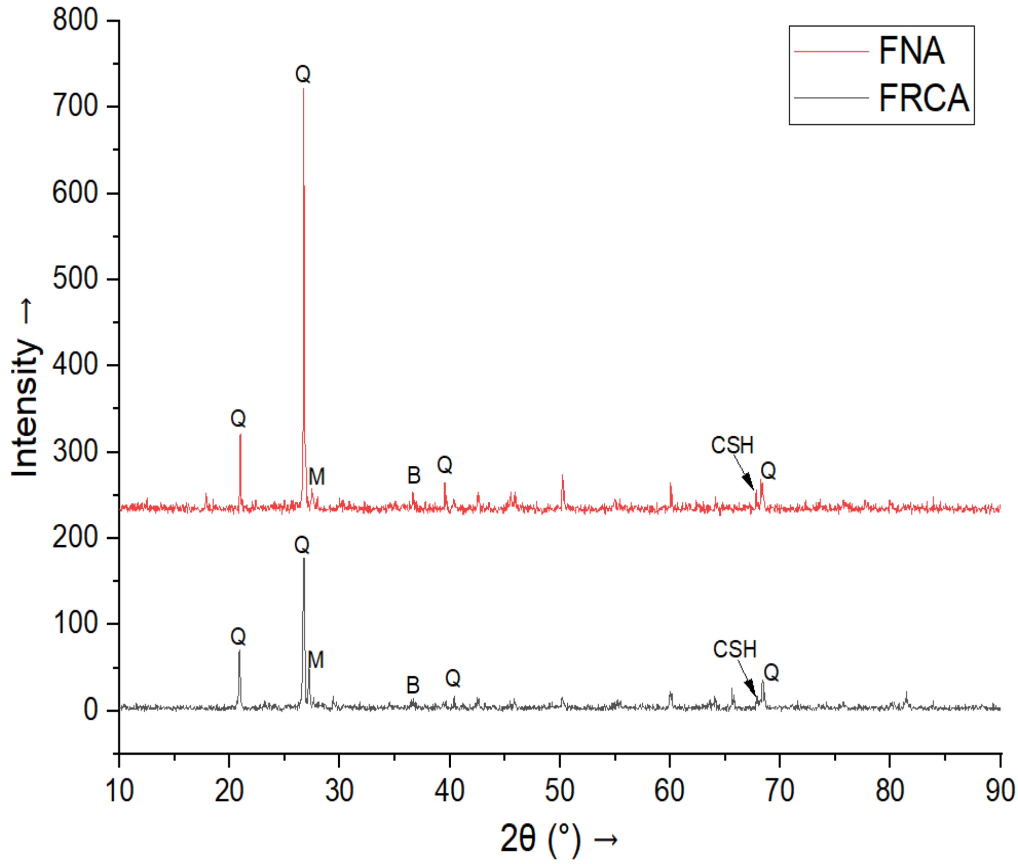


Fig. 4.3 XRD of FNA and FRCA aggregates using Origin© (B-Belite; C-Calcite; D-Dolomite; CSH-Calcium Silicate Hydrate; Q-Quartz; P-Portlandite; M-Microcline)

4.2 FRESH CONCRETE PROPERTIES

In this section, properties of concrete like workability and unit weight of various samples are measured which are measured in concrete's fresh state. For the purpose of determining workability, slump test is performed while unit weight is measured with the help of concrete mould and weighing balance.

4.2.1 Workability

To compensate for the high-water absorption capacity of RCA, concrete containing RCA often contains additional water. This can be accomplished in one of two ways: either by prewetting the RCA or by continuously adding water until the concrete is well mixed (equal to the RCA's water absorption). The most difficult aspects of pre-saturating RCA are predicting the amount of water necessary and knowing how to get there.

According to Sadagopan et al. [32], the RCA absorbs more than 90 percent of the water consumed in a 24-hour period in just 15 minutes. Without corrective measures, this high rate of water absorption by RCA reduces the effective water-to-cement ratio of the concrete mixture, hence decreasing its workability [21]. Sadagopan et al. [32] suggested pre-soaking RCA with only 50 percent of the amount of water absorbed by RCA in 15 minutes to get a workability comparable to that of ordinary RAC.

The quantity of water compensation in the water compensation approach is decided by the size of the RCA and the workability criterion (more water is required in FRCA than in CRCA) [33]. Concrete should not be combined with a quantity of additional water equal to the FRCA's 100 percent water absorption capacity, since doing so might result in bleeding [34].

Moreover, when concrete is rapidly mixed, FRCA may not be able to quickly absorb this extra water [35]. Furthermore, extra water accumulates in the interfacial transition zone, weakening the connection between aggregates and paste matrix [36]. Therefore, Bouarroudj et al. [37] and Zhao et al. [38] suggested employing FRCA in a dry environment to enhance the interaction between the cement matrix and aggregates.

Through autoclave curing [39], hot curing [40], or the use of a polycarboxylate-based high-range water reducer [41], it is feasible to alleviate the complications produced by the addition of more water during concrete mixing. There are several possible explanations for complicated phenomena, such as the workability of concrete with FRCA, which is the flow behaviour of FRCA-incorporated concrete, and each explanation must be tested by tests.

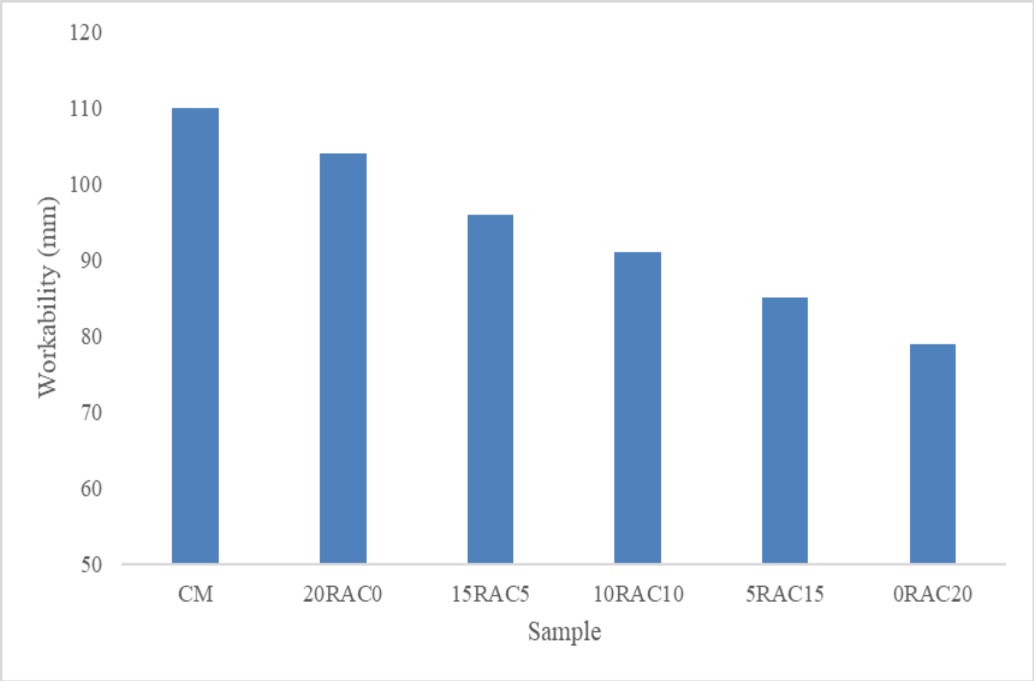


Fig. 4.4 Graph illustrating the workability of several samples.

Fig. 4.5 Conducting a slump test on CM

4.2.2 Fresh unit weight

Fresh concrete unit weight is controlled by void content, water/cement ratio, and aggregate type [3]. These components also contribute to the features of cement-bound concrete. Because a drop in density signifies an increase in the quantity of water and voids in concrete, there is a link between the low density of fresh concrete and its low strength once it has hardened [42]. RAC is usually less dense than natural aggregate concrete [43] because to the integration of low-density adhering mortar.

Clearly, the unit weight of the CRCA is 3.65 percent less than that of the CNA, which may be attributed to the presence of adhering mortar, which fills gaps to reduce unit weight. Moreover, the removal of the adhering mortar layer increases the unit weight by 1.32 percent compared to CRCA following treatment with a one-molar acetic acid solution [10]. According to the unit weight curve, the unit weight of fresh concrete drops significantly with an increase in coarse and fine aggregate replacement, however the effect is greater with an increase in FRCA.

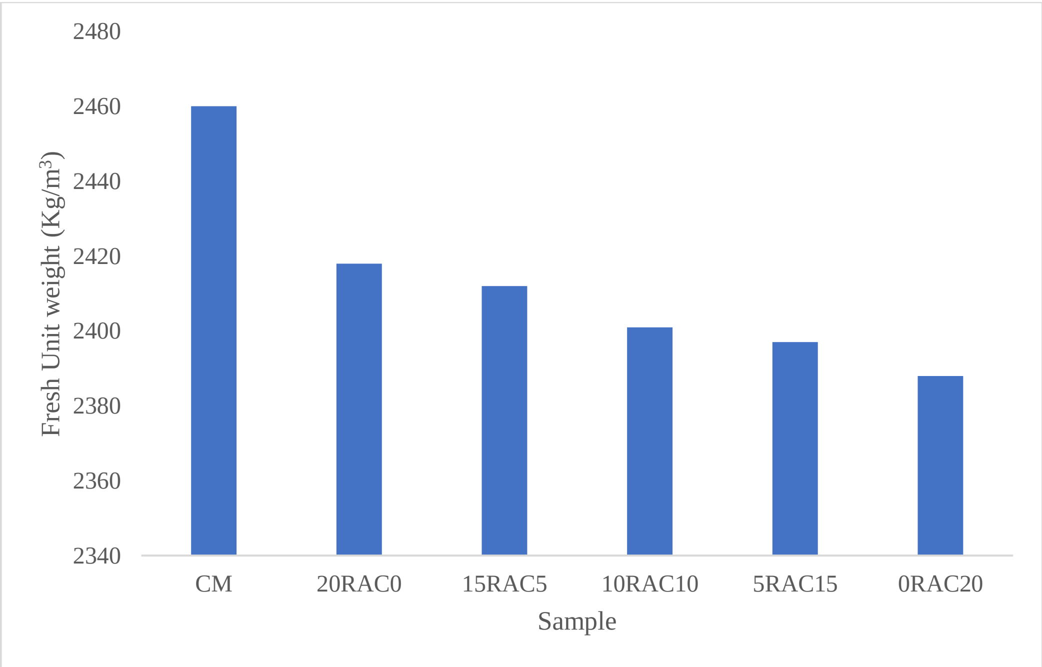


Fig. 4.6 Variation in Unit weight among diverse samples.

Moreover, the highest unit weight decrease for the 0RAC20 sample is 3 percent smaller than that of the CM. Normal concrete has a density between 2240 and 2400 kilogrammes per cubic metre [44], while semi-lightweight concrete has a density between 1840 and 2240 kilogrammes per cubic metre [41]. Therefore, all concrete compositions are regarded as standard concrete.

4.3 HARDENED CONCRETE ATTRIBUTES

In this section, properties of concrete are measured in hardened state, these includes compressive and flexural testing. For the experimental purpose, cubes of 150mm size are casted for compressive strength, whereas for bending strength test purpose beam of dimension 100x100x500 mm are casted taking into account the maximum nominal size of aggregates was less than 38mm. These beams were then tested using 2 - point flexure test.

4.3.1 Compressive strength

Figure 4.7 depicts the variation in compressive strength among several samples. The control mix (CM) was designed with a target strength of 34.26MPa, which is greater than the required target strength of 31.60MPa, as it was intended to have a characteristic strength of 25MPa. Further analysis reveals that 20RAC0 had the highest replacement ratio, with a strength 7.44% lower than CM. Since there was a general tendency for strength to decrease as FRCA increased, 0RAC20 had the lowest strength of all the samples, which was 12.72 percentage points below CM.

Regardless of concrete series or curing age, the addition of RCA lowered compressive strength, as seen in Figure 4.7. There was a higher difference in compressive strength between CM and recycled concrete at early ages (7 and 28 days) compared to later ages (56 days). In addition, this pattern reveals that the sensitivity of these materials to FRCA reduces as the curing age increases.

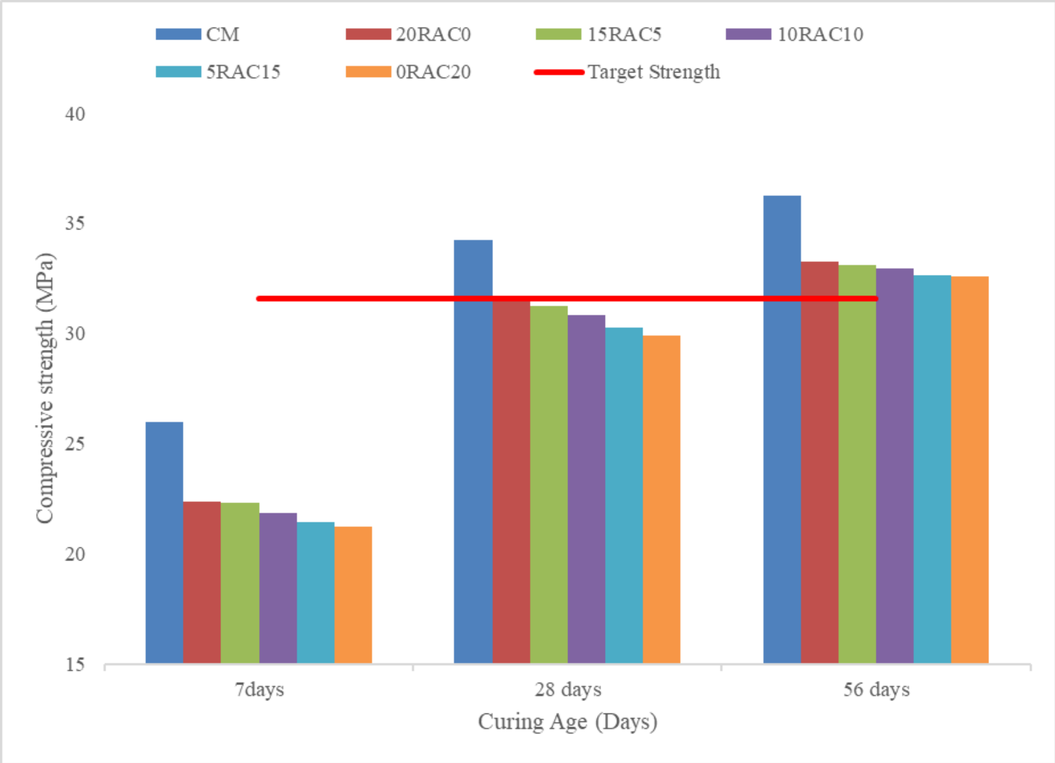


Fig. 4.7 Variation of Compressive strength

According to Nedeljkovic et al [45] review's of more than 30 prior studies on the incorporation of FRCA in concrete, the maximum reduction in 28-day compressive strength at an FRCA replacement ratio of greater than or equal to 30 percent ranges from 11.1% to 50%, which is less than the results of this study.

As the curative age grew, the sample's efficacy and FRCA content also increased. This implies that the compressive strength of 20RAC0 increased more rapidly up to 28 days. However, after 28 days, it was larger for 0RAC20.


ABHISHEK
CM

(a)


HEICO
COMPRESSION TESTING MACHINE
CAPACITY - 2000 KN

(b)


HEICO
COMPRESSION TESTING MACHINE
CAPACITY - 2000 KN

(c)


HEICO
COMPRESSION TESTING MACHINE
CAPACITY - 2000 KN
ABHISHEK

(d)


ABHISHEK
CM
345

(e)

(f)

(g)

(h)

Fig. 4.8 (a);(b);(c);(d) represents compression test of samples CM, 20RAC0, 10RAC10, 0RAC20 respectively; (e) Rebound Hammer test on CM; (f) Crushed 20RAC0 sample indicating CDCA particles; (g) Crushed 10RAC10 sample indicating CDCA particles; (h) Crushed 0RAC20 sample

The XRD examination of FRCA verified the existence of belite (Fig. 4.3), showing that the unhydrated cement particles found in the adhering mortar of FRCA were responsible. Since belite is responsible for imparting strength at later ages, its presence helped 0RAC20 harden faster than 20RAC0 at curing ages beyond 28 days by increasing its hydraulicity. Observe that the increase in compressive strength of 0RAC20 did not equal that of 20RAC0 until 28 days had passed, and even then it was lower. Due to the need for additional water to attain the same workability as CM, the addition of FRCA drastically decreased the concrete's compressive strength.

The improvement in compressive strength is because of infill effect (when finer than FNA), internal curing effect, uneven exterior surface, and angular form of FRCA [46]. In conclusion, it is reasonable to conclude that the FNA/FRCA replacement ratio, the w/c ratio, saturation condition of the FRCA are the three most influential factors influencing the compressive strength of FRCA concrete.

4.3.2 Flexural strength

Figure 4.9 depicts the results for concrete's bending strength. The bending strength closely matched the compressive strength model, with a maximum strength of 4.42 MPa for CM and minimum values of 7.01 and 18.33 percent less than CM for 0RAC20 and 20RAC0, respectively.

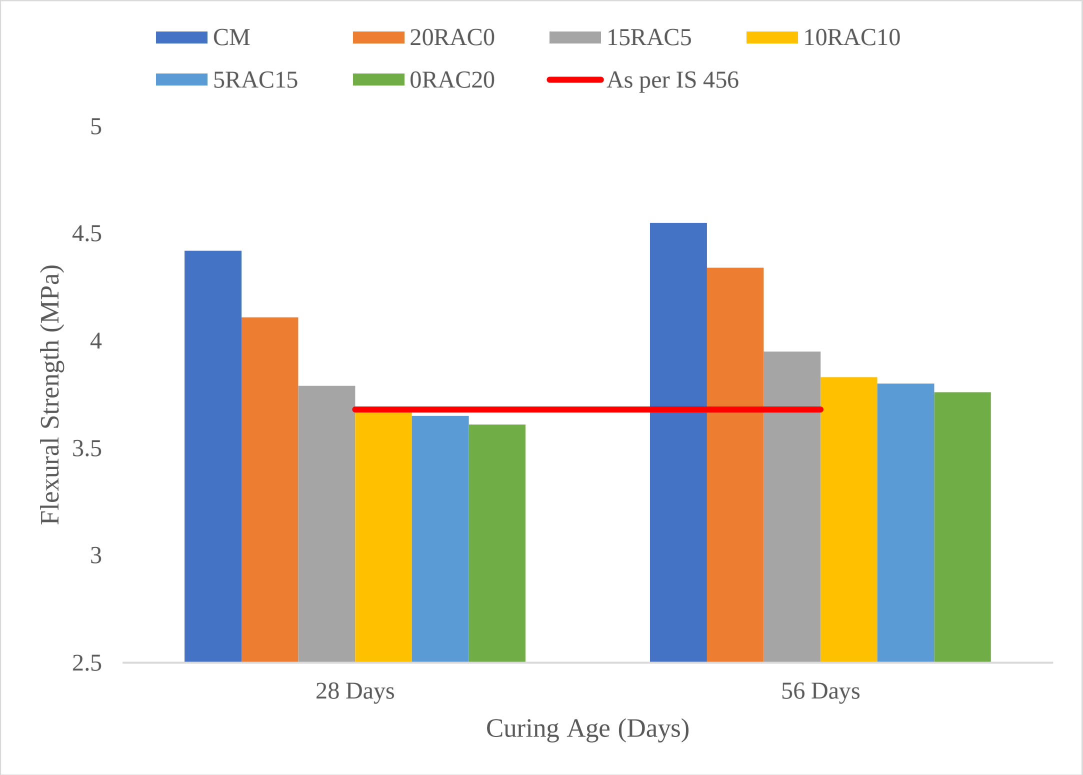


Fig. 4.9 Differences in flexural strength between samples.

The properties of FRCA and CRCA, such as exterior texture, high water absorption capacity, weak layer of old adhered mortar, and low angularity, etc., which weakened the interfacial transition zone due to poor lattice interlocking between these aggregates, are likely responsible for the flexural strength of all samples being less as compared to CM (regardless of curative age and replacement ratio) [47].

Because it controls the strength of the interfacial connection, the orientation or position of the greater dimension of coarse aggregates frequently dictates the total flexural strength of the sample [48]. It counteracts the detrimental effects of RCA on recycled concrete's flexural strength by enhancing the material's flexural resistance. This produced a bigger impact on the compressive strength of recycled concrete than its flexural strength.

(a) (b)

Fig. 4.10 Flexural examination of beam samples.

4.3.3 Water permeability and penetration depth

Durability of concrete is primarily determined by its water impermeability. Concrete's imperviousness to water is the most essential aspect in calculating its durability. In the past, the capacity of concrete to suck water has been calculated using different type of methods, including the saturated water absorption test and the water sorptivity test (which assesses the object's ability to suck water while entirely submerged) [[50], [51]].

The present study determined the permeability coefficient (k) of concrete (as shown in Figure 3.6) utilising the falling head technique mentioned in IS 2720 - Part 17

[30]. The water penetration test met IS 516 Part 2 Section 1 [25] requirements. 20RAC0 and 0RAC20 had a penetration depth 1.67 and 4.50 times that of CM, respectively.

The graph illustrates that the value of 'k' increases when C&D waste (both CRCA and FRCA) is added, but the increase is more pronounced when FRCA concentration increases. After 28 days of curing, the 'k' values of 20RAC0 and 0RAC20 were roughly 2.57 and 4.94 times larger than those of the control mixture (CM).

The tendency of FRCA to absorb more water during proportioning enhanced the permeability of concrete after 28 days of curing. However, for less than 28 days curing of concrete, extra water affects the buffer zone in between surfaces and cement matrix by altering the quantity of water and the number of pores. However, when the curing age surpasses 28 days, the same additional water aids the RCA's internal curing process. (the compressive strength test results verified this as well).

Previous research [52,53] advises adding cementitious additives, a low water-to-cement ratio, and superplasticizers to concrete containing RCA to boost its durability. According to Kapoor et al. [53], changing 10% of the cement in RAC with metakaolin improved pore refinement and decreased capillary pore volume, bringing RAC's water permeability to the same level as the control Mix.

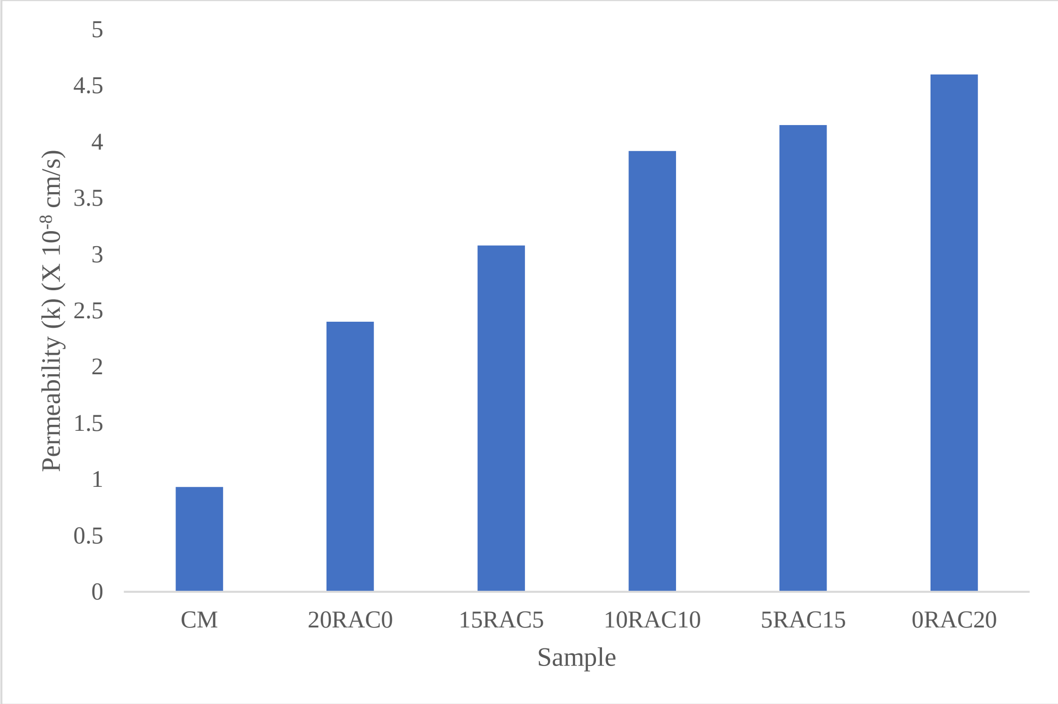


Fig. 4.11 Variation in permeability between samples.

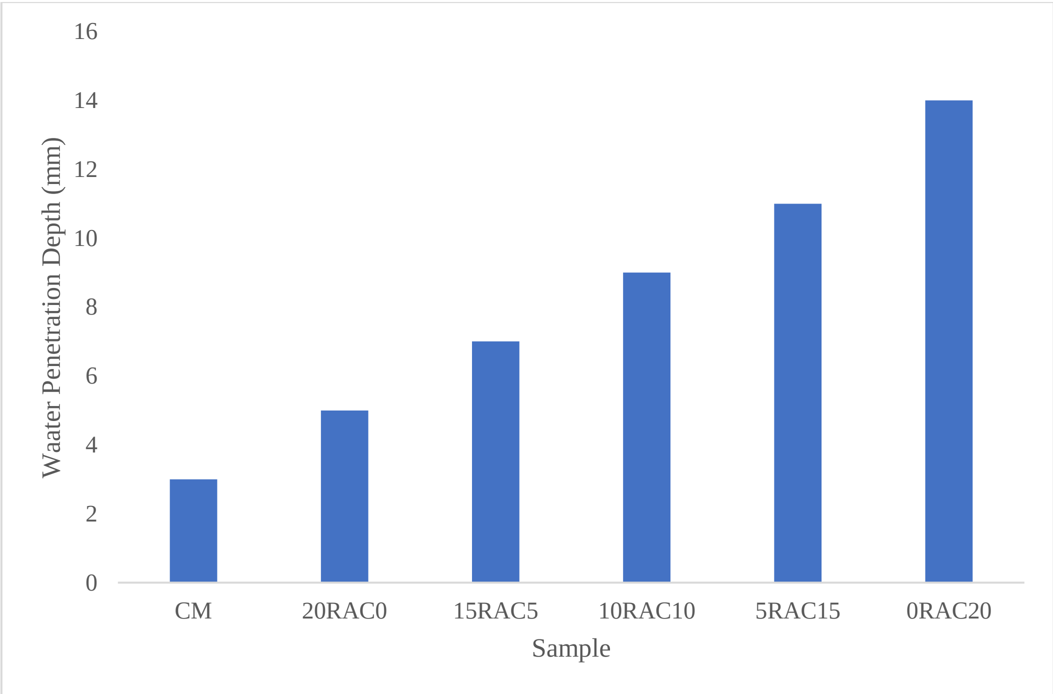


Fig. 4.12 Water penetration depth of various samples.

(a)

(b)

(c)

(d)

(e)

(f)

Fig. 4.13 (a) Water penetration depth marked on various samples; (b); (c); (d); (e); (f) represents measurement of water penetration depth of various samples; (g) Shearing of 20RAC0 sample to measure water penetration depth.

4.3.4 Relationship between numerous variables

After completing several experimental investigations, we discovered a general pattern in the different qualities of the samples. However, it is not always easy to undertake experimental investigations since they cost both time and money. Consequently, it became important to construct connections that would aid researchers in calculating the approximate values of different variables. Table 4.2 presents the coefficient of determination (R^2), which helps determine the relationship's stability.

Table 4.2 Classification of R^2 Values

R^2 Value	Comments
$R^2 < 0.65$	Unacceptable
$0.65 \leq R^2 \leq 0.80$	Acceptable
$0.80 \leq R^2 \leq 0.95$	Good
$R^2 \geq 0.95$	Very Good

4.3.4.1 Characteristic compressive strength and flexural strength

The experimental examination yielded a link between experimental compressive strength ('f_c') and flexural strength ('f_{ex}'), as represented in Figure 4.14, and deduced from Equation (4.1). Indian Standard IS 456 [54] offers Equation (4.2) for determining the flexural strength of concrete based on its compressive strength.

$$f_{ex} = 0.0675 f_c^{\,1.2617} \qquad R^2 = 0.9195 \tag{4.1}$$

$$f_{is} = 0.7059 f_c^{\,0.4974} \qquad R^2 = 1 \tag{4.2}$$

The context of the discussion revealed that IS 456 [54] considerably underestimates the flexural strength of 0RAC20 and 20RAC0 when compared to the actual value (Fig. 4.14) by 6.40–16.74 percent. The generalisation of Equations (4.1) and (4.2) can be quite beneficial for calculating the flexural strength of RAC from its compressive strength and minimising the need for experiments.

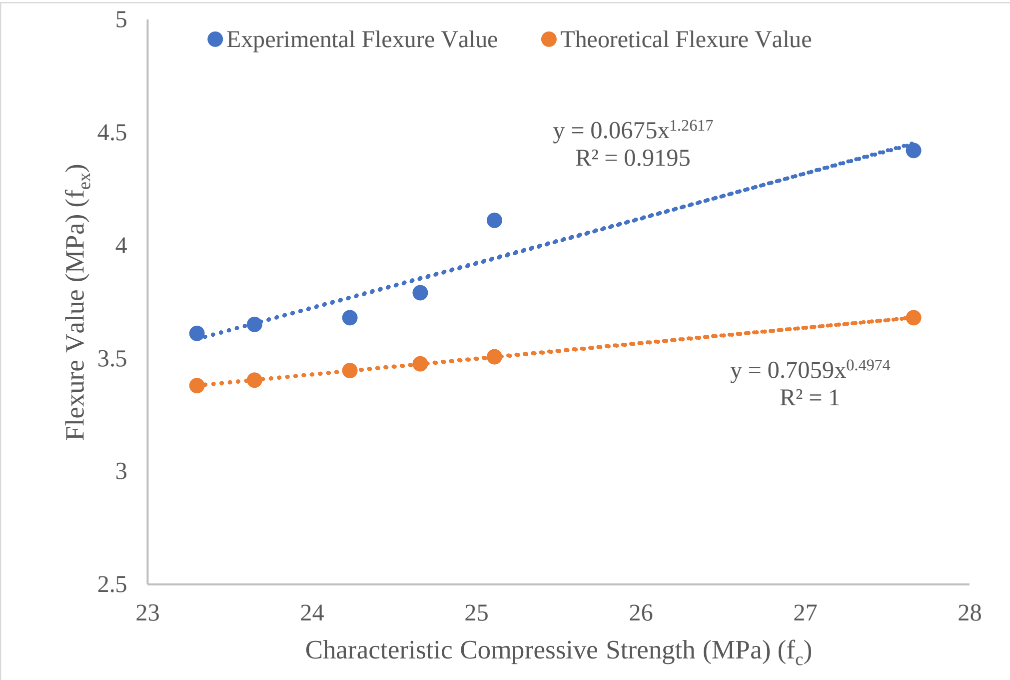


Fig. 4.14 Relationship between Flexural strength and Characteristic compressive strength.

4.3.4.2 Unit weight and target compressive strength.

It is evident from Fig. 4.15 and Eq. (4.3) that unit weight (f_u) follows a linear relationship, in which unit weight increases with an increase in compressive strength of sample, as demonstrated by the fact that Unit weight of CRCA and FRCA was less than that of CNA and FNA, resulting in a lower overall unit weight of mixes. The validity of the equation can also be confirmed because the R2 value falls within the allowable range, as shown in Table 4.2.

Therefore, equation (4.3) can be used to determine Unit weight for a given concrete compressive strength.

$$f_u = 16.312 f_t + 1901 \qquad R^2 = 0.9949 \tag{4.3}$$

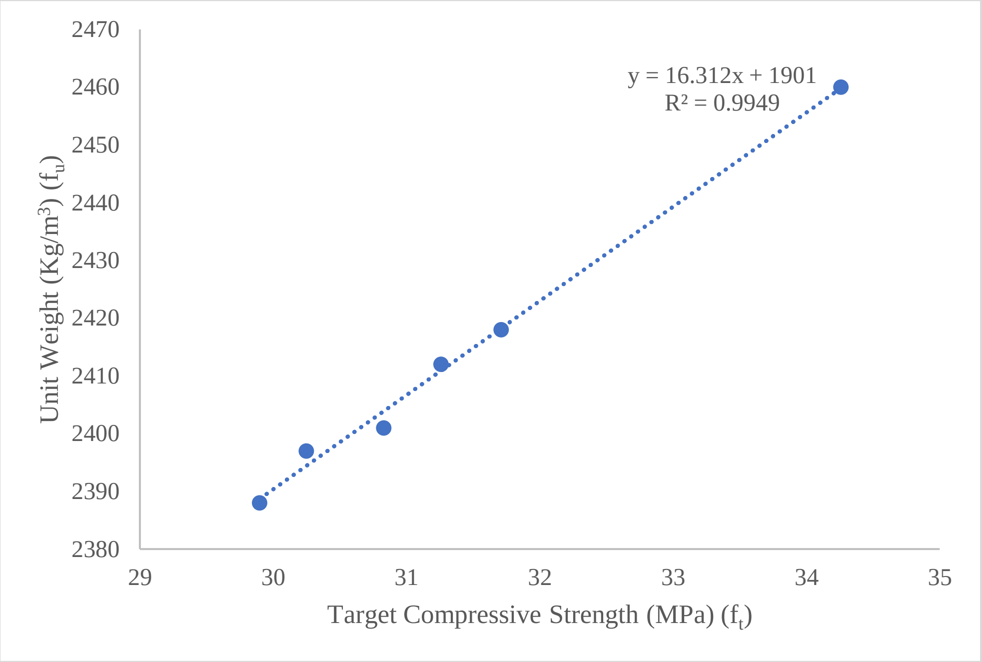


Fig. 4.15 Unit weight and compressive strength Relationship.

4.3.4.3 Water Permeability and Target compressive strength.

Fig. 4.16. And Equation (4.4) demonstrates the experimentally determined relationship between Water Permeability (k) and Compressive Strength (f_t). Clearly, as compressive strength (or FRCA replacement) increases, water permeability decreases. This phenomenon may be caused by the increase of cavities in a cement matrix made with RCA mortar and backed by a layer of adhered mortar, which disintegrates over time, resulting in the formation of micropores in the structure, thereby increasing its permeability.

$$k = -0.8472f_t + 29.755 \qquad R^2 = 0.9531 \tag{4.4}$$

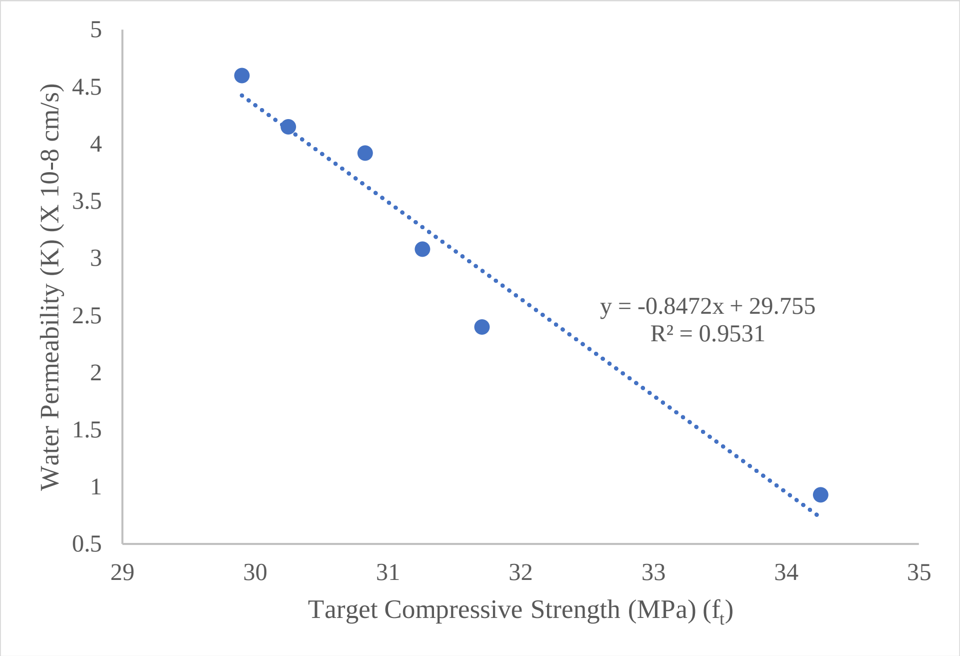


Fig. 4.16 Water permeability and Target Compressive Strength.

4.3.4.4 Water Permeability and unit weight.

Fig. 4.17 and eq. (4.5) indicates that the relationship between water permeability (k) and unit weight (f_w) is approximately linear. Water permeability increases as the unit weight of concrete decreases, because of an increase in the percentage of RAC in concrete. Thus, when unit weight is known with reasonable precision, equation (4.5) can be used to approximate the permeability of concrete.

$$k = -0.052f_w + 128.54 \quad R^2 = 0.9589 \tag{4.5}$$

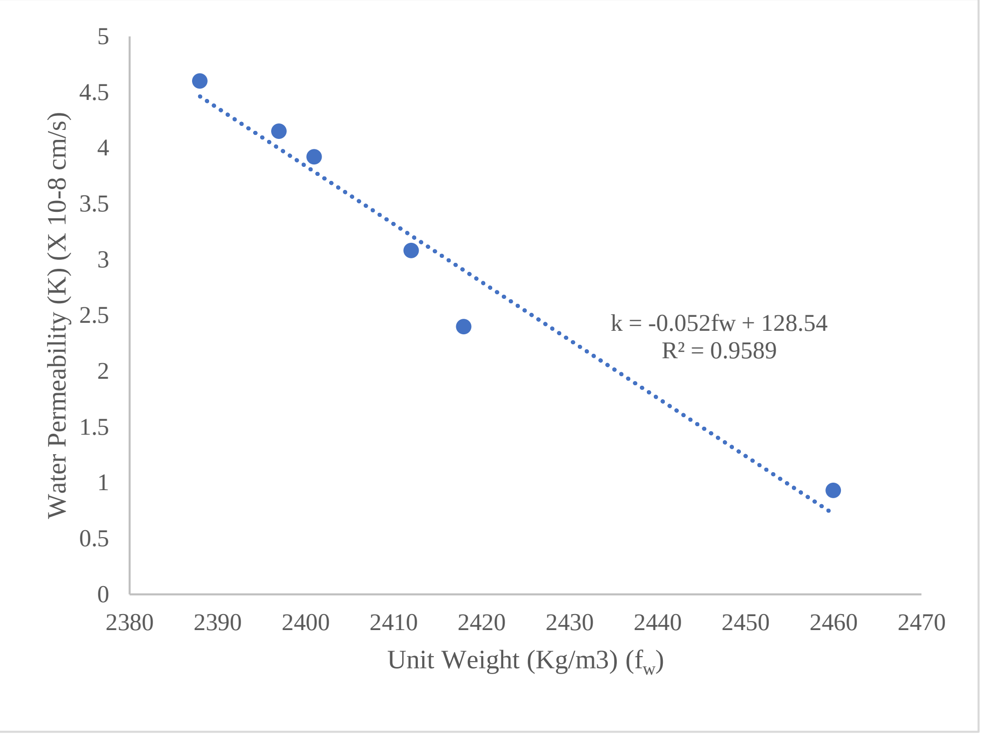


Fig. 4.17 Relationship of Unit weight to Permeability.

4.3.4.5 Water Penetration Depth and Compressive strength

The relationship between water penetration depth (d) and compressive strength (f_t) is erratic, as shown in Figure 4.18 and Equation (4.6), but can be approximated to be linearly dependent with a reasonable degree of accuracy, as shown in the table. Possible argument supporting the relationship is that at low replacement ratios (or in CM), the voids in the lattice are minimal, whereas as the replacement ratio increases, especially in FRCA, the concrete becomes more porous for the reasons outlined in section 4.3.4.4, resulting in greater water penetration depth. Consequently, equation (9) can be used to calculate water penetration depth for a given compressive strength, yielding acceptable results according to Table 4.2.

$$d = -2.304 f_t + 80.44 \qquad R^2 = 0.8003 \tag{4.6}$$

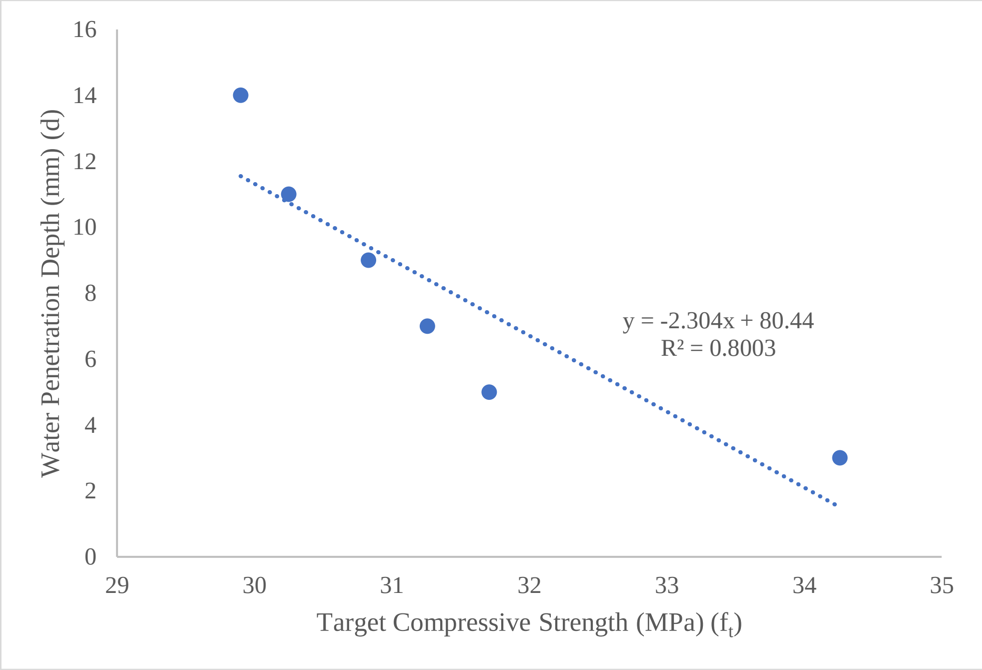


Fig. 4.18 Correlation between Water Penetration Depth and Sample Compressive Strength.

4.3.4.6 Water penetration depth and unit weight

As shown in Fig. 4.19 and Equation (4.7), the water penetration depth (d) decreases as the Unit weight (f_w) of concrete increases. This phenomenon can be explained by the fact that unit weight increases as RAC content decreases (this effect is more pronounced for FRCA) and by the fact that a higher percentage of adhered mortar in RAC leads to more cavities in concrete, thereby increasing the water penetration depth. Therefore, equation (4.7) can be used to approximate the depth of water penetration.

$$d = -0.1407 f_w + 347.69 \quad R^2 = 0.7985 \qquad (4.7)$$

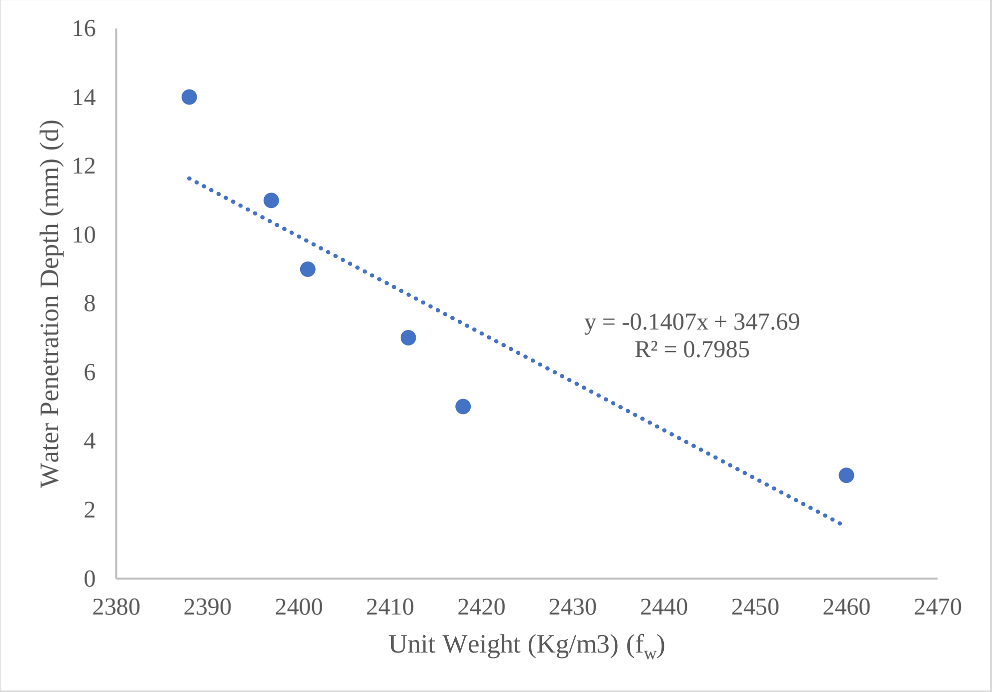


Fig. 4.19 Relationship between Sample Unit Weight and Depth of Penetration.

4.4 COST – ANALYSIS

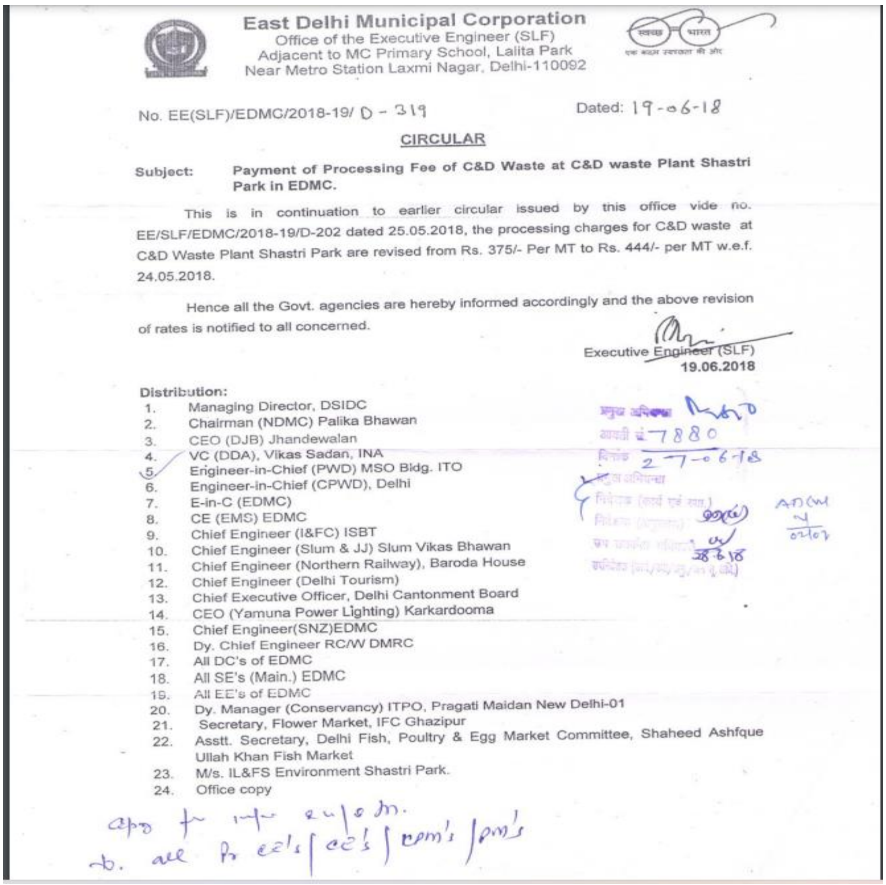
In this quick comparison, we assumed that the transportation and extraction costs for aggregate and C&D waste are same. The expenses for each component are indicated in Table 4.3. CNA and FNA are procured from a local market close to the DTU campus, whereas CRCA and FRCA are acquired at the East Municipal Corporation C&D facility in Shastri Nagar. The C&D waste processing fee levied by the East Delhi Municipal Corporation is depicted in Figure 4.20. We analysed the cost of producing 1 m3 of concrete using the mix design presented in Table 3.2.

Figure 4.21 illustrates a cost theme diagram for all samples generated for one cubic metre of sample. The graph illustrates a decline in sample costs relative to CM.

Table 4.3 Cost incurred per material for 1m^3 concrete production.

Constituents	Cost (₹)
CNA	2240/Ton
FNA	2240/Ton
CRCA	444/Ton
FRCA	444/Ton
Cement (OPC-43)	450/Bag (50Kg)

Moreover, sample 20RAC0 had the lowest cost, which was 7.39 percent less than sample CM, while sample 0RAC20 had the greatest cost, which was 3.28 percent less than sample CM. Thus, it is evident that the integration of RCA greatly decreases costs, with CRCA incorporation in concrete providing the greatest cost advantage.



East Delhi Municipal Corporation
Office of the Executive Engineer (SLF)
Adjacent to MC Primary School, Lalita Park
Near Metro Station Laxmi Nagar, Delhi-110092

No. EE(SLF)/EDMC/2018-19/ D - 319 Dated: 19-06-18

CIRCULAR

Subject: **Payment of Processing Fee of C&D Waste at C&D waste Plant Shastri Park in EDMC.**

This is in continuation to earlier circular issued by this office vide no. EE/SLF/EDMC/2018-19/D-202 dated 25.05.2018, the processing charges for C&D waste at C&D Waste Plant Shastri Park are revised from Rs. 375/- Per MT to Rs. 444/- per MT w.e.f. 24.05.2018.

Hence all the Govt. agencies are hereby informed accordingly and the above revision of rates is notified to all concerned.

Executive Engineer (SLF)
19.06.2018

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21. Secretary, Flower Market, IFC Ghazipur
22. Asstt. Secretary, Delhi Fish, Poultry & Egg Market Committee, Shaheed Ashfque Ullah Khan Fish Market
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24. Office copy

Fig. 4.20 Circular showing Processing Fee for Demolition Waste

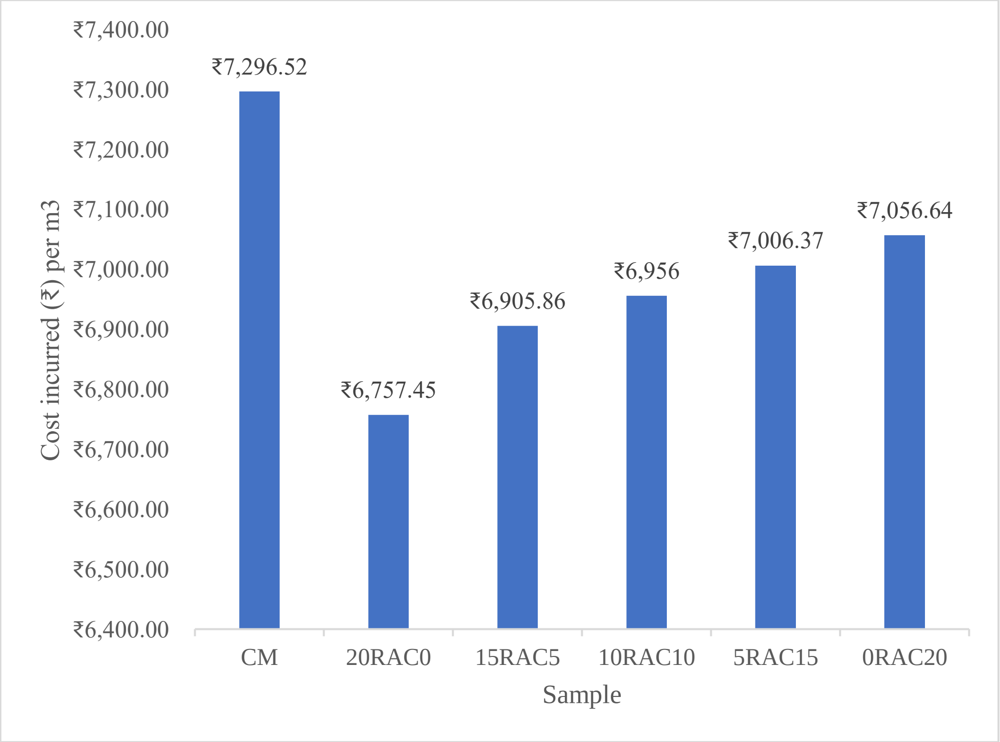

Fig. 4.21 Comparative study of the costs of several samples (1m^3 Volume)

CHAPTER 5

CONCLUSION

Due to the complexity of FRCA, the great bulk of previous research has focused only on the impact of CRCA on the properties of concrete. To limit the total replacement to 20%, the authors felt compelled to evaluate the effect of varying FRCA and CRCA ratios on the characteristics of concrete containing them. Significant conclusions may be taken from the performed trials:

- The treatment of CRCA with a moderate acid greatly improves its mechanical and physical characteristics, although they continue to be inferior to CAN. The CRCA absorbs water nine to ten times better than CNA (without treatment) and six to seven times better after treatment. FRCA absorbs four-and-a-half times the amount of water as compared to FNA.

- The workability and fresh density of samples (xRACy) diminish when FRCA concentration increases. However, all types of concrete can be designated as "ordinary concrete."

- Regardless of curing age, all samples between 20RAC0 and 0RAC20 have lower strengths than CM, but subsequent curing may be sufficient to compensate for the strength loss. Among different variables tested, flexural strength showed least effected by RCA inclusion in concrete. As the curing period extends, the detrimental effects of FRCA on concrete strength begin to diminish. Prolonged curing, however reduced the detrimental effects caused by inclusion of FRCA.

- As the replacement ratio of FRCA grows, the water permeability of the sample increases, with the 'k' values of 20RAC0 and 0RAC20 being 2.57 and 4.94 times greater than those of the control mixture (CM), respectively.

- As the FRCA ratio increases concrete becomes more porous, indicating less durability, with 0RAC20 water penetration being 4.5-4.7 times more than that of CM.

- The 20RAC0 sample preparation was the least expensive, costing 7.39 percent less than the CM sample, according to the sample cost study. The least costly sample was 0RAC20, which cost 3.29 percent less than CM.

- Both CRCA and FRCA can be integrated into concrete at the same time if expedited curing, which mitigates the detrimental impacts of C&D waste, is undertaken.

- Therefore, it is reasonable to assume that the integration of C&D waste into concrete not only decreases building costs, but also promotes waste recycling and effective utilisation.

FUTURE SCOPE OF WORK

Most of the journals have touched upon the use of CRCA or FRCA in concrete, but very few journals studied the effect of incorporation of both in concrete. Present study focused on incorporation of both in concrete. Furthermore, this study can be extended to the use of additional fibres in RAC to make up for the loss of strength due to incorporation of C&D waste in concrete.

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2. Efficient Reuse of Demolition Waste in Concrete: Durability Behaviour and Economic Study (Conference Proceedings – "Sustainable Development of Smart Cities Infrastructure", SDSCI-2023, NIT Kurukshetra)