Chapter 3

Materials and Methods

3.1 General

This chapter discusses the types of material used, sample preparation, testing methods, experimental process adopted in order to analyze the various properties of RCA and RCA-concrete. This study is focused on the maximum utilization of RCA in place of NA for the production of new medium grade (M30 grade) concrete. In this chapter, several methods used to investigate the impact of F-RCA, C-RCA, and their combination on the characteristics of concrete are outlined in detail. For cement, OPC 43 was used in this experimental investigation. The recycled aggregates used in this study was processed from the old concrete specimens discarded after the testing in laboratory. The history of those samples were known, like w/c, strength, mineral admixtures. Natural sand was obtained from the outskirts of Varanasi city and for coarse natural aggregate crushed dolomites of nominal size 20 mm and 10 mm were used. This experimental study is divided into three parts:

Phase I- In this phase first major objective was to produce recycled aggregates from the old concrete samples. Sampling of recycled aggregates were done according to the strength of its parent concrete. Second objective was to observe the effect of parent concrete strength on produced aggregate by analysing the various physical and mechanical properties of F-RCA and C-RCA.

Phase II- First major objective of this phase was to study the adhered mortar reducing capacity of three types of mechanical/thermal treatment methods from C-RCA. The treatment methods reduced highest and lowest amount of adhered mortar was then

selected for further study. C-RCA produced in phase I was mixed to produce four types aggregate samples for further study, in order to observe the effect of RCA mix obtained from different quality of concrete.

Phase III- For this phase, aggregates produced in phase I was mixed together to produce one whole sample for both C-RCA and F-RCA. In this part of experimental study, C-RCA and F-RCA was varied from 0 to 100% in place of C-NA and F-NA respectively to produce new concrete. Firstly, C-RCA and F-RCA was varied individually, then in combination. The objective behind this study was to analyse the impact of varied percentage of C-RCA and F-RCA on the properties of new concrete, also the compatibility between all four type of aggregate based on their combined influence on concrete (F-RCA, C-RCA, F-NA, and C-NA).

The curing periods of samples were also stated and the procedures involved in the tests were described. The methodology adopted in the present study is described step-wise in this chapter.

3.2 Material Selection

The materials used in the tests and the process employed to analyze their characteristics are described below.

3.2.1 Cement

3.2.1.1 Normal consistency

Normal Consistency of cement was found according to the method mentioned in [94]. Vicat's apparatus confirming to IS 513 [95] was used with plunger of 10 mm diameter. Photo of Vicat's shown in Fig. 3.1.

Consistency refers to the relative mobility of a freshly mixed cement paste or mortar or its ability to flow. This test helps to determine water content for other tests like initial and final setting time and compressive strength. In this experiment the quantity of water required to produce a cement paste of standard consistency is determined. Paste was made by mixing 400 gm of cement and 30% by weight of portable water with the help of spatula and hand for about two-three minutes. Mould was then completely filled with

the paste, top was levelled before placing it with metal plate under the plunger. The plunger was first lowered to touch the surface of the paste before releasing it to sink into the paste. The penetration of plunger (10 mm diameter) in cement paste was noted. To call a cement with normal consistency should penetrate by 33 to 35 mm from the top of the paste (5 to 7 mm) from the bottom. Trial pastes was made with varying percentage of water to determine the percentage for which the desired penetration is obtained. The amount of water, thus obtained, expressed as percentage by weight of the dry cement, is the normal consistency.

Figure 3.1: Vicat's Apparatus

3.2.2 Initial and Final setting time

The constituents and fineness of cement has to be maintained in such a way that the concrete remains in plastic condition for a certain minimum time which is required for mixing, transporting, placing, compacting and finishing. This time interval during which the cement product remains in plastic condition is known as initial setting time. Normally a minimum of 30 minutes is given for mixing and handling operations.Once the concrete is placed in final position, compacted and finished, it should lose its plasticity in the earliest

possible time so that it is least vulnerable to damages from external destructive agencies. This time should not be more than 10 hrs which is referred as final setting time. Both this initial and final setting times are the essential requirements for satisfactory placing and storing of concrete and thus need to be evaluated to ensure the quality of cement.

A 400 gm of dry cement is mixed with 0.85P percent of water by weight of dry cement paste, where P is the normal consistency. The paste is mixed in the manner and under the conditions prescribed in IS 4031 (Part 4) [94] and filled in the test mould. The Vicat's needle is gently lowered and allowed to penetrate into the test mould. The period elapsed between the time when water is added to the cement and the time at which the needle fails to pierce the test mould to a point 5.0 mm measured from the bottom of the mould is noted as the initial setting time. The needle of the Vicat's apparatus is replaced by an annular attachment. The period elapsing between the time when water is added to the cement and the time at which the needle makes an impression on the surface of test mould while the attachment fails to do so is taken as the final setting time. IS 4031 (Part 5) [96] provides the standard initial and final setting time that cement should satisfy to be used in concrete. It is observed from the experimental results displayed in Table 3.1 that the cement used in the present work had a initial setting time of 90 minutes and final setting time of 305 minutes and thus within the satisfactory range.

Specification: As per IS 269 [97] initial setting time for cement shall not be less than 30 minutes.

3.2.2.1 Soundness test

Soundness of cement was found according to the method mentioned in IS 4031 (Part 3) [98] using Le-Chatelior's apparatus. Photo of Le-Chatelior's apparatus is shown in Fig. 3.2. Through this test the extent of free uncombined lime present in the cement was determined. The cement containing free lime slakes on hydration, resulting in the expansion of cement which is one of the causes of cracks in concrete / mortar. Therefore, the amount of uncombined lime presence in cement should be under specified limit. For this test, 100 gm of cement was mixed with 0.78 times the water required for normal consistency. That cement paste was placed in the mould resting on a steel plate, another glass plate was placed on its top. The whole thing was then immediately placed in the water bath with between 27^{o}C to 32^{o}C, after 24 hrs the distance between the tips of the

pointers was measured. The mould was then immersed in a water bath heated to boiling point and kept at this temperature for one hour. After cooling to 27^{o}C the distance between the tips of the pointer was again measured. The difference between the two readings represents the expansion of the cement, i.e., soundness of the cement. As per IS 269 [97] code this should not exceed 5 mm for aerated OPC and 10 mm for non-aerated OPC and as per IS 1489 (Part 1) [99] for PPC, & as per IS 455 [100] for Portland slag cement.

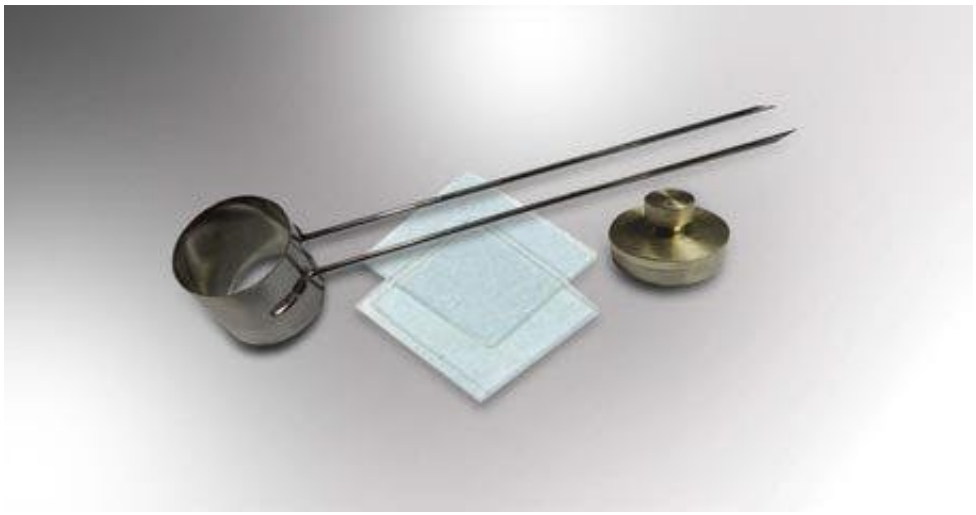

Figure 3.2: Le-Chatelior's Apparatus

3.2.2.2 Fineness of Cement

Fineness of cement was found according to the method mentioned in IS 4031 (Part 1) [101]. Finer Cement has quicker action with water, though the ultimate strength is not much affected. Cement fineness also reduces bleeding, whereas shrinkage and cracking is more in finer cement due to increase in strength gain rate. There are three methods to find fineness of cement, namely

- by Sieve Analysis,
- by measuring specific surface area of cement using air permeability method, and
- Wagner's Turbidimeter method.

For this study sieve analysis method was used, 100 gms of cement was sieved on IS Sieve no. 9 (90 micron) for 15 minutes with gentle motion of the wrists. To satisfy fineness criterion, retained residue shall not exceed 10% by weight of the sample.

3.2.2.3 Specific Gravity and Unit Weight of Cement

Specific gravity and unit weight of cement was found according to the method mentioned in [102]. In this test, kerosene oil was filled in Le-Chatelier's Flask up to 0 to 1 ml marks. Image of Le-Chatelier's Flask is shown in Fig. 3.3. First reading was recorded after immersing it in water bath at $27^oC \pm 2^oC$. 64 gms of cement was slowly and carefully added in the flask. Second reading of displaced level of kerosene was then recorded. Displaced volume by cement was then calculated by subtracting second and first level reading.

$$Specific\ Gravity = (Weight\ of\ cement\ in\ gms)/(Displaced\ volume\ in\ ml)$$

Also, find unit weight of cement by loosely filling a container (Fig. 3.4) of known volume and finding weight of cement Unit Weight= (Weight of cement)/(Volume of cement)

Figure 3.3: Le-Chatelior's Flask

Figure 3.4: Cylinder for unit weight calculation

3.2.2.4 Compressive Strength of Cement

The compressive strength of hardened cement paste is the most important of all the properties. Thus cement is always tested for its compressive strength in the laboratory before it is used in important works. Strength tests are not made on neat cement paste because of difficulties of excessive shrinkage and subsequent cracking of neat cement. Strength of cement is indirectly found on cement sand mortar in specific proportions. This test is necessary to understand the grade specification of cement as defined by the manufacturer. Cubes of size 70.6×70.06×70.06 mm are prepared using ingredients like cement (200 gm), standard sand (600 gm) and water (p%) using Equation (3.1) of combined mass of cement and sand, where P is the percentage of water required to produce a paste of standard consistency determined as described in IS 4031 (Part 4) [94].The Nine filled moulds after vibration are kept for 24 hours at a temperature of $27^o \pm 2^o$C and are than cured for 3,7 and 28 days. Casting of mortar cubes are shown in Fig. 3.5 and the process of testing on

compression testing machine is shown in Fig. 3.6 The compressive strength of the cubes is calculated by dividing the maximum load applied at failure to the cross sectional area of the specimen. Three specimens each were tested for evaluating the compressive strength of cement at 3, 7, and 28 days respectively. Compressive strength of cement was found according to the method mentioned in [103].

$$p\% = \frac{P_n}{4} + 3.0 \tag{3.1}$$

where, P_n is the amount of water required for normal consistency.

Figure 3.5: Casting of 100 mm cubes

Table 3.1: Chemical composition and physical properties of cement

Chemical composition		Physical properties	
Compound	Weight percentage	Properties	Observed value
CaO	63.09	Blaine's fineness (m2/kg)	250
SiO2	22.19	Soundness (mm)	1
Al2O3	4.44	Consistency (%)	34
Fe2O3	4.24	Initial setting time (min.)	95
SO3	1.81	Final setting time (min.)	241
Na2O	1.45	Compressive strength at 28 days (MPa)	47
MgO	0.30	Specific gravity	3.13
Cl	0.08		
K2O	0.51		

3.2.2.5 Chemical composition

The chemical composition of cement determined by X-Ray Fluorescence (XRF) test. It was performed on cement particles by using ARL OPTIM X X-Ray Analyzer.

3.2.2.6 Specific surface area

The specific surface area of the cement was determined by Blaine air permeability method as per IS 4031 (II) [102]. Results of chemical and physical properties of cement used in this experimental research is given in Table 3.1.

3.2.3 Tests on coarse aggregates: - Natural as well as Recycled

3.2.3.1 Sieve Analysis

The sieve analysis is done to analyze the grain size fineness of the coarse and fine aggregates. This test was done according the procedure specified in IS 2386 (Part 1) [104].

To perform this test, aggregates were first cleaned and then oven dried at 110 ^{o}C temperature. Sieves were arranged in ascending order of their size. Aggregates were then sorted through those sieves and retained amount on particular was weighed. Cumulative weight percentage of aggregates retained on the different sieve sizes were divided by 100 to obtain the fineness modulus. To plot the gradation curve, log scaled x-axis was used for sieve sizes and y-axis to represent finer percentage. Proportioning of coarse and fine aggregate was done according to the requirements mention in [20].

3.2.3.2 Water absorption, Specific gravity, and Apparent specific gravity of Aggregate

- **Coarse aggregate**

Water absorption, Specific gravity, and Apparent specific gravity of coarse recycled aggregate is found according to the method mentioned in [105]. The specific gravity and water absorption of aggregates are important properties that are required for the design of concrete mix. The specific gravity of a solid is the ratio of its mass to that of an equal volume of distilled water at a specified temperature. Because the aggregates may contain water-permeable voids, so two measures of specific gravity of aggregates are used:

- Apparent specific gravity, and
- Bulk specific gravity

Almost 2 kg of aggregate was taken to conduct this test. After washing aggregates thoroughly, it was submerged in water for 24 hrs. Then aggregate was transferred to the wired bucket, to measure the weight of aggregates in water (A1), weight of empty bucket under water was also measured (A2). Aggregates were then dried to saturated surface dry condition and then weighed (B). The aggregates were then placed in the oven at a temperature of 100 to 110 ^{o}C for 24 hr. After 24 hrs aggregates were taken out of oven then cooled to weigh (C). Calculation of specific gravity, apparent specific gravity and water absorption of coarse aggregate is done by Equations (3.2),(3.3) and (3.4) respectively.

$$\rho = \frac{C}{B - A} \tag{3.2}$$

$$\rho^{'} = \frac{C}{C - A} \tag{3.3}$$

$$W = \frac{B - C}{C} \times 100 \tag{3.4}$$

Where, $A = A_1 - A_2$, ρ= Specific gravity, $\rho^{'}$=Apparent specific gravity and W= Water absorption.

Same procedure is followed for both 10 mm and 20 mm aggregate.

- **Fine aggregate**

Water absorption, Specific gravity, and Apparent specific gravity of fine aggregate was found according to the method mentioned in [105]. For mix design of concrete, it is necessary to find specific gravity and water absorption. This test was carried out using pycnometer. 500 gm of fine aggregate was first washed thoroughly then placed in a tray filled with water for 24 hours. After 24 hours., water was drained out and sand was allowed to dry upto saturated and surface dry (SSD) condition. This SSD weight (weight A) was taken. After that sand was placed in pycnometer filled with water which was first rotated to eliminate the trapped air, then the weight (B) was measured. After that, pycnometer was emptied and weight (C) was measured after again filling it with water. Sand was then place in oven for 24 hours at 100 ^{o}C, sand was cooled after removing from oven and the weight (D) was taken. By using equations mentioned below specific gravity, apparent specific gravity and water absorption was determined. The specific gravity, apparent specific gravity and water absorption is calculated by Eq. (3.5), (3.6) and (3.7) respectively.

$$\rho = \frac{D}{A - (B - C)} \tag{3.5}$$

$$\rho^{'} = \frac{D}{D - (B - C)} \tag{3.6}$$

$$W = \frac{A - D}{D} \times 100 \tag{3.7}$$

3.2.3.3 Bulk density and aggregate void test for coarse aggregates

For this test cylindrical metal measure of 3-liter capacity was taken and its empty weight was measured (W). Cylinder was first filled with aggregates for about one-third of its height and tamped evenly with 25 strokes of the rounded end of the tamping rod. Similarly add third and second layer of aggregate into the cylinder. Cylinder with aggregate was then weighed (W') after striking off the surplus aggregate using the tamping rod as a straight edge.

Calculation of bulk density of aggregate is done by the Eq. (3.8), and void percentage is calculated by Eq. (3.9).

$$\rho'' = \frac{(W' - W)}{V} \tag{3.8}$$

where,

W' = Weight of compacted aggregate in a cylindrical metal measure, kg

V = Volume of cylindrical metal measure, liter

Calculation of Void percentage:

$$V = \frac{G - \gamma}{G} \times 100 \tag{3.9}$$

Where,

G = Specific gravity of the aggregate

γ = Bulk density in kg/liter

3.2.3.4 Aggregate Impact Value

Aggregate impact value of coarse recycled aggregate was found according to the method mentioned in [105]. To conduct this test, coarse aggregates were first sieved through sieve size of 12.5 mm and 10 mm. Aggregates passing through 12.5 mm and retained on 10mm IS sieve was considered in this test. The aggregates passing through 12.5mm sieve and retained on 10.0mm sieve comprises the test material. Aggregates were then filled about just 1/3rd depth of measuring cylinder and then compacted by giving 25 gentle blows with the rounded end of the tamping rod. Two more layers was added in similar manner, to make cylinder full. Net weight of the aggregates was taken to the nearest gram(W). Cup was firmly positioned on the base of impact testing machine. Photograph of impact testing machine is shown in Fig. 3.6. Hammer was raised to 380 mm until above the surface of aggregate sample in the cup and then allowed to fall freely. 15 such blows were given at an interval of not less than one second between successive falls. The crushed aggregate was removed from the cup and sieved through 2.36 mm IS sieves until no further significant amount passed. The fraction passing the sieve was then weighed to an accuracy of 1 gm. Also, the fraction retained in the sieve was weighed. Aggregate impact value is calculated by the Eq. (3.10)

$$I(\%) = \frac{W'}{W} \times 100 \tag{3.10}$$

Figure 3.6: Impact testing machine

3.2.3.5 Crushing Value of Coarse Recycled Aggregate

Aggregate crushing value of coarse recycled aggregate was found according to the method mentioned in [104]. The aggregate crushing value provides a relative measure of the resistance to crushing under gradually applied crushing load. Metal cylinder positioned on the base plate and weigh it (W). Aggregate samples were put inside cylinders in 3 layers, each layer being subjected to 25 strokes using the tamping rod. Then the weight (W') of aggregates and cylinders was measured. After that the cylinder with plunger was put on the loading platform of the compression testing machine. Load was applied at a uniform rate so that a total load of 40T was applied in 10 minutes. Subsequently, aggregates were removed from the cylinder after releasing the load. 10 mm aggregate was then sieved through 1.70 mm IS sieve and 20 mm aggregate was sieved through 3.4 mm sieve. Weight of the fraction passing through the desired IS sieve (W") was measured. Crushing value is calculated by Eq. (3.11)

$$C(\%) = \frac{W"}{W'} \times 100 \tag{3.11}$$

3.2.3.6 Abrasion value test

To test the hardness of coarse aggregate, abrasion value test is performed in the Los Angeles abrasion machine as per [106]. For this test, aggregate size of 20 and 10 mm weighed 5 kg each were put inside the drum of the abrasion machine with 11 and 8 steel balls of total weight 4.584 kg and 3.33 kg respectively. Drum rotation speed was kept between 30 to 33 rotation per minute and total number of drum rotation was fixed to 500 count. The weight of the material passing 1.7 mm IS sieve was expressed as the percentage of the initial weight.

3.2.3.7 Shape test

The shape test of the coarse aggregates was performed as per [106]. 200 pieces of each size of 25 – 20 mm, 20 – 16 mm, 16 – 12.5 mm, 12.5 – 10 mm and 10 – 6.3 mm were weighed. All the pieces of a particular size were gauged through thickness and length gauge and weighed. The ratio of the total weight of the pieces which passed through thickness gauge and which retained on length gauge to the total weight of the pieces considered was reported as the flakiness index and elongation index respectively.

3.2.4 Mineralogical Studies

The crystalline phases of cement, F-NA, C-NA, F-RCA, and C-RCA was determined by X-ray diffraction (XRD) analysis on RIGAKU Ultima IV X-Ray Diffractometer (Figure). XRD analysis is a rapid analytical technique used to determine the primary mineralogical components of cement and aggregates. The mineralogical analysis was done according to [107]. The oven-dried samples of OPC, natural sand (NS), recycled sand (RS) (0, 30, 60 and 100%) and coarse aggregate were subjected to X-Rays of monochromatic copper Kα radiation with wavelength (λ) of 1.5418 Å with a scan step size of 0.020 and scanning rate of 50 per minute. The range of 2θ was 200 to 800 for OPC/NS/RS/coarse aggregate. Approximately 10 g of the OPC/NS/RS/coarse aggregate powder was fixed to a metal stub using double-sided conductive tape. X-ray diffractograms (plots between intensity (counts) and 2θ values) were drawn and the prominent peaks in the observed pattern were indexed using JCPDS software.

3.2.5 Mix design approach

Concrete mix design is the process of finding right proportions of cement, sand and aggregates for concrete to achieve target strength in structures. Mix design of concrete are generally controlled by the following factors: Characteristic compressive strength of concrete required at end of 28 days, nominal maximum size of aggregate, shape of coarse aggregate, degree of workability required at site, degree of quality control, type of exposure condition, type of cement, method of placing concrete on site. Mix design was done using two Indian standard codes; [108] and [109]. Following IS 456, the target strength was calculated using the Eq. (3.12)

$$f_{ck}^{'} = f_{ck} + 1.65s \tag{3.12}$$

where, $f_{ck}^{'}$=target average compressive strength at 28 days, f_{ck}=characteristic compressive strength at 28 days and, s=standard deviation (decided from Table 1 of [109]).

In this experimental study, mix design was done to produce M30 grade concrete, for which water cement ratio of 0.5 was fixed for all concrete mixes. Generally, water-cement ratio adoption is based on the exposure condition provided in Table 5 of [108] and experience. Table 2 of [109] was used for selecting the maximum water content for the required mix design. Amount of cement was calculated out using water cement ratio and water content. The amount of cement taken for mix design was then verified by Table 5 of [108]. Calculation of ingredients was done for 1 m^3 of concrete. For the calculation, test data of materials like specific gravity of cement, specific gravity of coarse aggregate, specific gravity of fine aggregate was examined in the laboratory. For finding proportion of volume of coarse aggregate and fine aggregate, Volume of coarse and fine aggregate was then estimated, corresponding to maximum nominal size of aggregate and zone of fine aggregate for water-cement ratio of 0.50 was calculated. The mix calculations per unit volume of concrete was done as follows:

Volume of concrete = 1 m^3

Volume of cement = Mass of cement / (1000*specific gravity of cement)

Volume of water = Mass of water / (1000* specific gravity of water)

Volume of admixture = Mass of super plasticizer / (1000*specific gravity of admixture)

Volume of aggregate= [a- (b+c+d)]

Accordingly, then weight of coarse and fine aggregates was calculated. Calculated mix

proportion were then tabulated, following which mixing of all materials was then done to produce concrete. Trial mixes were prepared for achieving the required slump by adjusting the water content and dosage of superplasticizer.

3.2.5.1 Concrete mixing approach

For the mixing purpose, drum type concrete mixer with 20-22 RPM was used. The photograph of drum type concrete mixer is shown in Fig. 3.7. Concrete containing natural aggregates were mixed together by traditional mixing method. For concrete with RCA, a new mix design approach was adopted; modified version of Two Stage Mixing Approach (TSMA) suggested in literature. The main idea of the TSMA is to encapsulate the RCA particles with a low w/c, of high quality cement paste in order to enhance the (ITZ) formed between the RCA particle and the fresh surrounding hydrated cement paste. Fig. 3.8 describes the flow chart of the two stage mixing approach from literature and the remodified TSMA i.e., (RTSMA) adopted in this study. In TSMA provided through literature, water was added in mixer before and after addition of binding material into two equal proportions. In the RTSMA adopted in this study, water as well as binding materials are added in the mixer in two parts; first coarse aggregates were mixed with water equivalent to its water absorption capacity, then 10% of total binding material was added to the mix, in next stage premixed sand and cement was added before mixing the remaining water. By using R-TSMA, coating of coarse RCA with binding material is achieved which then improves its bonding with the new mortar.

3.2.6 Study on fresh concrete properties

3.2.6.1 Workability

The slump test was done to determine the workability of concrete. It was performed in accordance with [110]. The slump mould was placed above the base plate. It was filled with concrete in 4 layers with each layer being tamped 25 times. The internal body of the mould was oiled before filling with concrete. The top surface of the mould was levelled with a trowel, and excess concrete was removed. The mould was gradually raised in the vertical direction. The slump was calculated as the difference between the height of mould and the height of concrete after the mould was raised entirely. The assembly used in the

Figure 3.7: Concrete drum mixer

slump test is shown in Fig. 3.9.

3.2.6.2 Fresh concrete density

The density of a fresh concrete is the amount of newly mixed concrete required to fill a unit-volume container. Concrete's bulk density represents its functionality for durability, water movement and structural support. This approach aids in calculating the yield per cubic meter of concrete. According to [111], the cylindrical measuring cylinder was filled with freshly mixed concrete and compacted using tamping rod. the layers of 50 mm was placed and compacted with not less than 60 strokes till the measure fills up. Compaction was done by tamping rod. The exterior surface of the cylinder was tapped 15 times. After consolidation of the concrete, the top surface was struck-off and finished smoothly with a flat cover plate. All excess concrete was then cleaned from the exterior. The filled measure jar was weighed (W). Density of Concrete is the weight per cubic meter of concrete and calculated by dividing the weight of fully compacted concrete in the cylindrical measure by the capacity of measure in kg/m^3

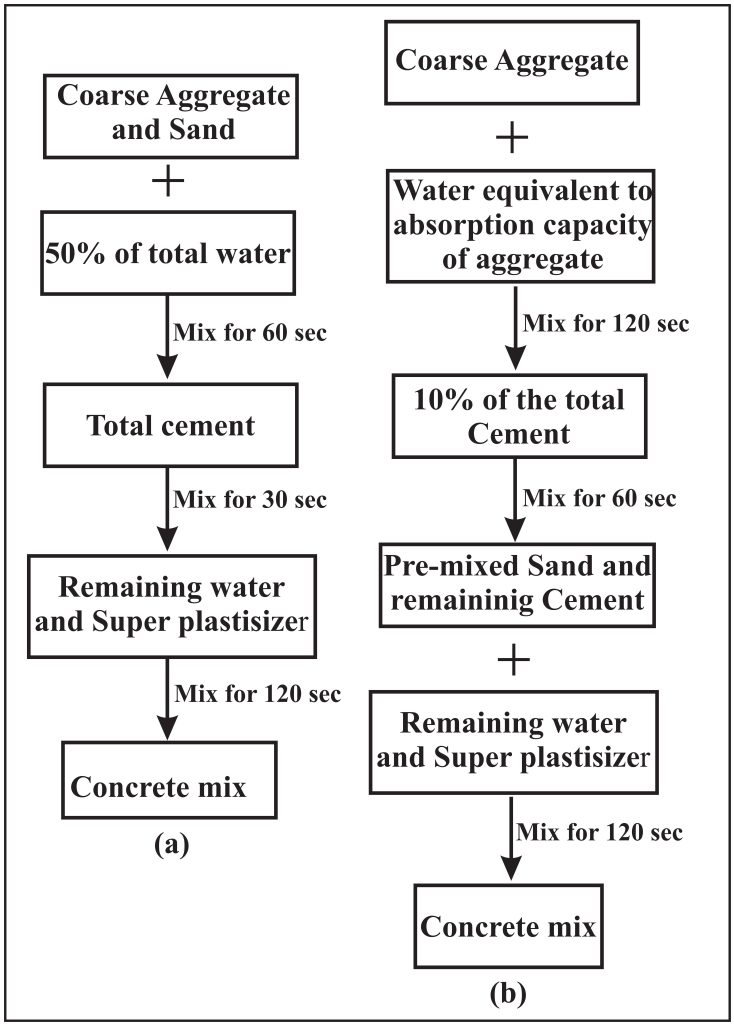

Figure 3.8: Mixing techniques : (a) Two-stage mixing approach (TSMA) (Vivian W.Y. Tam, Tam, and Le 2007; Otsuki et al. 2003); (b) Re-modified two-stage mixing approach (R-TSMA)

3.2.7 Study on hardened concrete properties

3.2.7.1 Compressive Strength

Compressive strength is the primary and most important property of concrete, through this strength only classification of concrete is practiced. The testing for compressive strength of hardened concrete was carried out according to the [112]. Cubical mould of size 150 mm was used for casting of concrete samples for this test, shown in Fig. 3.11. Concrete were filled in those moulds and left for 24 hours in the humid condition, after which concrete cubes were removed from mould and kept in kept in water tank for curing. The temperature of curing water was maintained at 27 $\pm$ 2^o C. Concrete cubes were taken

Figure 3.9: Slump measurement

out of curing tank after the period of 7, 14, 28, 56 and 90 days for its testing. Compression testing machine (CTM) was used for the testing purpose as per [112]. Testing arrangement for compressive strength is shown in Fig. 3.10. The load was gradually increased at a rate of 310 KN/min. Three concrete cubes of each mix were cast for respective day of curing. The average of the three compressive strength values was reported as the compressive strength of concrete (f_c).

3.2.7.2 Splitting tensile strength

Splitting tensile strength was carried out by placing a cylindrical specimen (150 mm diameter and 300 mm height) horizontally between two surfaces of a compression testing machine and the load is applied until failure of the cylinder, along the vertical diameter. After casting of concrete cylinders (Fig. 3.12), samples were cured 28, 56 and 90 days. After completion of 28, 56 and 90 days of curing, cylinders were removed and examined for their split tensile strength in CTM as per IS 5816 [113]. The load was applied on the horizontal axis (height) of the cylinder and the testing arrangement is shown in Fig. 3.13. The loading rate applied was as per. The split tensile strength ('f_s in N/mm^2 or MPa)

Figure 3.10: Compressive strength testing arrangement

Figure 3.11: Cube casting for Compressive strength testing

was calculated as per Eq. (3.13).

$$f_s = 2\frac{P}{\pi l d} \tag{3.13}$$

where P: Failure load, l: length of cylinder, d: diameter of cylinder, f_s: Splitting tensile strength (10% of compressive strength)

Figure 3.12: Cylinder casting for splitting tensile strength test

3.2.7.3 Flexural strength

Flexural Strength is measured for an unreinforced concrete beam to resist failure in bending. A beam mould size of 150 mm X 150 mm X 700 mm was used to cast the prismatic beam to find out flexural strength of concrete. After 24 hours of casting, the prisms were removed from the mould and placed in the curing tank for curing in water as per ASTM C192 [107]. The curing water was restored every week, and its temperature was maintained at 27 $\pm$ 2^{o}C. After completion of 28, 56 and 90 days of curing, prisms were removed

Figure 3.13: Splitting tensile strength testing arrangement

and examined for their flexural strength in Flexural Strength Test Machine (Three-point bending) as shown in Fig. 3.14 as per [112]. The markings on the beam was done to position it on the rollers, as shown in Figure 3.15 (b). The load was gradually increased at a rate of 1.8 KN per minute. Three concrete prisms of each mix were cast for each day of curing. The average of the three flexural strength values was reported as the flexural strength of concrete at respective day of curing.

The flexural strength of the specimen is expressed as the modulus of rupture F_b which if 'a' equals the distance between the line of fracture and the nearer support, measured on the centre line of the tensile side of the specimen, in cm, is calculated by Eq. (3.14) and (3.15)

$$F_b = \frac{P_l}{b_{d2}} \tag{3.14}$$

where, 'a' is greater than 20 cm for 15 cm specimen

$$F_b = \frac{3P_a}{b_{d2}} \tag{3.15}$$

where, 'a' is less than 20 cm but greater than 17 cm for 15 cm specimen, and, b = measured width in cm of the specimen, d = measured depth in cm of the specimen at

point of failure, l = length in cm of the span on which specimen was supported, P = maximum load in kg applied to the specimen.

if 'a' is less than 17 cm for 15 cm specimen, the results of the test be discarded.

Figure 3.14: Flexural strength testing arrangement

3.2.8 Study on durability of concrete

3.2.8.1 Water permeability

In the water permeability test, the concrete cubes of 100 × 100 × 100 mm size were cured in water for 28 days and further tested as per the procedure described in IS [114]. They were centrally placed in a specially designed watertight permeability cell, and the desired hydrostatic pressure was applied from one side. The amount of water percolating through the concrete cube was measured, and the permeability coefficient was calculated using Eq. (3.16). The water permeability test setup is shown in Fig. 3.15.

$$k = \frac{Q}{A \times T \times (H/L)} \tag{3.16}$$

where, k = coefficient of permeability (cm/sec.), H/L = ratio of pressure head and concrete cube thickness, A = area of exposed side of concrete cube (cm^2), Q = amount of water percolating through cube (after the steady state) (mm), T = duration over which 'Q' was measured (sec.).

Figure 3.15: Water permeability testing arrangement

3.2.8.2 Carbonation

The carbonation test was performed on 100 × 100 × 100 mm size concrete cubes to study the effects of Accelerated Carbonation Curing (ACC) on the hardened concrete. Three cubes of each concrete mix were cast for testing the compressive strength after ACC. After casting, all the specimens were left covered in the casting room for 24 hours. After 24 hours of casting, the cubes were removed from mould and placed in water curing tank as per [107]. These samples of concrete (cube) were kept in the water curing tank for 28 days. Then, the samples were removed from the curing tank and kept in the oven for 24 hours at 60 0C. Subsequently, they were kept in the carbonation chamber for another

28 days for accelerated carbonation curing (Fig. 3.16) in the carbonation chamber (Fig. 3.17). The concentration of CO_2, temperature and relative humidity in the carbonation chamber were maintained at 5%, 27 ± 2 ^{o}C and 65 ± 5% respectively as per other studies. After the completion of ACC, these samples of concrete were subjected to compression strength test as per [112]. The strength (compressive/flexural/split tensile) of the concrete samples at 28 days of combined curing (water + ACC) were compared with strength at 28 days of water curing to study the effect of ACC.

The cubes subjected to ACC were cut vertically into two parts, and phenolphthalein indicator was sprayed on the cut faces. The phenolphthalein indicator was prepared by mixing 1gm of phenolphthalein with 90 ml of ethanol. It was diluted to 100 ml with water. The carbonation affected zone was colourless while the unaffected zone (where CO_2 was not able to penetrate) turns pink in colour. The depth of CO_2 penetration in each cube was measured.

Figure 3.16: Accelerated carbonation curing

Figure 3.17: Carbonation chamber

3.3 Research Methodology Adopted

This section explains the research methodology and experimental procedure involved to fulfil the objectives highlighted in the present study. The research methodology aimed to analyze the influence of the old concrete strength on the properties of produced RCA, and influence of RCA quality on the produced concrete.

The whole experimental program was conducted in three phases. In the first phase, the effect of parent concrete strength on produced aggregate by analysing the various physical and mechanical properties of F-RCA and C-RCA. In the second phase, the adhered mortar reducing capacity of three types of mechanical/thermal treatment methods from C-RCA was compared. In addition to this, concrete mixes produced with C-RCA treated by two different methods are compared for the efficacy of the particular treatment methods on the properties of concrete. In the third phase, C-RCA and F-RCA was varied from 0 to 100% in place of C-NA and F-NA respectively to produce new concrete. Firstly, C-RCA and F-RCA was varied individually, then in combination. The objective behind this study was to analyse the impact of varied percentage of C-RCA and F-RCA on the properties of new concrete, also the compatibility between all four type of aggregate based

on their combined influence on concrete (F-RCA, C-RCA, F-NA, and C-NA).

3.4 Summary

The chapter describes the details of materials along with their relevant properties in detail and also explained the proposed methodology adopted to achieve the objectives of the study. Their experimental setup, procedures and results have been discussed in detail in the subsequent chapters.