Chapter 4

Study on the production of RCA

4.1 General

This chapter gives the detailing of RCA production from old concrete waste. Properties of produced RCA and its variation with change in quality of old concrete is also discussed in this chapter. To improve the properties of coarse aggregate three types of treatment method for reducing the adhered mortar from RCA has been compared. Quantification method of adhered mortar on RCA is also discussed in detail. Sampling of RCA for the production of different concrete mixes used in the experimental studies for this research work are detailed in this chapter.

4.2 Production of recycled concrete aggregates (RCA)

For this experimental study, concrete prepared and tested in laboratory of structural engineering department was used as the raw material for RCA production. The concrete samples included old tested cubes (used in compressive strength test), cylinders (used in splitting tensile strength test) and beams (used in flexural strength test). The history of concrete was known, and each type of concrete was crushed separately, so that the impact of old concrete's quality on the produced RCA. Details of the old tested concrete sample chosen for the study is given in Table 4.1. Four types of concrete namely P1, P2, P3 and P4 provided the sufficient strength variation to study its effect on the RCA produced. Fifth lot of concrete waste was chosen to represent the mixture waste containing concrete with different mineral admixtures and w/c. Mineral admixtures involved in the old concrete

Table 4.1: Old concrete samples

Concrete sample	Comment
P1	w/c of concrete was 0.4 prepared without any mineral admixture or superplasticizer
P2	w/c of concrete was 0.5 prepared without any mineral admixture or superplasticizer
P3	w/c of concrete was 0.55 prepared without any mineral admixture or superplasticizer
P4	w/c of concrete was 0.6 prepared without any mineral admixture or superplasticizer
M	Old concrete samples with w/c (0.4, 0.5, 0.55, and 0.6) containing mineral admixture and superplasticizer. All of the Mixed together in equal proportion.

production were ground granulated blast furnace slag (GGBFS), fly ash (FA), silica fume (SF). Those concrete samples were exposed to the open environment for about three four months, but there was no contamination with any other material like bricks, marbles, wood etc.

For the production of RCA, old concrete samples produced and tested in the laboratory was used. Jaw crusher shown in Fig. 4.1 was used for crushing the old concrete samples into smaller size (desired to produce structural concrete). As the size of concrete samples were larger than the feed size of Jaw crusher, therefore the larger sized concrete samples were reduced to 40-60 mm size by using hand hammer. As the maximum size of aggregate used in the production of old concrete was 20 mm, to obtain RCA of similar size range the opening size of jaw crusher was fixed to 25 mm (shown in Fig. 4.1 (d)). Combination of manual and Jaw crusher proves better in reduction of AM [115]. Crushing process of old concrete samples (cubes, beams, and cylinders) to RCA (from fine to coarse) is shown in Fig. 4.2. RCA obtained after the crushing process were then graded into C-RCA (both 10 and 20 mm) and F-RCA (≤ 4.75 mm). C-RCA and F-RCA after gradation are shown in Fig. 4.3. For gradation C-RCA and F-RCA, limits specified in

Table 4.2: Aggregate samples produced after crushing of old concrete

RCA samples	Description
RCAP1	RCA obtained from old concrete samples P1
RCAP2	RCA obtained from old concrete samples P2
RCAP3	RCA obtained from old concrete samples P3
RCAP4	RCA obtained from old concrete samples P4
RCAPM	RCA obtained after mixing P1, P2, P3 and P4 in equal proportion
RCAM	RCA obtained from old concrete samples M

IS 383 [20] was followed. Produced coarse aggregate was first sampled as given in Table 4.2, to study the variation in physical and mechanical properties with the variation in the strength of old concrete.

After sampling of different types of RCA (both 10 mm and 20 mm), their physical and mechanical properties were obtained and analyzed. The properties of RCA were compared with NA as well as compared with each other to manifest the impact of old concrete strength on produced RCA.

4.3 Properties of produced RCA

Physical and mechanical properties of RCA samples prepared and NA used in parent concrete are presented in Table 4.3 to Table 4.5. Tests were carried out according to IS 2386 (part-III) [104] and IS 2386 (part-IV) [106].

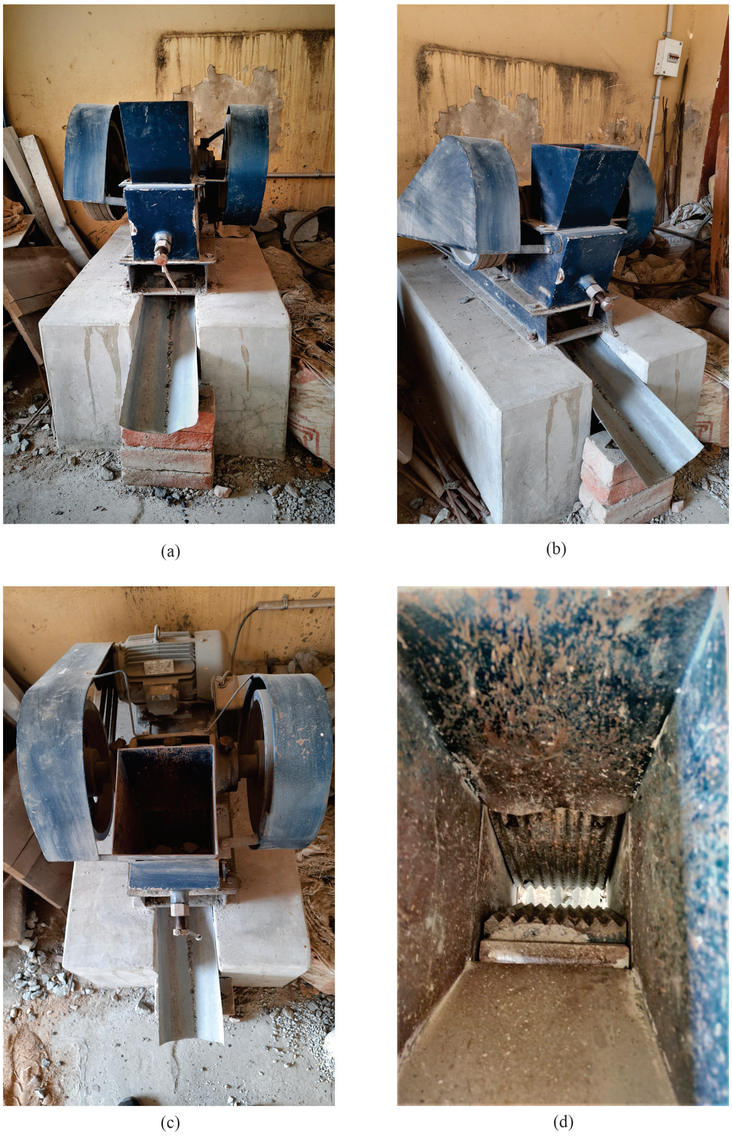

(a) (b) (c) (d)

Figure 4.1: Jaw crusher used for crushing the concrete waste. (a) Front view (b) Side view (c) Top view (d) Jaw opening.

4.3.1 Property analysis

4.3.1.1 Coarse aggregate

Specific gravity being one of the principal parameter of aggregate for mix design of concrete, controls various properties of the new concrete produced. Specific gravity of RCA follows opposite trends with the quantity of adhered mortar on it [29], it decreases if content of adhered mortar increases and vice-versa.

The physical and mechanical properties were examined following IS 2383:1963 (Part III and IV) [][14], [15]. Properties of C-NA and untreated C-RCA samples are tabulated

(a) Old cube samples (b) Old beam samples © Old cylinder samples

(d) Manual crushing by hand hammer (e) Crushing by jaw crusher

(f) C-RCA (20 mm) (g) C-RCA (10 mm) (h) F-RCA (Recycled fines)

Figure 4.2: Crushing process of old concrete into RCA of different sizes.

in Table 4.3 (10 mm) and Table 4.4 (20 mm). The difference between C-NA and C-RCA samples are quite evident for all the physical and mechanical properties. From the results, influence of origin of RCA on its properties can be clearly observed. As the w/c of old concrete increases the specific and apparent specific gravity, whereas water absorption capacity increases. Larger size aggregate (20 mm) showed lower variation in the physical

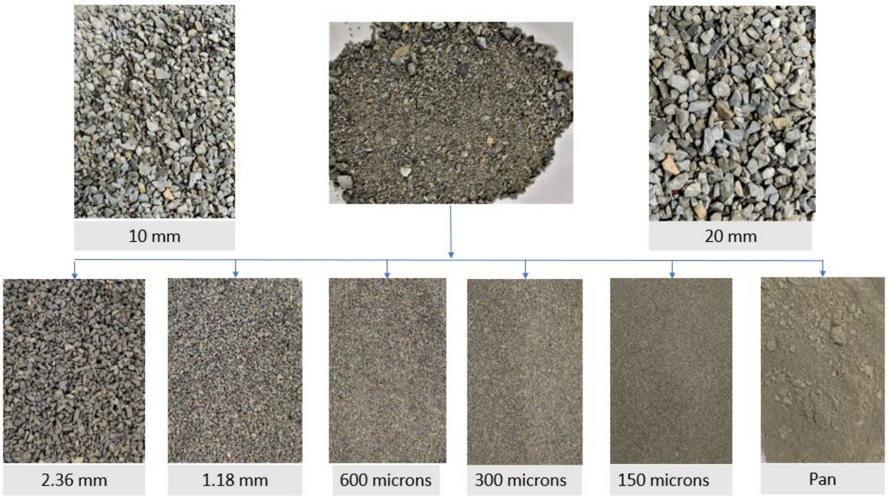


Figure 4.3: C-RCA as well as F-RCA after gradation.

and mechanical properties than the smaller size aggregate (10 mm) [36, 47, 49]. Specific gravity reduction for 10 and 20 mm C-RCA were found to be 13.60% to 16.18% and 10.21% to 12.68% lower than the respective C-NA. Highest reduction was observed for RCAP1 (16.18% for 10 mm and 12.68% for 20 mm), and lowest reduction was observed in RCAM (13.60% for 10 mm and 10.21% for 20 mm). C-RCA samples arranged in ascending order of percentage reduction in its specific gravity with respect to C-NA is shown in equation (4.1) and (4.2).

$$RCAM = RCAP4 < RCAPM < RCAP3 < RCAP2 < RCAP1 \quad (10mm) \tag{4.1}$$

$$RCAM < RCAP4 < RCAPM < RCAP3 < RCAP2 < RCAP1 \quad (20mm) \tag{4.2}$$

Bulk density reduction for 10 and 20 mm C-RCA were found to be 17.58% to 21.82% and 16.48% to 19.32% lower than the respective C-NA. Highest reduction was observed for RCAP2 (21.82% for 10 mm) and for 20 mm three samples (RCAP1, RCAP3 and RCAM) showed similar percentage (19.32%) reduction, and lowest reduction was observed in RCAP3 (17.58% for 10 mm) and for 20 mm, RCAPM showed lowest reduction of 10.21%. C-RCA samples arranged in ascending order of percentage reduction in its bulk density with respect to C-NA. is shown in equations (4.3) and (4.4).

$$RCAP3 < RCAPM < RCAP4 < RCAM < RCAP1 < RCAP2 \quad (10mm) \tag{4.3}$$

$$RCAPM < RCAP4 < RCAP2 < RCAP1 = RCAP3 = RCAM \quad (20mm) \tag{4.4}$$

Water absorption of C-RCA samples decreased with the increase in the water-cement ratio of old concrete from RCA is derived. Smaller sized C-RCA showed higher water absorption capacity than larger sized C-RCA. For 10 mm C-RCA sample, highest water absorption was observed in RCAP1 and lowest in RCAP4; for 20 mm also highest water absorption was in RCAP1 and lowest in RCAP4. C-RCA possessed water absorption value between 4.91 to 6.04% (for 10 mm) and 3.53 to 4.15 % (for 20 mm); whereas C-NA showed water absorption of 0.24 (for 10 mm) and 0.21 (for 20 mm). 10 mm and 20 mm C-RCA samples arranged in ascending order of its water absorption capacity are given in equations (4.5) and (4.6).

$$RCAP4 < RCAM < RCAP3 < RCAPM < RCAP2 < RCAP1 \quad (10mm) \tag{4.5}$$

$$RCAP4 < RCAM < RCAPM < RCAP3 < RCAP2 < RCAP1 \quad (20mm) \tag{4.6}$$

Results for fineness modulus of C-RCA shows that 10 mm C-RCA obtained was coarser than 10 mm C-NA, whereas 20 mm C-RCA produced was in the size range of 20 mm C-NA. The crushing, impact, and abrasion value of C-RCA also showed higher loss than C-NA. The reduction in the mechanical properties of RCA was also observed to increase as the w/c ratio of old concrete increased. Crushing value of 10 mm C-RCA for different samples was between 47.8% to 50.3%, and for 20 mm C-RCA it was between 31.2% to 36.21%. Abrasion loss of 10 mm C-RCA was between 30.2% to 35.6% with highest loss in RCAP4 and lowest in RCAP2, for 20 mm C-RCA loss was between 25.72% to 30.06%, with highest loss in RCAP4 and lowest in RCAP2. This could be understood as RCA obtained from old concrete of higher w/c has more amount of weaker and porous adhered mortar than that obtained from old concrete of lower w/c. RCA obtained from low strength concrete are expected to possess lower mount of adhered mortar than the same obtained from higher strength old concrete [24,116]. RCA produced from old concrete containing different mineral admixtures showed comparatively better properties than those obtained from old concrete without any mineral admixture. The use of mineral admixtures in the concrete as a partial replacement of cement improves concrete's overall strength [117]. The improved strength of concrete results in the better quality of RCA produced from it [116].

4.3.1.2 Fine aggregate

Physical properties of fine aggregates are shown in Table 4.5. Study on the property of fine aggregates was done on samples with increasing percentage of F-RCA (0%, 30%, 60%

Table 4.3: Physical and mechanical properties of 10 mm aggregates.

Parameters	NA	RCAP1	RCAP2	RCAP3	RCAP4	RCAPM	RCAM
	Physical properties						
	10 mm	10 mm					
Specific gravity	2.72	2.28	2.3	2.31	2.35	2.32	2.35
Bulk density	1.65	1.3	1.29	1.36	1.33	1.34	1.32
Apparent specific gravity	2.81	2.48	2.53	2.52	2.56	2.52	2.58
Water absorption	0.24	6.04	5.23	5.1	4.91	5.13	5.05
Fineness modulus	5.93	6.17	6.16	6.13	6.14	6.15	6.23
	Mechanical properties						
Crushing value %	23.7	47.9	47.8	49	50.3	49.2	48.2
Impact value %	15.45	27.42	24.34	27.89	28.95	27.9	26.59
Abrasion value %	19.68	32.12	30.2	34.8	35.6	35.52	34.12

Table 4.4: Physical and mechanical properties of 20 mm aggregates.

Parameters	NA	RCAP1	RCAP2	RCAP3	RCAP4	RCAPM	RCAM
	Physical properties						
	20 mm	20 mm					
Specific gravity	2.84	2.48	2.49	2.52	2.54	2.53	2.55
Bulk density	1.76	1.42	1.43	1.42	1.44	1.47	1.42
Apparent specific gravity	2.93	2.62	2.64	2.68	2.69	2.68	2.71
Water absorption	0.21	4.15	3.97	3.8	3.53	3.74	3.54
Fineness modulus	7.19	7.28	7.19	7.2	7.14	7.21	7.3
	Mechanical properties						
Crushing value %	16.87	31.2	31.49	34.84	36.21	36.02	34.03
Impact value %	12.3	27.48	24.34	27.76	28.24	27.96	26.21
Abrasion value %	17.54	27	25.72	28.04	30.06	29.21	28.89

Table 4.5: Properties of increasing percentage of F-RCA in place of F-NA.

Parameters	F-NA	F-RCA30	F-RCA60	F-RCA100
Specific gravity	2.63	2.48	2.37	2.24
Bulk density (kg/litre)	1.6	1.51	1.35	1.28
Apparent specific gravity	2.76	2.75	2.84	3.08
Water absorption (%)	1.2	2.46	5.42	6.24
Fineness modulus	2.68	2.75	2.84	3.08

and 100%). From the results, it can be clearly concluded that with increasing percentage of F-RCA in place of F-NA the specific gravity, bulk density, apparent specific gravity, water absorption and fineness modulus worsens. Specific gravity of F-NA was 2.63 kg/m^3 which reduced by 5.7% to 2.48 kg/m^3 when 30% F-RCA used, with 60% F-RCA loss increased to 9.9%, and with 100% F-RCA, around 15% of loss was registered. Similarly, bulk density also reduced with increasing replacement of F-NA with F-RCA. Apparent specific gravity of fine aggregates increased with increasing percentage of F-RCA in it. Water absorption of fine aggregate with 100% F-RCA showed water absorption of 6.24%, which was 80.76% higher than F-NA. Results of fineness modulus show that coarseness of fine aggregates increases with increase in F-RCA in it.

4.4 Properties enhancement processes

F-RCA was directly used in the concrete, while for C-RCA was used after the application of treatment processes. For the treatment process, combination of thermal and mechanical action was used to remove adhered mortar by losing its bonding with RCA. The concept behind using the mechanical process is the effective removal of adhered mortar by the constant rubbing of C-RCA against each other. Los Angeles (LA) abrasion machine was used for the abrasive action, but steel balls were not used in the grinding process to avoid excessive damage to angular edges and irregular flakes of C-RCA, which are very much needed for their interlocking [118]. RCA obtained from parent concrete (RCAP1) of 0.4 w/c was used for this study of RCA treatment. Hence, to improve the physical and mechanical properties of RCA, three types of treatment methods were studied (1. Abrasion (A), 2. Heating & Abrasion (HA), 3. Quenching & Abrasion (QA)). All the treatment methods were compared against the capability to reduce the AM content, results are compiled in Table 4.7. Then accordingly, two methods with highest (HA treatment) and lowest (SDA treatment) efficiency was then selected for treating C-RCA for its use in concrete.

4.4.1 Different types of treatment methods

4.4.1.1 Quenching and abrasion (QA) method

In this method, three cycles of quenching were followed by abrasion in LA machine. A cycle of quenching involves sample heating in Oven at 400 °C for 12 hours followed by immediate submergence of sample in cold water, this process was repeated for three times. After three cycles of quenching, RCA was placed in LA abrasion machine. In abrasion machine, drum containing C-RCA was rotated for 1000 rounds, after taking material out of the drum, it was sieved through 4.75 mm sieve and loss in weight was calculated. In this method average reduction of AM content was 24-26%(for 20mm) and 32-34% (for 10 mm) by weight, Table 4.7 presents the result for reduction in adhered mortar content after the application of this method. This method is a modified version of thermal treatment in which also various cycles heating and soaking is involved, in which RCA is first soaked then heated to break the bond between AM and aggregate [42].

4.4.1.2 Heating and abrasion (HA) method

This method consists of thermal treatment followed by abrasion in Los Angeles (LA) machine. In this method aggregate was first placed in oven at 400 °C for 24 hrs. After 24 hours, RCA was taken out from the oven and immediately transferred to the Los Angeles (LA) abrasion machine. Drum containing C-RCA was rotated for 1000 rounds, after which material was taken out from drum and sieved with the help of 4.75 mm sieve and loss in weight was calculated. In this method average reduction in AM content was 30-32% (for 10 mm) and 20-22% (for 20 mm) by weight. Table 4.7 provides the calculated reduction in adhered mortar content after the application of this method.

4.4.1.3 Simple dry abrasion method

In this method, the RCA was abraded in the LA abrasion machine. As previously stated, dry mixing of RCA in Los Angeles abrasion machine was carried out without using any

Table 4.6: Estimation of adhered mortar content by soundness test.

Aggregate sample	Size	Initial weight (gm)	Weight after 5 cycle		% loss	
			$(MgSO_4)$	$(NaSO_4)$	$(MgSO_4)$	$(NaSO_4)$
U-RCA	10-20 mm	1000	924	554	7.6	44.6
	4.75-10 mm	300	244	135	18.67	55
T-RCA	10- 20 mm	1000	946	678	5.4	32.2
	4.75-10 mm	300	266	193	11.33	35.67
Recycled sand	300 micron to 4.75 mm	500	467	316	6.6	36.8

steel ball. For conducting the test, RCA sample size of 2 kg in air dried condition was placed in drum of machine. The drum was rotated for 1000 rounds after which the aggregate are sieved (with 4.75mm) and the loss in weight was measured. In this method average reduction of 12-14% (for 20 mm) and 28-30% (for 10mm) by weight was achieved. Results of are presented in Table 4.7.

4.4.2 Quantification of adhered mortar

To quantify the adhered mortar content on RCA, several methods has been discussed in literature. For this study, method provided in soundness test as per IS 2386 (Part V) [119] was applied to estimate the adhered mortar content on the 10 and 20 mm C-RCA. Both treated and untreated C-RCA were tested in this study for their estimation of respective adhered mortar content. Magnesium sulphate ($MgSO_4$) and sodium sulphate ($NaSO_4$) were the reagents used for this test are shown in Fig. 4.4. Solutions of magnesium and sodium sulphate as well as samples of both C-RCA and F-RCA were made as per the guidelines provided in IS 2386 (Part V) [119]. Samples of C-RCA and F-RCA were immersed in the prepared solution of sulphates for 16 to 18 hours as shown in Fig. 4.4 (b) and (c). After the immersion period aggregates were removed from the solution and placed in the drying oven at 110 °C till the constant weight of aggregates were obtained. Aggregates after one cycle of immersion and oven drying are shown in Fig. 4.4 (d), (e), (f), (g), (h) and (i). The whole process of immersion and oven drying was the again repeated for 5 cycles. Untreated C-RCA (U-RCA) and F-RCA after 5 cyles of both reagents are shown in Fig. 4.4 (j), (k), (l), (m), (n) and ((o). Similarly, this process was also repeated

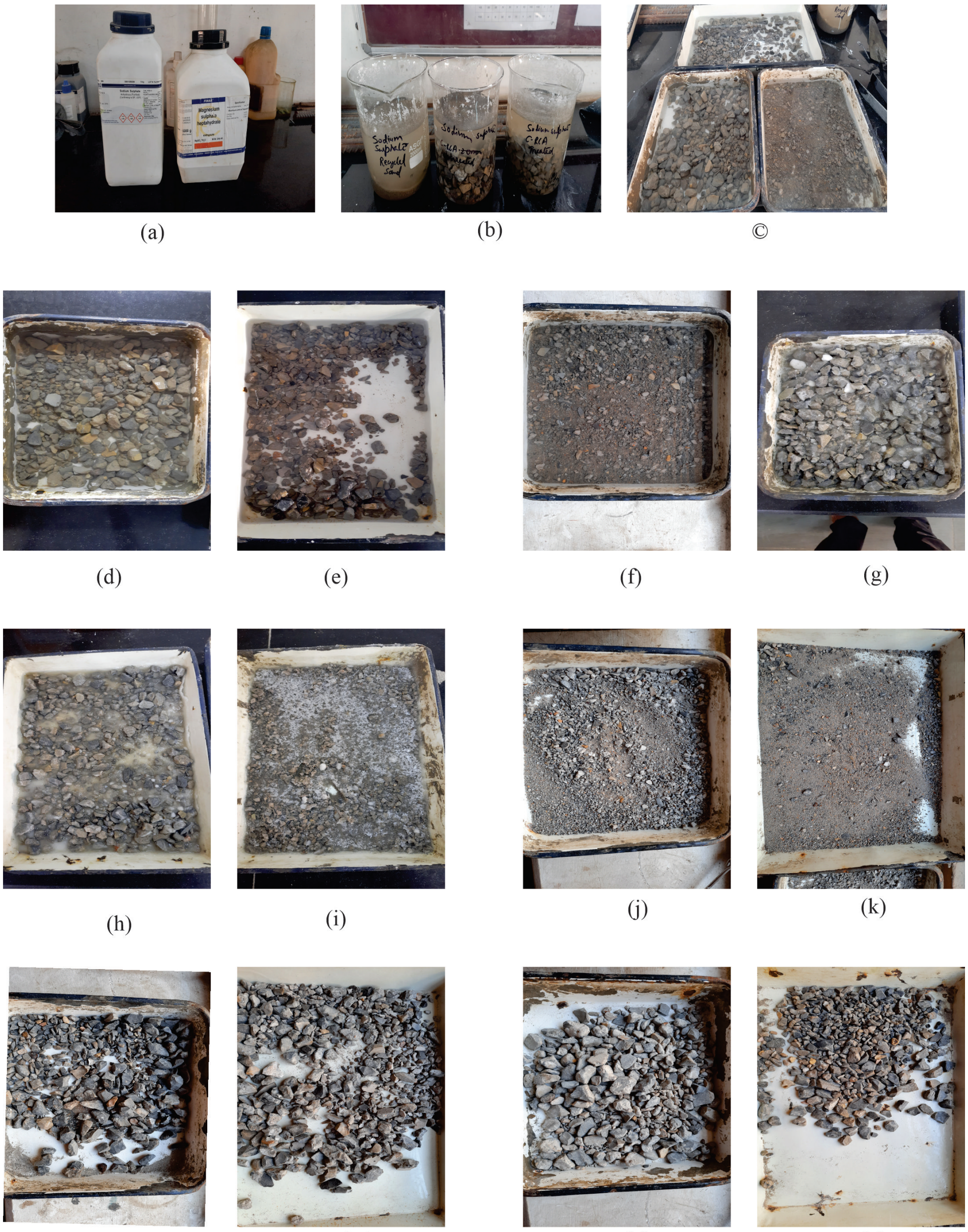
Table 4.7: Comparison of different treatment methods adhered mortar reducing capacity.

Size of aggregate	Mortar content (%) before treatment	Reduction of adhered mortar (%)	Mortar content (%) after treatment	Treatment method
10 mm	56	36.6	35.5	Simple Dry Abrasion (SDA)
20 mm	46	28.88	32	
10 mm	56	44.02	31.5	Heating and abrasion (HA)
20 mm	45	33.34	30	
10 mm	56	44.91	30.85	Quenching and abrasion (QA)
20 mm	45	37.22	28.25	

on C-RCA after treatment application (T-RCA). Table 4.6 shows the result of percentage loss in 10 mm C-RCA, 20 mm C-RCA and F-RCA after the five cycles of immersion (in sodium and magnesium sulphate solution) and oven drying. Results show that solution of sodium sulphate reagent caused higher loss of weight percentage in aggregates than magnesium sulphate reagent. U-RCA lost 7.6% (10 to 20 mm), 18.67% (4.75 to 10 mm) in ($MgSO_4$) solution, whereas it lost 44.6% (10 to 20 mm), and 55% ((4.75 to 10 mm) in ($NaSO_4$) solution. T-RCA showed loss of 5.4% (10 to 20 mm), 11.33% (4.75 to 10 mm) in ($MgSO_4$) solution, whereas it lost 32.2% (10 to 20 mm), and 35.67% (4.75 to 10 mm) in ($NaSO_4$) solution. Recycled sand (F-RCA) showed loss of 6.6% and 36.8% in ($MgSO_4$) and ($NaSO_4$) solution respectively.

4.4.3 Comparison of treatment methods

The comparison of the three treatment method used for the study of their adhered mortar reducing capacity is tabulated in Table 4.7. Mortar content of C-RCA before and after application of treatment was estimated by using the solution of sodium sulphate solution. Among the three methods, quenching and abrasion (QA) method reduced highest amount of adhered mortar from C-RCA which was 44.91% for 10 mm and 37.22% for 20 mm. Heating and abrasion (HA) method reduced 44.02% old mortar from 10 mm aggregate and 37.22% from 20 mm. Lowest reduction of adhered mortar from RCA was observed in simple dry abrasion method, 36.6% in 10 mm and 28.88% in 20 mm RCA. All the treatment methods were able to reduce the adhered mortar content of 10 mm and 20 mm RCA under 40% which is as per literature, the suggested limit for adhered mortar content in RCA. For further study on the effect of RCA treatment on resulting concrete, HA and



(a) (b) ©

(d) (e) (f) (g)

(h) (i) (j) (k)

(l) (m) (n) (o)

Figure 4.4: Adhered mortar content estimation; (a) Chemicals used; $(MgSO_4)$, $(NaSO_4)$ (b) C-RCA (both 10 and 20 mm) and F-RCA in $(MgSO_4)$ solution, (c) Aggregates in $(NaSO_4)$ solution; After 1 cycle of immersion in $(MgSO_4)$ (d) C-RCA (20 mm), (e) C-RCA (10 mm), (f) F-RCA; After 1 cycle of immersion in $(NaSO_4)$ (g) C-RCA (20 mm), (h) C-RCA (10 mm) (i) F-RCA; F-RCA after 5 cycles of (j) $(MgSO_4)$, (k) $(NaSO_4)$; Untreated C-RCA after 5 cycles of (l) $(NaSO_4)$, (m) $(MgSO_4)$; and treated RCA after 5 cycles of (n) $(MgSO_4)$ (o) $(NaSO_4)$.

SDA treatment was used.

Table 4.8: RCA sampling for phase I

RCA Samples	Made by mixing prepared RCA samples	Percentage	Remark	Treatment method
RCAH	RCAP1 and RCAP2	50% each	RCA obtained from old concrete having w/c less than or equal to 0.5 old concrete	QA
RCAL	RCAP3 and RCAP4	50% each	RCA obtained from old concrete having w/c more than 0.5	QA
RCAM1	RCAP1, RCAP2, RCAP3, and RCAP4	25% each	RCA obtained from old concrete of different w/c	QA
RCAM2	RCAM	100%	RCA obtained from old concrete containing mineral admixtures	SDA

4.5 Sampling of RCA for production of concrete.

RCA produced from the old tested concrete samples was mixed together to produce aggregate samples for the production of concrete samples. Two types of RCA sampling were required as this experimental study is phased in two parts; a) in the first part the impact of parent concrete quality on RCA and consequently on concrete produced were studied, b) in the second phase, C-RCA and F-RCA was varied from 0 to 100% both individually as well as in simultaneously for the production concrete.

RCA sampling for phase I: Three varieties of RCA were used in this experiment to investigate the impact of parent concrete quality; a) RCA obtained from low-strength old concrete, b) RCA obtained from high-strength old concrete, and c) RCA obtained from the mixed type of tested old concrete samples. For the production of concrete, RCA samples were prepared as described in Table 4.8. RCAP1 and RCAP2 were mixed to produce RCAH, RCAP3 and RCAP4 were mixed to prepare RCAL, RCAM1, and RCAM2 were produced by mixing all types of RCA samples. RCAH, RCAL, and RCAM1 were treated with the quenching and abrasion (QA) treatment method and RCAM2 with the dry abrasion (DA) treatment method.

RCA sampling for phase II: All type of RCA samples produced were mixed together to produce single lot of both C-RCA and F-RCA, in this phase of study. F-

Table 4.9: RCA sampling for phase II

Sample	Full form
0C0F	0% C-RCA and 0% F-RCA
30C0F	30% C-RCA and 0% F-RCA
60C0F	60% C-RCA and 0% F-RCA
100C0F	100% C-RCA and 0% F-RCA
0C30F	100% C-NA and 30% F-RCA
0C60F	100% C-NA and 60% F-RCA
0C100F	100% C-NA and 100% F-RCA
100C30F	100% C-RCA and 30% F-RCA
100C60F	100% C-RCA and 60% F-RCA
30C30F	30% C-RCA and 30% F-RCA
60C60F	60% C-RCA and 60% F-RCA
100C100F	100% C-RCA and 100% F-RCA

RCA was directly used in the concrete, while C-RCA was further treated with simple dry abrasion. Simple dry abrasion was specifically used in this study on the economic grounds. Percentage replacement used in this study were 0%, 30%, 60% and 100%. Table 4.9 shows the sampling of RCA for the production of concrete samples in this phase.

4.6 Physical inspection

Difference in the physical form of RCA and NA are discussed through photographic analysis in this section. Crushed natural aggregate possess clean angular structure with sharp edges, a close range photograph of C-NA are shown in Fig. 4.11. Basic difference between RCA and NA is the presence of adhered mortar in the previous. As RCA are obtained after crushing of concrete the presence of old mortar adhered on it is obvious. RCA is nothing but combination of C-NA and old mortar. Majorly three kinds of RCA piece were observed in the untreated RCA as shown in Fig. 4.5; C-NA coated with old mortar, C-NA attached with lump of old mortar and cluster of small sized aggregate bonded by old mortar. Due to the presence of adhered mortar, the surface of untreated RCA was distinctly porous and rough. The presence of F-NA from the original concrete was easily identifiable in the adhered mortar. However, after treatment, the roughness of C-RCA significantly improved, and more fines were broken off. Fig. 4.6 shows the photographs of the mechanically treated C-RCA, which contained the RCA with no adhered mortar, partially coated and aggregate with lump of mortar. Fig. 4.7 and 4.8 shows the close range photographs of the untreated and treated C-RCA. The photographs clearly visualize the differences in the surface texture of all the three types of aggregate. The photographs shows that the mechanical treatment process certainly improved the surface texture and shape of C-RCA as a consequence of adhered mortar reduction. The surface of untreated RCA was distinctly porous and rough, however the surface of treated RCA had less amount of adhered mortar due to which it has become smoother and less porous. The mechanical treatment did not alter any morphology of RCA but the treated RCA attained rounded shape compared to untreated RCA as well as C-NA, which was the result of abrasion action on RCA. Treated RCA having smoother surface than Untreated RCA and C-NA results into better workability of concrete. The abrasion against each other did not cause excessive damage to the angular morphology of C-RCA but resulted in a variety of particles. However, particles of treated C-RCA (Fig. 4.9) were more rounded as compared to C-NA particles (Fig. 4.11). Fig. 4.8 show terated C-RCA particles entirely and partially covered with old mortar, respectively, while Fig. 4.11 shows almost 100% removal of adhered mortar. Fig. 4.10 shows different shapes and sizes of treated C-RCA particles. Untreated C-RCA were mostly sharp-edged, while treated C-RCA obtained equi-dimensional as well as spherical shape. Also, C-RCA-A had a relatively smoother surface than untreated C-RCA, resulting in better workability of concrete.

4.7 Summary

In the present chapter, production process of RCA from the old concrete samples are detailed. The variation in physical and mechanical properties RCA produced from different strength of old concrete samples are discussed. Also the sampling of RCA for different phases of study was done in this chapter. Comparison of three different treatment methods was done in this chapter for their capacity of adhered mortar removal from C-RCA. The maximum percentage of adhered mortar was removed from adhered mortar by using QA method, whereas SDA method removed lowest amount of adhered mortar. The properties

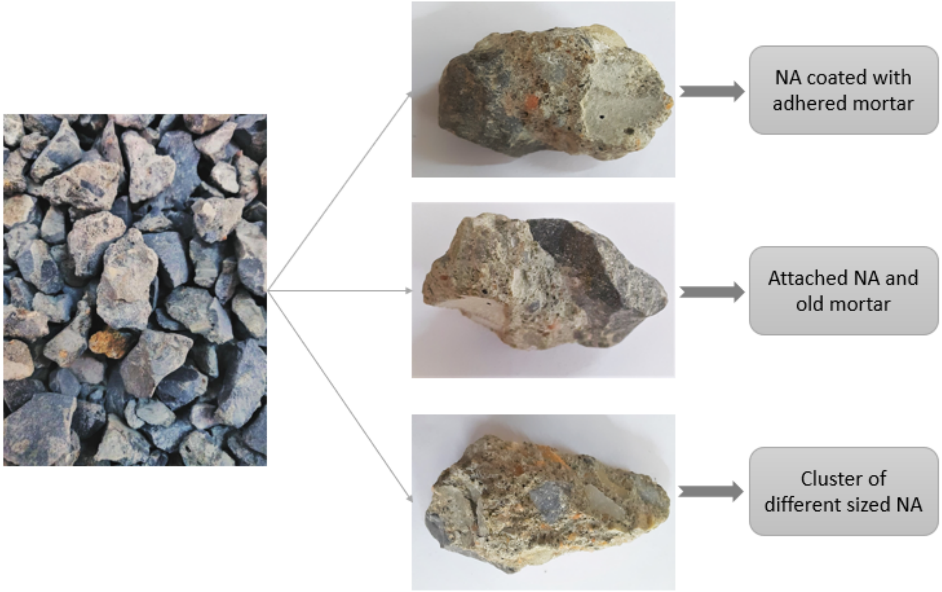


Figure 4.5: Untreated C-RCA

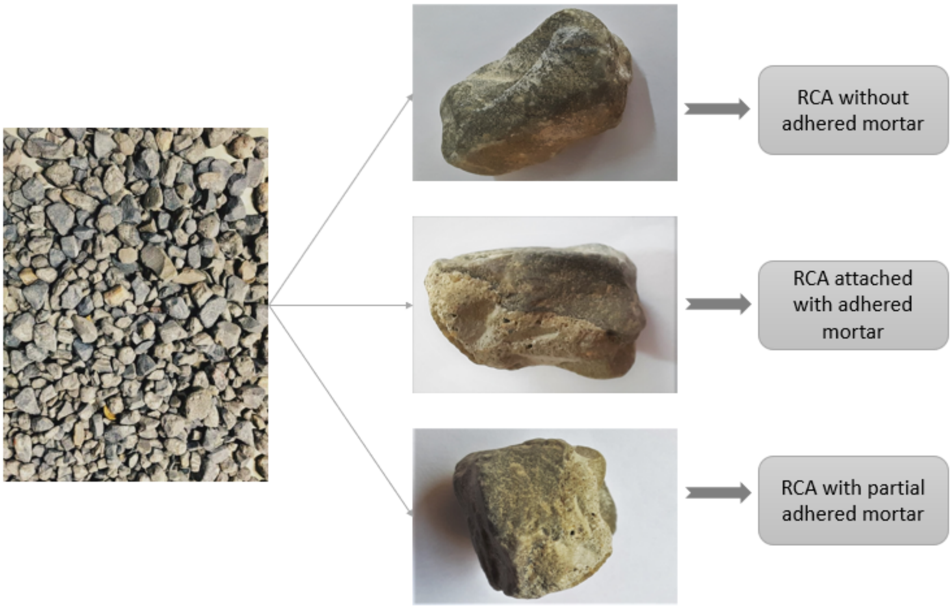


Figure 4.6: Treated C-RCA

of C-RCA was affected by the change in the strength of old concrete. For quantification of adhered mortar content in C-RCA, process used for estimating soundness of aggregate (by using ($MgSO_4$) and ($NaSO_4$)) was adopted in this study.

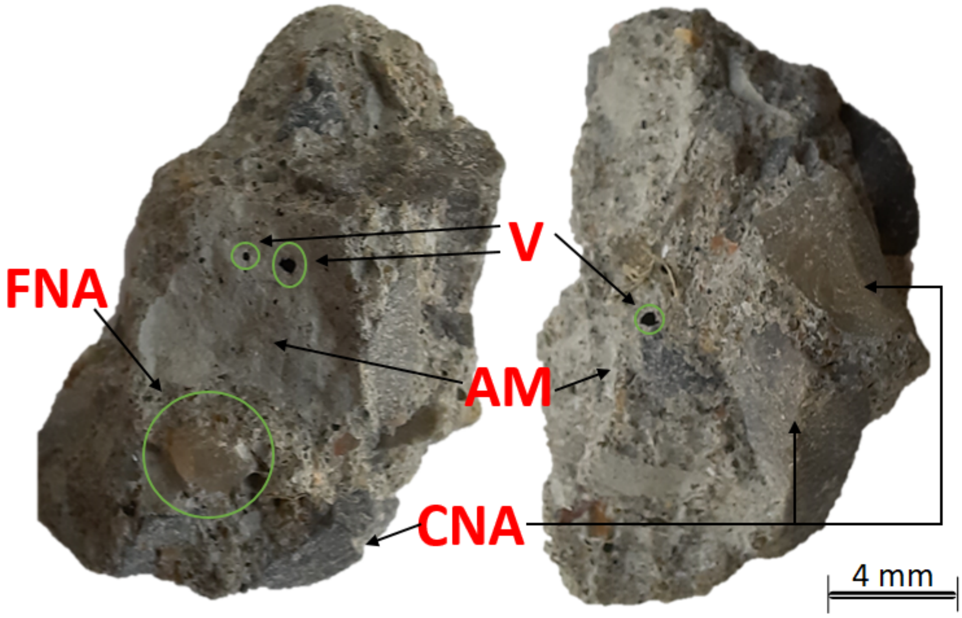


Figure 4.7: Close range photograph of untreated C-RCA

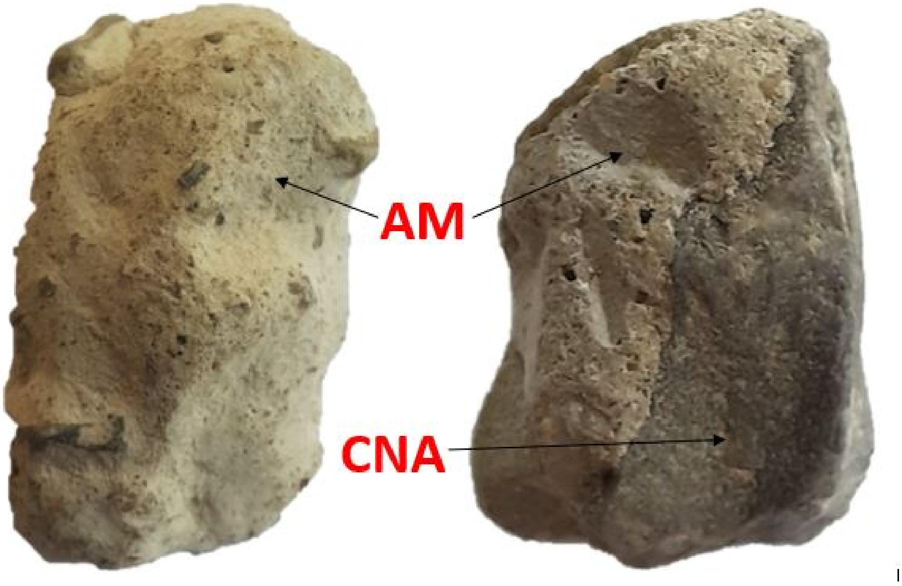


Figure 4.8: Close range photograph of treated C-RCA

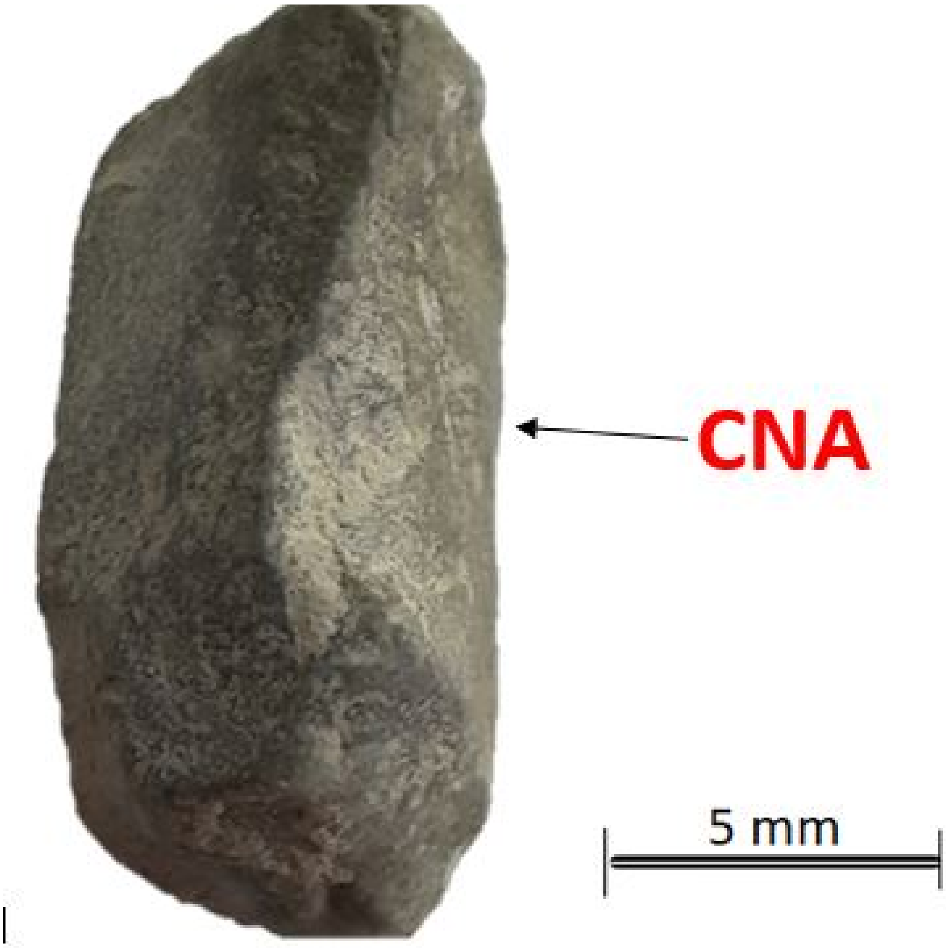


Figure 4.9: Complete removal of adhered mortar from C-RCA

Figure 4.10: Variance in shape and size of C-RCA

Figure 4.11: Crusher coarse natural aggregates