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Comparison of Properties of Coarse Aggregate Obtained from Recycled Concrete with that of Conventional Coarse Aggregates

Abba Bashir[1], Chhavi gupta[1], M.A. Abubakar[2] and S.I. Abba*[3]

[1]Sharda University, Department of Civil Engineering
[2]Ministry of Works, Housing and Transport. Dept of Civil Engineering
**[3]Yusuf Maitama Sule University, Kano PPD&M Department*
saniisaabba86@gmail.com

ABSTRACT

In this fast-growing world, the quantum of construction waste has increased considerably in past decades, and social and environmental concerns on the recycling of the waste have accordingly been increased. It is estimated that core waste (described as those types of materials which are obtained from demolished building or civil engineering infrastructure) amounts to around 180 million tons per year or 480 kg/person/year in the EU. Waste concrete is particularly crucial among the construction wastes. Recent technology has also improved the recycling process. In this rapid industrialized world, recycling of construction material plays an important role to preserve the natural resources. Hence, the application of recycled aggregate has been started in a large number of construction projects of many European, American, Russian and Asian countries. This project reports the suitability of recycled coarse aggregate as 100% replacement in concrete at different water-cement ratio (0.45, 0.50 and 0.55) and attempts to compare the mechanical and physical properties of recycled coarse aggregate with that of conventional coarse aggregate concrete. It also attempts to compare properties of concrete made with recycled coarse aggregate with that of concrete made with natural coarse aggregate. In this paper concrete waste from demolished structure has been collected and crushed with a mechanical jaw crusher. The various test results showed that the Recycled Coarse Aggregate is less dense, more porous, and has a higher water absorption capacity than Natural Coarse Aggregate. Recycled Coarse Aggregate is found to be slightly weaker than Natural Coarse Aggregate in terms of mechanical and physical properties but the compressive strength of concrete made from Recycled Coarse Aggregate is almost comparable with that of concrete made from Natural Coarse Aggregate.

Key words: Recycled Aggregates, Natural Aggregates, Compressive Strength, Mechanical and Physical Properties

1. INTRODUCTION

Concrete is the chief construction material used across the world and plays an important role in the development of a country. It is used in all types of civil engineering works, including infrastructure, low and high-rise buildings, defense installations, environment protection and local/domestic developments. Concrete is essentially composed of cement, coarse and fine aggregates, water and admixture(s). Among these, aggregates, i.e. inert granular materials such as sand, crushed stone or gravel form the major part. Traditionally aggregates have been readily available at economic price but recently there has been a decline in the quality and quantity of the aggregates due to its over utilization on the account of rapid industrial development. Given this background, the concept of sustainable development was put forward, at the 1992 Earth Summit in Rio de Janeiro, and it has now become a guiding principle for the construction industry worldwide. Various measures are being taken around the world to reduce the use of natural aggregate and to promote the concept of reuse and recycling of aggregate, wherever technically, economically, or environmentally acceptable. The main objective of sustainable development is to reduce the environmental impact of a constructed facility over its lifetime. Concrete is the main material used in construction world due to its long life, low maintenance cost and better performance. For increasing the GDP rate of a nation smaller and older structures are being demolished and new and gigantic structures are being built. The increase in Construction and Demolition activities worldwide results in the

accumulation of huge concrete waste which is not being used for any purpose and leads to a loss in the economy of the country as natural resources are depleting day by day. The waste also creates a major problem for municipal authorities as it occupies a considerable volume and makes it difficult to collect and transport. Waste arising from Construction and Demolition constitutes one of the largest waste streams within the EU, Asian and many other countries of world. For example, it is estimated that core waste (described as those types of materials which are obtained from demolished building or civil engineering infrastructure) amounts to around 180 million tons per year or 480kg/person/year in the EU. This ranges from over 700 kg/person/year in Germany and the Netherlands to under 200 kg/person/year in Sweden, Greece and Ireland. The estimates for the UK are 30million tons/year and just over 500 kg/person/ year respectively, putting the UK in second place behind Germany. As per report of The Hindu Newspaper of March 2007, India generates 23.75 million tons demolition waste annually. As per report of Central Pollution Control Board (CPCB) Delhi, in India, 48million tons solid waste is produced out of which 14.5 million tons waste is produced from the construction waste sector, out of which only 3% waste is used for embankment. Out of the total construction demolition waste, 40% is of concrete, 30% ceramic's, 5% plastics, 10% wood, 5%metal, & 10% other mixtures. For production of concrete, 70-75% aggregates are required. Out of this 60-67% is of coarse aggregate & 33- 40% is of fine aggregate. As it is a common practice in all over the world that most of the materials like paper, plastic, rubber, wood etc. are being recycled to save the natural resources and environment, the concrete can also be recycled and used again as recycled concrete aggregate (RCA) in the construction processes, thereby reducing the cost and improving the environment as a whole. From environmental point of view, for production of natural aggregates of 1 ton, emissions of 0.0046 million ton of carbon exist whereas for 1ton recycled aggregate produced only 0.0024 million tons carbon is produced. Hence by the use of RCA the carbon footprint of concrete can be by almost 50%.
The paper discusses the properties of Recycled Coarse Aggregates and compares it with the Natural Coarse Aggregate.

2. METHODS AND METHODOLOGY

The tests were conducted in the laboratory of Sharda University, Greater Noida. The experimental program was divided into two phases:

1. Phase 1 dealt with evaluation and comparison of the mechanical and physical properties of RCA and NCA.
2. Phase 2 dealt with the evaluation of properties of concrete made with RCA at different water-cement ratio and comparing it with concrete made with NCA.

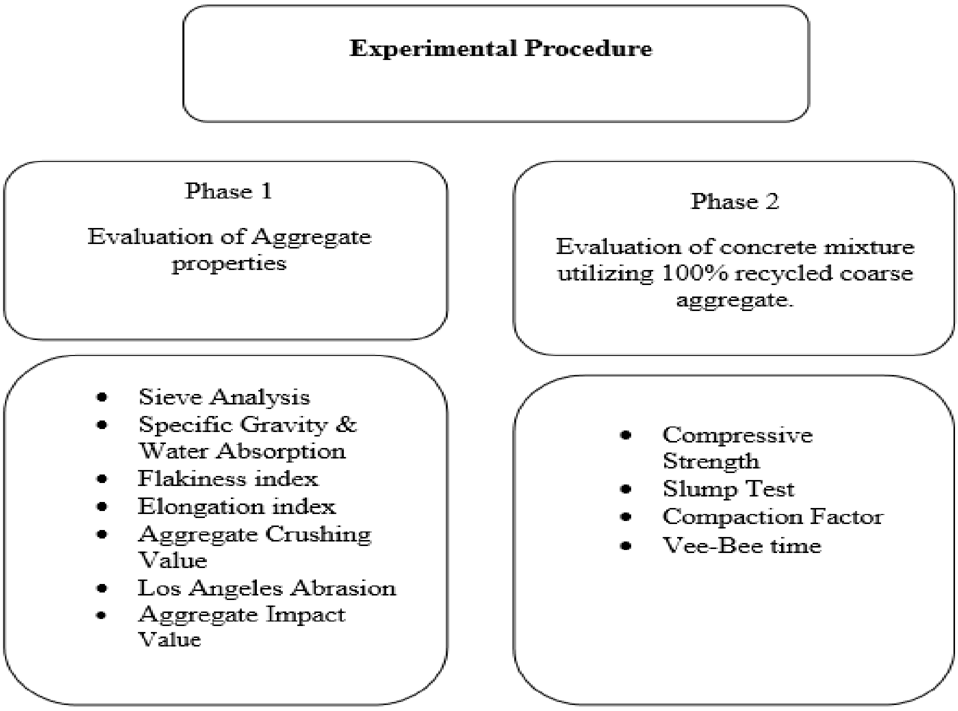

Fig. 2.1 Summary of Experimental Program conducted in the investigation

The waste concrete was collected from demolished structure (10 years old) near Kalandi Kunj Park, New Delhi. This collected material was crushed by using a mechanical jaw crusher to reduce their sizes into smaller fraction. The aggregates passing through 20 mm IS sieve and retaining on 4.75mm IS sieve (coarse aggregate) were used for the project. The yield of coarse aggregate from the demolished was about 80%.
On these separated coarse aggregates various tests were conducted in laboratory as per Indian Standard codes to determine the physical and mechanical properties and their results were compared with natural coarse aggregates.

Tests were carried out on these aggregates to determine their specific gravity and water absorption, impact value, crushing strength and flakiness and elongation index.

Nominal Mix of M20 grade concrete was then produced with 100% replacement of recycled coarse aggregate with varying water-cement ratio of 45%, 50% and 55%. Three types of aggregates were used in this research which include Natural coarse aggregate, Natural fine aggregate and recycled coarse aggregate. Natural coarse aggregate was of maximum size of 20 mm, Natural fine aggregate used is river sand of Zone III and Recycled coarse aggregate used is crushed demolished concrete.

Tests were conducted on these concretes to determine slump, vee-bee time and compaction factor. The compressive strength of concrete made with RCA was also determined at 7 days and 28 days and the results were compared with concrete made with NCA.

3. RESULT AND DISCUSSION

An endeavor is made to compare the physical and mechanical properties of Recycled coarse aggregate with that of Natural coarse aggregate and also an attempt is made to study the suitability of Recycled coarse aggregate as 100% replacement in concrete at different water-cement ratio.

Physical and Mechanical Properties

In this study, the recycled aggregate was obtained from crushed concrete. After washing the Recycled coarse aggregate and the natural aggregate were tested for various mechanical and physical properties.

Particle Size Distribution

Sieve analysis was carried out as per IS 2386 (Part I)-1963 for crushed recycled coarse aggregate and natural aggregates. The IS Sieve Set used for this test were of size 40mm, 20mm, 12.5mm, 10mm, 6.3mm, 4.75mm and 2.63mm.

Table -3.1 Sieve Analysis for Recycled coarse aggregate

Sieve Size (mm)	Weight Retained sample 1 (g)	Weight Retained sample 2 (g)	Weight Retained sample 3 (g)	Average Weight Retained (g)	% Weight Retained (g)	Cumulative % Weight Retained (g)	% Passing
40	0.00	0.00	0.00	0.00	0.00	0.00	100.00
20	100.00	0.00	75.00	58.33	1.16	1.16	98.84
16	1204.00	1426.00	1398.00	1342.66	26.85	28.01	71.99
12.5	1818.00	1461.00	1480.00	1586.33	31.72	59.73	40.27
10	354.00	518.00	458.00	443.33	8.86	68.59	31.41
4.75	1433.00	1477.00	1485.00	1465.00	29.30	97.89	2.11
2.36	66.00	76.00	70.00	70.66	1.413	99.30	0.70
Pan	25.00	44.00	28.00	30.33	0.046	-	-

Table -3.2 Sieve Analysis for Natural coarse aggregate

Sieve Size (mm)	Weight Retained sample 1 (g)	Weight Retained sample 2 (g)	Weight Retained sample 3 (g)	Average Weight Retained (g)	% Weight Retained (g)	Cumulative % Weight Retained (g)	% Passing
40	0.00	0.00	0.00	0.00	0.00	0.00	100.00
20	70.00	153.00	115.00	112.66	2.25	2.25	97.75
16	2137.00	1687.00	1920.00	1914.60	38.29	40.54	59.45
12.5	2504.00	2843.00	2678.00	2675.00	53.50	94.04	5.46
10	277.00	236.00	268.00	260.33	5.21	99.25	0.078
4.75	10.00	68.00	13.00	27.66	0.55	99.80	0.20
2.36	0.00	6.00	3.00	3.00	0.86	99.86	0.11
Pan	0.00	9.00	2.00	3.66	0.07	99.92	-

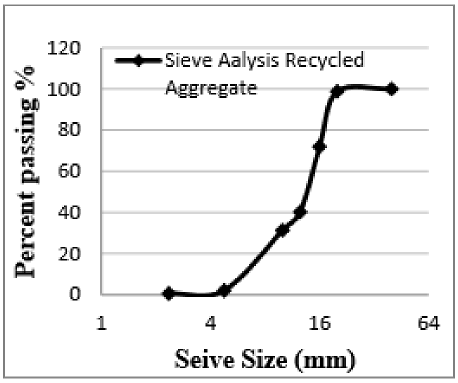

Fig. 3.1 Sieve Analysis for RCA

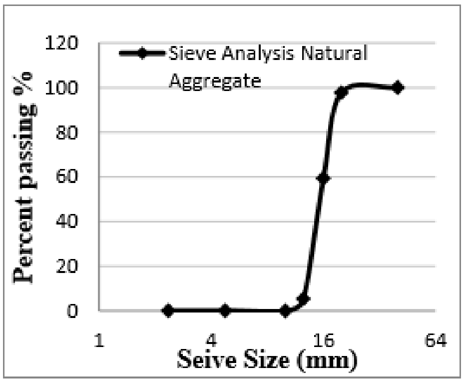

Fig. 3.2 Sieve Analysis for NCA

Discussion: Based on figure 3.1 and figure 3.2, it can be inferred that the recycled coarse aggregates are reduced to various sizes during the process of crushing and sieving, which gives RCA a better particle size distribution as compared to NCA. The Recycled coarse aggregate showed a well graded graph as opposed to Natural coarse aggregate which showed a gap graded graph. This is due to crushing of Recycled coarse aggregate under controlled conditions.

Aggregate Impact Value

The property of a material to resist impact is known as toughness. Due to movement of vehicles on the road the aggregates are subjected to impact resulting in their breaking down into smaller pieces. The aggregates should therefore have sufficient toughness to resist their disintegration due to impact. This characteristic is measured by impact value test. The aggregate impact value is a measure of resistance to sudden impact or shock, which may differ from its resistance to gradually applied compressive load.

Table -3.3 Aggregate Impact Value test for Recycled Aggregate

Description	Test 1	Test 2	Test 3
Weight of mould (g)	889	889	889
Weight of mould and sample (g)	1194	1186	1198
Weight of sample W1 (g)	305	297	309
Weight of fraction retained on 2.36mm sieve W2 (g)	228	222	230
Weight of fraction passing through 2.36mm sieve W3 = (W1-W2) (g)	77	75	79
Aggregate Impact Value $\frac{W3}{w1} * 100$	25.24	25.25	25.5
Average Value % = 25.33			

Table -3.4 Aggregate Impact Value test for Natural Aggregate

Description	Test 1	Test 2	Test 3
Weight of mould (g)	889	889	889
Weight of mould and sample (g)	1249	1240	1246
Weight of sample W1 (g)	360	351	357
Weight of fraction retained on 2.36mm sieve W2 (g)	289	290	292
Weight of fraction passing through 2.36mm sieve W3 = (W1-W2) (g)	71	61	65
Aggregate Impact Value $\frac{W3}{w1} * 100$	19.7	17.3	18.2
Average Value % = 18.4			

Discussion: Aggregate Impact value is carried as per IS 2386(Part IV). It is found that recycled coarse aggregate is relatively weaker than the natural aggregate against impact or shock. This is possibly due to fact that RCA was already stressed during crushing thereby decreasing its strength. As per IS 383, the impact values for concrete wearing surfaces should not exceed 45 per cent for aggregate used for concrete other than for wearing surfaces and 30 % for concrete for wearing surfaces. The result of aggregate impact value for Recycled coarse aggregate is 23.33% and for Natural Coarse aggregate is 18.5%. Thus, Recycled aggregate is satisfactory for road surfacing while as Natural Coarse Aggregate is exceptionally strong.

Aggregate Crushing Value

The aggregate crushing value gives a relative measure of the resistance of an aggregate crushing under gradually applied compressive load. In this test aggregates were exposed to a loading of 400 KN and the results were compared.

Table -3.5 Crushing Value for Recycled Aggregate

Description	Test 1	Test 2	Test 3
Weight of mould (g)	1889	1889	1889
Weight of mould and sample (g)	3894	3898	3911
Weight of sample W1 (g)	2005	2009	2022
Weight of fraction retained on 2.36mmsieve W2 (g)	1425	1432	1426
Weight of fraction passing through 2.36mm sieve W3 (g)	580	577	596
Crushing Value % $\frac{W3}{w1} * 100$	28.9	28.7	29.4
Average Value = 29%			

Table -3.6 Crushing Value for Natural Aggregate

Description	Test 1	Test 2	Test 3
Weight of mould (g)	1889	1889	1889
Weight of mould and sample (g)	4712	4705	4714
Weight of sample W1 (g)	2823	2816	2825
Weight of fraction retained on 2.36mmsieve W2 (g)	2110	2118	2107
Weight of fraction passing through 2.36mm sieve W3 (g)	713	698	718
Crushing Value % $\frac{W3}{w1} * 100$	25.2	24.7	25.4
Average Value % = 25.1			

Discussion: Aggregate Crushing value is carried as per IS 2386(Part IV). It is found that recycled coarse aggregate is relatively weaker than the natural aggregate against crushing under gradually applied load. This is possibly due to fact that RCA was already stressed during crushing thereby decreasing its strength. As per IS 383, the crushing values for concrete should not exceed 45 per cent for aggregate used for concrete other than for wearing surfaces and 30 % for concrete for wearing surfaces. The result of aggregate crushing value for Recycled Aggregate is 29% and for Natural Coarse Aggregate is 25.1%. In our case RCA is having mild strength and has the ability to resist pressure under traffic wheel loads such as car, lorry, and motor-cycle.

Los Angles Test

The Los Angeles (L.A.) abrasion test is a common test method used to indicate aggregate toughness and abrasion characteristics. Aggregate abrasion characteristics are important because the constituent aggregate must resist crushing, degradation and disintegration in order to produce a high-quality concrete. The L.A. abrasion test measures the degradation of a coarse aggregate sample that is placed in a rotating drum with steel spheres. As the drum rotates the aggregate degrades by abrasion and impact with other aggregate particles and the steel spheres (called the charge).

Table -3.7 Abrasion Value for Recycled Aggregate

Description	Test 1	Test 2	Test 3
Weight of sample (g)	5000	5000	5000
Weight retained on 1.7mm sieve (g)	3230	3242	3189
Weight of fines (g)	1770	1758	1811
Abrasion aggregate%	35.4	35.16	36.2
Average Value % = 35.56			

Table -3.8 Abrasion Value for Natural Aggregate

Description	Test 1	Test 2	Test 3
Weight of sample (g)	5000	5000	5000
Weight retained on 1.7mm sieve (g)	3446	3520	3498
Weight of fines (g)	1554	1480	1502
Abrasion aggregate%	31.08	29.6	30.04
Average Value % =30.2			

Discussion: Los Angeles Test is carried as per IS 2386(Part IV). It is found that recycled coarse aggregate is relatively weaker than natural coarse aggregate against crushing, degradation and disintegration as the abrasion value of Recycled coarse aggregate is 35.56% and that of natural coarse aggregate is 30.24%. This is because the RCA has a mortar adhered to its surface resulting in reduced surface hardness. As per IS 383, the values for concrete should not exceed 50 per cent for aggregate used for concrete other than for wearing surfaces and 30 % for concrete for wearing surfaces. Hence RCA is suitable for use in structural works.

Flakiness and Elongation Index

The usual shapes of the particles are Rounded, Flaky, Elongated, Angular, Flaky and Elongated particles are considered as a source of weakness. A flaky particle is the one whose least dimension (thickness) is than 0.6 times the mean size. These are the materials of which the thickness is small as compared to the other two dimensions.

Discussion: The test is carried as per IS 2386(Part I), the elongation and flakiness index of Recycled coarse aggregate was 19.08% and 5.84% respectively while it was 24.4% and 15.41% respectively for Natural coarse aggregate. It is found that recycled coarse aggregate consists of rounded and angular shaped particles in greater percentage as compared to natural coarse aggregate. AS the values for flakiness and elongation should be less than 30% and 45%, therefore it is suitable for use in structural works.

Table -3.9 Flakiness and Elongation Index for Recycled Aggregate

	Flakiness index calculation Total Weight of sample 2000g				**Elongation index calculation Total Weight of sample 2000g**			
IS Sieve Size mm	**Weight of sample 1 (g)**	**Weight of sample 2 (g)**	**Weight of sample 3 (g)**	**Average weight of sample (g)**	**Weight of sample 1 (g)**	**Weight of sample 2 (g)**	**Weight of sample 3 (g)**	**Average weight of sample (g)**
20-16	46.0	45.0	40.0	**43.6**	130.0	128.0	126.0	**128.0**
16-12.5	44.0	42.0	51.0	**45.6**	167.0	160.0	168.0	**165.0**
12.5-10	23.0	26.0	25.0	**23.6**	67.0	70.0	69.0	**66.6**
10-6.3	4.0	3.0	5.0	**4.0**	22.0	23.0	21.0	**22.0**
Total Weight	117.0	116.0	120.0	**116.8**	386.0	381.0	384.0	**381.6**
	Flakiness index = 5.84%				**Elongation index = 19.08%**			

Table -3.10 Flakiness and Elongation Index for Natural Aggregate

	Flakiness index calculation Total Weight of sample 1200g				**Elongation index calculation Total Weight of sample 1200g**			
IS Sieve Size mm	**Weight of sample 1 (g)**	**Weight of sample 2 (g)**	**Weigh t of sample 3 (g)**	**Average weight of sample (g)**	**Weight of sample 1 (g)**	**Weight of sample 2 (g)**	**Weight of sample 3 (g)**	**Average weight of sample (g)**
20-16	78	75	81	**78**	88	91	87	**88.6**
16-12.5	99	98	89	**95.3**	131	135	130	**132**
12.5-10	9	12	7	**9.33**	63	69	66	**66**
10-6.3	0	2	5	**2.33**	6	8	5	**6.33**
Total Weight	186	187	182	**184.96**	288	297	288	**292.93**
	Flakiness index = 15.41%				**Elongation index = 24.4%**			

Specific Gravity and Water Absorption

The specific gravity of an aggregate is considered to be a measure of strength or quality of the material. Stones having low specific gravity are generally weaker than those with higher specific gravity values.

Discussion: Specific Gravity and Water Absorption test is carried out as per IS 2386. It was found that the specific gravity (saturated surface dry condition) of Recycled coarse aggregate was found 2.29 which is lower as compared to Natural coarse aggregates with a value of 2.81. Hence RCA can be used in light weight construction. The water absorption for recycled coarse aggregate was 4.25%, which is much higher than that of the natural coarse aggregates with a value of 0.25. This is due fact that the Recycled Coarse Aggregate from demolished concrete consist of crushed stone aggregate with old mortar adhering to it. As the water absorption of Recycled coarse aggregates are higher, it is advisable either to increase the quantity of water or maintain saturated surface dry (SSD) conditions of aggregate before start of the mixing operations.

Table -3.11 Specific Gravity & Water Absorption Test for Recycled Aggregate

Description	Test 1	Test 2	Test 3
Weight of mould containing sample and filled with distilled water (A) (g)	4348	4312	4361
Weight of mould filled with distilled water (B) (g)	3736	3736	3736
Weight of saturated surface dry sample (C) (g)	1030	1029	1053
Weight of oven dry sample (D) (g)	986	989	1010
Specific Gravity $\frac{D}{C-(A-B)}$	2.35	2.18	2.35
Apparent Specific Gravity $\frac{D}{D-(A-B)}$	2.63	2.39	2.62
Water Absorption $\frac{C-D}{D}$	4.46	4.04	4.25

Average Value Specific gravity = 2.29
Average Value Apparent Specific gravity = 2.54
Average Value Water absorption = 4.25%

Table -3.12 Specific Gravity & Water Absorption Test for Natural Aggregate

Description	Test 1	Test 2	Test 3
Weight of mould containing sample and filled with distilled water (A) (g)	4410	4390	4425
Weight of mould filled with distilled water (B) (g)	3728	3728	3728
Weight of saturated surface dry sample (C) (g)	1058	1041	1063
Weight of oven dry sample (D) (g)	1055	1039	1059
Specific Gravity $\frac{D}{C-(A-B)}$	2.805	2.74	2.89
Apparent Specific Gravity $\frac{D}{D-(A-B)}$	2.828	2.75	2.92
Water Absorption $\frac{C-D}{D}$	0.28	0.19	0.3

Average Value Specific gravity = 2.81

Average Value Apparent Specific gravity = 2.83

Average Value Water absorption = 0.25%

On comparing some of the mechanical and physical properties of Recycled coarse aggregate with that of Natural coarse aggregate, it was found that Recycled coarse aggregate is relatively weaker than the Natural coarse aggregate but still it is satisfactory for Concrete production as the values are within the permissible range as per Indian Standard Code.

Properties of concrete

Nominal mix of M20 grade (1:1.5:3) was prepared using RCA and NCA and tests for workability and strength were carried out. The results for the tests are tabulated in Table 3.14, Table 3.15, Table 3.16 and Table 3.17. The Mix proportion for 1m^3 of concrete is tabulated in table 3.13.

Table -3.13 Mix proportion for 1m^3 of concrete

Type of mix	W/C ratio	Cement* (kg)	Sand** (kg)	NCA (kg)	RCA (kg)	Water (kg)
Nominal Mix M20 1:1.5:3	0.45	410.4	602.8	1478.3	1176.8	184.6
	0.50	410.4	602.8	1478.3	1176.8	205.2
	0.55	410.4	602.8	1478.3	1176.8	225.7

*OPC grade 43 **River sand Zone III

Workability Tests

The workability of Recycle aggregate concrete and Natural aggregate concrete was determined in accordance with Indian Standards. Tests conducted for determining the workability were Slump test, Compaction Factor test and Vee-bee consist meter test. The experiments were conducted at varying water-cement ratio of 0.45, 0.50 and 0.55.

Discussion: The slump is taken for each mixing of concrete at water-cement ratio of 0.45, 0.50 and 0.55. The results form table 3.14 show that slump of concrete made with Natural coarse aggregate at different water-cement ratio is higher than that of concrete made Recycled coarse aggregate. The low slump is caused by high absorption of water by Recycled aggregate concrete during the mixing process due to presence of mortar adhered to RCA. For a given water-cement ratio, workability of concrete made from RCA would be less as compared to concrete made with NCA. The compaction factor test results from table 3.15 for both Recycled aggregate concrete and Natural aggregate concrete show an increasing trend with corresponding increase in water-cement ratio. However, the values of compaction factor for concrete made with Natural coarse aggregate is found to be higher than concrete made with Recycled coarse aggregate. This indicates high workability and self-compaction property of natural aggregate concrete over Recycled aggregate concrete and thus RAC is not suitable for piling operations and construction in confined areas. While comparing the Vee-Bee time from table 3.16 for concrete made with recycled aggregate and concrete made with natural aggregate, it is found that due to high absorption of water by Recycle coarse aggregate it has low workability and with increase in water– cement ratio it can be overcome but it will also affect the strength of concrete.

Table -3.14 Comparison of slump of RAC and NAC

Water-cement ratio	Slump (mm)	
	NAC	RAC
0.45	0	0
0.50	120	50
0.55	140	110

Table -3.15 Comparison of Compaction Factor of RAC and NAC

Water-cement ratio	Compaction Factor	
	NAC	RAC
0.45	0.801	0.803
0.50	0.907	0.808
0.55	0.950	0.852

Table -3.16 Comparison of Vee Bee time of RAC and NAC

Water-cement ratio	Vee-Bee time (seconds)	
	NAC	RAC
0.45	13.9	38.0
0.50	5.0	35.0
0.55	2.5	10.0

The various tests show that workability of RAC is less than that of NAC for a given water-cement ratio. This is due to high water absorption of RCA during concrete mixing. Since the workability is less so additional vibration will be required to achieve the required degree of compaction. In order to get the desired workability using RCA it is advisable to either increase the quantity of water or to maintain saturated surface dry conditions of aggregate before the start of mixing operations.

Tests for Compressive Strength

Compressive strength is defined as the maximum resistance of a concrete cube to axial loading. Testing of specimens was carried out after curing. Specimen dimensions were measured before testing. Clean and surface dried specimens were placed in the testing machine. The platen was lowered and touched the top surface of the specimen. The load was applied gradually and maximum load was recorded. The Compression Strength Tests were conducted for nominal M20 grade of concrete with 43 grade OPC cement.

Discussion: On the basis of test results from table 4.17, it can have inferred that the strength of concrete depends on water-cement ratio taken. The 28days strength of RAC and NAC are comparable. From figure 3.4 it can be inferred that the maximum strength in case of NAC is found at water-cement ratio of 0.45 and thereafter with the increase in water the strength decreases. While as in case of RAC the strength at water-cement ratio of 0.45 is 25.18 N/mm^2 but it increases up to maximum of 26.29 N/mm^2 at water-cement ratio of 0.50, but with further increase in water-cement ratio the strength starts to decrease. The weights of various cubes were also taken during the course of experimentation and their results are summarized in table 3.18. From this table, it is evident that the concrete prepared from RCA is lighter than the concrete prepared from NCA for all water-cement ratio. The average reduction in weight of concrete prepared from RCA is approximately 8% as compared to the concrete prepared from NCA. Thus, it further verifies the results from specific gravity and making it suitable for light weight construction.

Table -3.17 Comparison of Compressive Strength of RAC and NAC

Water Cement Ratio W/C%	Average 7days Strength (N/mm^2)		Average 28 days Strength (N/mm^2)	
	NAC	RAC	NAC	RAC
45	12.54	13.83	25.40	25.18
50	15.85	15.16	21.16	26.29
55	9.42	9.86	12.47	19.99

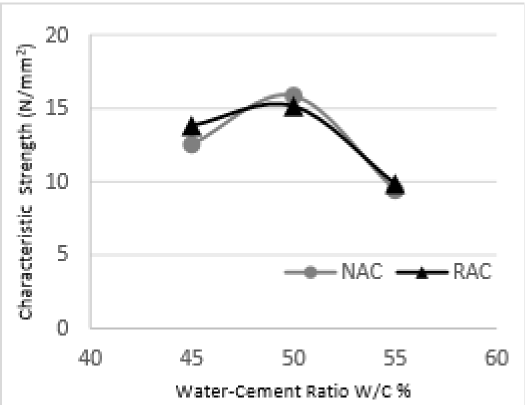

Fig. 3.3 Characteristic strength (MPa) at 7days

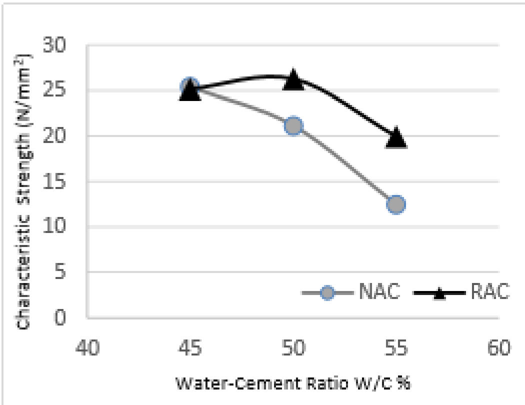

Fig. 3.4 Characteristic strength (MPa) at 28days

Table 3.18 Weight of NAC and RAC for one cube of concrete

W/C ratio	Weight of NAC (kg)	Weight of RAC (kg)
0.45	8.8	7.83
0.50	8.31	7.85
0.55	8.37	7.79

4. CONCLUSION

On the basis of our comparative analysis of test results of physical and mechanical properties of RCA and basic properties of concrete made with RCA at three different percentages of water-cement ratio (0.45, 0.50 and 0.55) the it can be concluded that although Recycled Coarse Aggregate is relatively weaker than the natural coarse aggregate but still it is satisfactory for Concrete Production as the values are within the permissible range as per Indian Standard Code. Furthermore, the concrete made with RCA is light in weight while as its strength is comparable with that of concrete made NCA, which suggest its applicability in light weight constructions. Hence the use of RCA as 100% of NCA in concrete can be seen as a positive step towards sustainable development in concrete production.

Future Scope

Since the qualities of Recycled Coarse Aggregate are still highly varied among different sources, there is room for more testing to make sure the conclusions that have been drawn in this report are applicable in the broad sense of Recycled Coarse Aggregate concrete, regardless of the Recycled Coarse Aggregate source. Furthermore, economic analysis can be carried to determine whether the obtained RCA can be economically used for preparing concrete or not with desirable strength. More tests can be carried out for partial replacement of RCA at different water-cement ratio.

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APPENDIX

CASTING SCHEDULE

Table -A1 Casting Schedule

Code	Aggregate	Water-Cement Ratio	Date of casting	No.of cubes	Date of 7 day Test	7 day strength			Average Strength	Date of 28 day Test	28 day strength			Average Strength
						(MPa)			(MPa)		(MPa)			(MPa)
						1	2	3			1	2	3	
AN7	Natural Coarse Aggregate	0.45	07/01/17	3	14/01/17	12.75	13.33	11.55	12.54		-			
AN28		0.45	10/01/17	3	-	-				07/02/17	27.51	20.97	27.73	25.40
BN7		0.5	11/01/17	3	18/01/17	15.24	14.93	17.37	15.85		-			
BN28		0.5	12/01/17	3	-	-				09/02/17	20.26	21.28	21.93	21.16
CN7		0.55	17/01/17	3	24/01/17	10.53	5.73	12.04	9.43		-			
CN28		0.55	18/01/17	3	-	-				15/02/17	12.75	12.22	12.44	12.47
AR7	Recycled Coarse Aggregate	0.45	07/01/17	3	14/01/17	12.4	16.57	12.53	13.83		-			
AR28		0.45	07/01/17	3	-	-				04/02/17	23.91	26.13	25.51	25.18
BR7		0.5	10/01/17	3	17/01/17	16.31	17.11	12.08	15.17		-			
BR28		0.5	11/01/17	3	-	-				08/02/17	25.95	27.91	25.02	26.29
CR7		0.55	13/01/17	3	20/01/17	9.37	9.91	10.31	9.86		-			
CR28		0.55	13/01/17	3	-	-				10/02/17	20.48	19.2	20.31	19.99