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EXPERIMENTAL INVESTIGATION ON SUSTAINABLE CONCRETE USING RECYCLED COARSE AGGREGATE

Faizanul Haque[1], Akbar H. Tramboo[2], Salik Tramboo[3], Iqra Manzoor[4], Anuj Singh[5]

[1]*Assistant Professor,DepartmentofCivil Engineering, Sharda University, Greater Noida, U.P,India*

[2,3,4,5]*B. Tech, Student Sharda University, Greater Noida, U.P,India*

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 tonnes per year or 480kg/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 paper 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 compareproperties of concrete made with recycled coarse aggregate with that of concrete made with natural coarse aggregate. In this research 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.

Keywords-Construction and Demolition waste, Recycling, Recycled Aggregates, Recycled Aggregate Concrete, Waste Management, Durability.

I. 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, defence installations, environment protection and local/domestic developments. Concrete is essentially composed of cement, coarse and fine aggregates, water and admixture. 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.

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 tonnes 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 tonnes/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 ton waste is produced from the construction waste sector, out of which only 3% waste is used for embankment.

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.

Based on the background of problem, the research paper will try to discuss the following questions:

1. What is the comparison between properties of Recycled coarse aggregate and Natural coarse aggregate?
2. What is the suitability of Recycled coarse aggregate as 100% replacement in concrete at different water-cement ratio?

II. LITERATURE REVIEW

Poon and Chan have studied the use of RAC in a project at Hong Kong Wetland Park. The highest concrete grade used was 35 MPa, while the slump of concrete was in the range of 75 mm to 100 mm. The RAC was applied in pile caps, ground slabs, external works, mass concrete, minor concrete works and concrete blinding. The higher grade RAC is made by 20% replacement of recycled coarse aggregate (RCA); 100% recycled aggregate replacement is used to produce lower grade concretes. A total amount of 12918m3 of recycled aggregate concrete was used in this project [1].

Recycled aggregate can also be used for producing normal structural concrete with the addition of fly ash and condensed silica fumes [2].

The use of recycled aggregates in concrete is both economically viable & technically feasible. Apart from demolition waste sources, Recycled coarse aggregate can also be composed of excess Concrete materials returned to the batching plant [3].

Research by Mirza and Saif have shown the effect of silica fumes on recycled aggregate concrete characteristics. The percentages of recycled aggregate replacements of natural aggregate used by weight were 0, 50, and 100%, whereas the percentages of silica fumereplacements of cement used by weight were 5, 10, and 15%. The results showed that the compressive and tensile strengths values of the recycled concrete aggregate increased as the recycled aggregate and the silica fume contents increased. The study also indicated that in order to accommodate 50% of recycled aggregate in structural concrete, the mix needs to incorporate 5% of silica fume [4].

The strength of recycled aggregate concrete is reported to be less by about 10% as compared to normal concrete [5].

III. METHODOLOGY

The research was conducted in the laboratory of Sharda University, Greater Noida.

The waste concrete was collected from demolished structure (10 year old) near Kalandi Kunj Park, New Delhi. This collected material was crushed by using a mechanical 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 research. 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 aggregate to determine the 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 including slump, vee-bee, compaction factor and compressive strength was also determined. The compressive strength of concrete was found out at 7 and 28 days and results were compared with natural concrete.

IV. RESULT AND DISCUSSION

1. 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. The results from the tests are tabulated in Table 1.

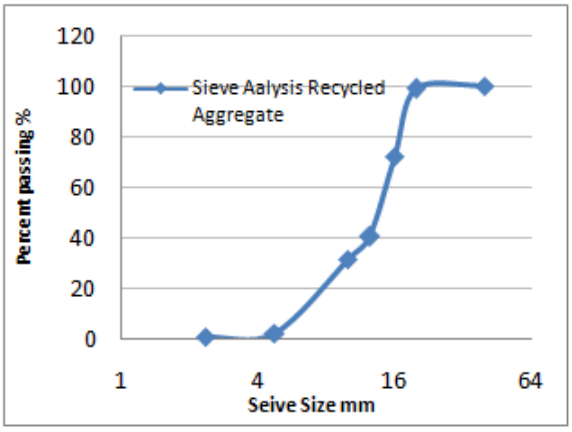
Table 1: Comparison of Properties of RCA* and NCA*

S. NO.	Properties	Recycled Coarse Aggregate	Natural Coarse Aggregate
1	Particle Size Distribution	Well Graded	Gap Graded
2	Aggregate Impact Value	23.33%	18.44%
3	Aggregate Crushing Value	29%	25.1%
4	Aggregate Abrasion Value	35.56%	30.2%
5	Flakiness Index	5.84%	15.41%
6	Elongation Index	19.08%	24.4%
7	Specific Gravity	2.29	2.81
8	Water Absorption	4.25%	0.25%

*RCA: Recycled Coarse Aggregate

**NCA: NaturalCoarse Aggregate

Based on Table 1, it can be inferred that the recycled coarse aggregate are reduced to various sizes duringthe process of crushing and sieving, which gives RCA a better particle size distribution as compared to natural coarse aggregates. 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.



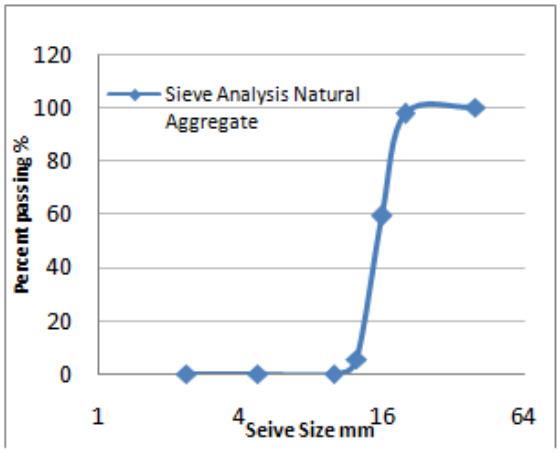


Figure 1: Sieve Analysis for Recycled Aggregate Figure 2: Sieve Analysis for Natural Aggregate.

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 is18.5% .Thus Recycled aggregate is satisfactory for road surfacing while as Natural Coarse Aggregate is exceptionally strong.

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 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.

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.

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 duefact 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.

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.

2. 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, Table 4, Table 5 and Table 6.

The Mix proportion for $1m^3$ of concrete is tabulated in table 2:

Table 2: 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

A. 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 consistometer test. The experiments were conducted at varying water-cement ratio of 0.45, 0.50 and 0.55. The results for the tests conducted are tabulated as follows:

Table 3: Comparison of slump of Recycle aggregate concrete (RAC) and Natural Aggregate concrete (NAC)

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

The slump is taken for each mixing of concrete at water-cement ratio of 0.45,0.50 and 0.55 .The results 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.

Table 4: Comparison of Compaction Factor of Recycle aggregate concrete (RAC) and Natural Aggregate concrete (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

The compaction factor test for both Recycled aggregate concrete and Natural aggregate concrete shows 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.

Table 5: Comparison of Compaction Factor of Recycle aggregate concrete (RAC) and Natural Aggregate concrete (NAC)

Water-cement ratio	Vee-Bee time (seconds)	
	NAC	**RAC**
0.45	13.9	38
0.50	5.0	35
0.55	2.5	10

This test measures the relative effort required to change mass of concrete from one definite shape to another. While comparing the Vee-Bee time of concrete made 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

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.

B. Test 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. On the basis of test results it can inferred that the strength of concrete depends on water-cement ratio taken. The 28 days strength of RAC and NAC are comparable. 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. Whileas 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.

Table 6: Comparison of Compressive Strength of Recycle aggregate concrete (RAC) and Natural Aggregate concrete (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

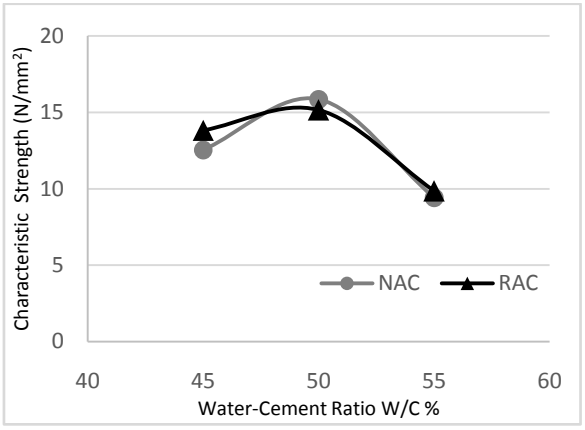


Figure 3: Characteristic strength (MPa) at 7 days

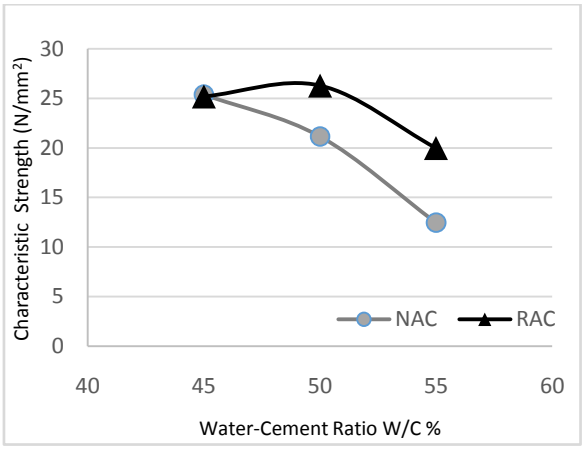


Figure 4: Characteristic strength (MPa) at 28 days

The weights of various cubes were also taken during the course of experimentation and their results are summarized in table 7.

Table 7: 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

From the table 6, 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.

V. SUMMARY OF FINDINGS

a. The recycled aggregate showed a well graded graph as opposed to natural aggregate which showed a gap graded graph.

b. Recycled Aggregates are found to have lower value for specific gravity, high water absorption and are slightly weak against crushing, degradation and disintegration thus making it satisfactory for road surfacing and low concrete works such as Plain Cement Concrete, Dry lean Concrete etc.

c. It is found that recycled coarse aggregate consists of rounded and angular shaped particles in greater percentage as compared to natural coarse aggregate.

d. The workability of recycled aggregate concrete was found to be less than natural concrete aggregate due to high water absorption of recycled coarse aggregate. However the values are within the permissible limits as per IS code.

e. The compressive strength of Natural aggregate concrete was comparable to that of Recycled aggregate concrete.

f. The compressive strength of concrete at different water-cement ratio of 0.45, 0.5 and 0.55 were determined,

however, the maximum strength of RACwas obtained at water-cement ratio of 0.50 while the same was obtained at water-cement ratio of 0.45 in case of NAC.

VI. 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 RCAat three different percentages of water-cement ratio (0.45, 0.50 and 0.55) the following conclusion are made.

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 steps towards sustainable development in concrete production.

VII. 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.

VIII. ACKNOWLEDGEMENT

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