EFFECT OF BENEFICIATED RECYCLED CONCRETE AGGREGATES ON PROPERTIES OF NEW CONCRETE

Amad Ur Rehman Bohroo[1], Mandeep Kaur[1], Kanish Kapoor[2], R L Riyar[2]

1. Lovely Professional University, Phagwara, India
2. Dr B R Ambedkar National Institute of Technology Jalandhar, India

ABSTRACT. Construction industry is a huge industry which is growing at a faster rate and that leads to the consumption of plenty of natural aggregates which puts the non-renewable natural resources in danger of extinction. Apart from the materials like plastic, glass, etc. which researchers have already substituted in concrete in place of natural aggregates, recycled concrete aggregates produced from construction and demolition waste can also be a suitable alternate but the use of recycled concrete aggregates is not much as it decreases the strength of concrete because of the adhered mortar present in the recycled concrete aggregates. The usage of recycled concrete aggregates can be increased if these are treated before using in the concrete. This paper focusses on the replacement of natural coarse aggregates with beneficiated coarse recycled concrete aggregates. In this study, the beneficiation of recycled concrete aggregates in hydrochloric acid was done before these are used in concrete. The concrete was then tested for Strength and durability. The results suggest that the beneficiation process improves the strength and durability of new concrete.

Keywords: Beneficiation, Durability, Hydrochloric Acid, Recycled Concrete Aggregates, Strength

Amad Ur Rehman Bohroo is a Post Graduate Scholar in School of Civil Engineering, Lovely Professional University, Phagwara, India.

Mrs Mandeep Kaur is an Assistant Professor and Deputy Dean in School of Civil Engineering, Lovely Professional University, Phagwara, India.

Dr Kanish Kapoor is an Assistant Professor of Civil Engineering at Dr B R Ambedkar National Institute of Technology Jalandhar, India. His research interests Concrete Composites, High Performance Concrete, Self Compacting Concrete, Pervious Concrete, Use of Recycled Materials in Concrete.

Ram Lal Riyar is a Post Graduate Scholar at Dr B R Ambedkar National Institute of Technology Jalandhar, India.

INTRODUCTION

Concrete can be described as a material which is made up of coarse aggregate and fine aggregate mixed together with cement, water and admixture. consumption of construction materials such as sand, gravel, and crushed rock by the concrete industry amounts a million tons every year. Due to high demand for construction activities in recent years in all over the world, the Natural Aggregates (NA) resources are remarkably waning day by day. On the other hand, millions of tons of construction and demolition (C&D) residues are generated. The amounts of C&D waste going to landfill sites cause significant damage to the environment. It also develops serious problems with denting the public and the environmentalists' aspirations for a waste-free society. Utilization of waste materials was not done by the civil engineering construction industry in earlier years and hence formation of larger landfills was inevitable.

Recently, effective uses of Recycled Concrete Aggregate (RCA) in concrete industry have attracted a lot of attention resource preservations. Therefore, the use of RCA obtained from construction and demolition waste in new concrete is a solution for effective waste utilization, but the use of recycled coarse aggregate directly does not give the safe result in terms of durability properties and compressive strength because it contains two additional components: adhered mortar and an Interfacial Transition Zone (ITZ) between the NA and the original cement mortar. As the original cement mortar attached on NA is more porous than NA. RCA have higher porosity and water absorption, and lower strength compared with NA.

For concrete made with 100% RA, the compressive strength and modulus of elasticity of RAC was reportedly decreased at different percentages. For instance, Bairagi and Kishore (1993) reported 40% reduction in compressive strength, Ravindrarajah et al. (2000) measured a 9% decrease, and Amnon (2003) reported 25% reduction. Several other researchers (Tavakoli and Soroushian 1996; Sagoe et al. 2001) have reported that the tensile strength of RAC is similar or usually better than that of NAC, which is contradictory to the results of compressive strength and modulus of elasticity. Ajdukiewicz and Kilszczewicz (2002) found that the difference between tensile strength of RAC and reference concrete at 28 days was less than 10%.

So, it has must to improve the properties of RCA for replacing it with NA. To enhance the properties of RCA, adhered mortar has to be removed or strengthened. Removing and strengthening the adhered mortar are the two common methods for improving the properties of RCA. The process of removal of adhered mortar or strengthen of adhered mortar is called beneficiation of RCA. However, more care must be taken about the physical and chemical characteristics of the recycled aggregate and hence it can be used to produce recycled aggregate concrete (RAC) by minimizing environmental problems and optimizing the cost without compromising the quality.

The current study aimed to evaluate the properties of recycled aggregate concrete made with beneficiated recycled aggregates. This study was also intended to determine the optimum percentage up to which treated RCA can be used as replacement and to check the optimum molarity of the acid used to beneficiate RCA.

Research significance

Concrete is the most widely used construction material in the world with annual consumption estimated between 21 and 31 billion tons (Sabnis, 2012). Concrete is used more than any other man-made material (Lomborg, 2001) and is the second largest material consumed by mankind after food and water (Adegbola and Dada, 2012). Production of concrete requires a host of material resources in terms of cement, sand and aggregates. Most of these materials used in concrete are naturally occurring and due to their extensive use are becoming scarce. River sand sources are fast depleting and the quantity of sand required is falling short of demand. It is well known fact that even aggregates are depleting and an alternative resource needs to be recognized and tried. The Countries who have faced with issues pertaining to shortage of supply of raw materials have already switched on to recycling for meeting their requirement. As a large proportion of this requirement can be supplemented by using the demolished material, nevertheless this secondary material needs to be assessed before being used in making of second generation concrete. This work tests such demolished material as an alternative material to be used in concrete by recycling thus saving onto the natural resources and also satisfying the social and environmental objective.

EXPERIMENT PROGRAM

Preparation of Specimen

According to IS: 10262-2009, the concrete mix of M30 was made. Total numbers of mixes were seven that were cast in seven batches. The cement employed in this study was ordinary Portland cement (OPC) with a grade 43. The fine aggregate was natural river sand. For comparison, both NA and RCA were used in this study. NA used in this study was crushed rock from 4.75 to 20 mm. The chemical treatment technique is adopted in order to improve the quality of RCA. The recycled aggregates were presoaked in an acidic environment at room temperature for 24 h and then washed with water to remove the acidic solvents afterward. These chemically treated aggregate is named as Beneficiated Recycled Coarse Aggregate (BRCA).

Table 1 Materials used

S NO.	MATERIAL	TYPE
1.	Cement	OPC 43
2.	Fine Aggregates	Standard Sand
3.	Coarse Aggregates	Crushed rocks
4.	RCA	Crushed waste cube specimens from Ready Mix plant Jalandhar
5.	Acid	Hydrochloric acid
6.	Water	Tap Water

Table 2 Test Results for Cement (OPC 43)

S NO.	PROPERTIES		VALUES OBTAINED	PERMISSIBLE VALUES	STANDARD REFERENCE
1.	Fineness		2%	Less than or equal to 10%	IS: 4031-1998(Part-1)
2.	Standard Consistency		31%	26%- 33%	IS: 4031-1998(Part-4)
3.	Specific Gravity		3.156	3.12- 3.19	IS: 4031-1998(Part-3)
4.	Initial Setting time		45 min 5 sec	Not less than 30 minutes	IS: 4031-1998(Part-5)
5.	Final Setting time		8 h 35 min	Not more than 10 hours	IS: 4031-1998(Part-5)
6.	Compressive Strength	3 days curing	27 MPa	Not less than 23 MPa	IS: 4031-1998(Part-6)
		7 days curing	39 MPa	Not less than 33 MPa	

Table 3 Test Results for Fine Aggregates

S NO.	PROPERTIES	VALUES OBTAINED	PERMISSIBLE VALUES	STANDARD REFERENCE
1.	Specific Gravity	2.578	2.4- 3.0	IS: 2386-1963(Part-3)
2.	Water Absorption	2.11%	Less than 5%	IS: 2386-1963(Part-3)
3.	Zone	II		IS: 2386-1963(Part-1)
4.	Fineness Modulus	2.88	2 - 4	IS: 2386-1963(Part-1)

Table 4 Test Results for Coarse Aggregates

S NO.	PROPERTIES	VALUES OBTAINED	PERMISSIBLE VALUES	STANDARD REFERENCE
1.	Specific Gravity	2.68	2.6- 2.8	IS: 2386-1963 (Part-3)
2.	Water Absorption	1.3%	0.1- 2%	IS: 2386-1963 (Part-3)
3.	Flakiness Index	17%	Less than 35%	IS: 2386-1963 (Part-1)
4.	Elongation Index	11%		IS: 2386-1963 (Part-1)

Table 5- Test Results for Recycled Concrete Aggregates

S NO.	PROPERTIES	VALUES OBTAINED
1.	Specific Gravity	2.7125
2.	Water Absorption	2.18 %
3.	Flakiness Index	16.71 %
4.	Elongation Index	18.91 %

Table 6- Mix proportions of all the mixes

MIX CODE	WATER (kg/m^3)	OPC (kg/m^3)	FA (kg/m^3)	NA (kg/m^3)	RCA (kg/m^3)	BRCA [0.1] (kg/m^3)	BRCA [0.5] (kg/m^3)
C-N100	191	456	610	1126	0	0	0
C-N50R50	191	456	610	563	563	0	0
C-N0R100	191	456	610	0	1126	0	0
C-N50B50[0.1]	191	456	610	563	0	563	0
C-N0B100[0.1]	191	456	610	0	0	1126	0
C-N50B50[0.5]	191	456	610	563	0	0	563
C-N0B100[0.5]	191	456	610	0	0	0	1126

Test Methods

Compressive strength

Cube samples of size 150mm×150mm×150mm were made for compressive strength test and were conducted under compressive test machine in accordance with IS 516-1959 after curing periods of 7, 28, 56 and 90 days for all the mixes.

Split Tensile Strength

Cylinder samples of size 300mm×150mm were cast for split tensile strength test and were conducted under testing machine in accordance with IS 5816-1999 after curing periods of 7, 28, 56 and 90 days for all the mixes.

Acid Resistance

Cube samples of size 150mm×150mm×150mm were made for Acid resistance test and were tested after curing periods of 28 and 56 days for all the mixes. Cube specimens of different concrete mixes were immersed 5% acid solution of HCL in distilled water for 28 days. Specimens were taken out after 28 days, weighed and tested for compressive strength.

RESULTS AND DISCUSSIONS

Compressive Strength Test Results

The results showed that there was a general decrease in the compressive strength of concrete with partial as well as full replacement of NA with RCA in comparison to control mix at all curing periods.

Table 7 Compressive strength test results of concrete

MIXES	7 DAYS (MPA)	28 DAYS (MPA)	56 DAYS (MPA)	90 DAYS (MPA)
C-N100	27.55	36.16	39.18	41.33
C-N50R50	25.78	34.31	36.22	38.02
C-N0R100	19.90	26.74	28.30	28.39
C-N50B50[0.1]	30.06	38.49	41.55	42.61
C-N0B100[0.1]	25.09	28.67	34.89	36.50
C-N50B50[0.5]	26.33	43.26	43.93	44.65
C-N0B100[0.5]	26.44	36.93	37.33	38.71

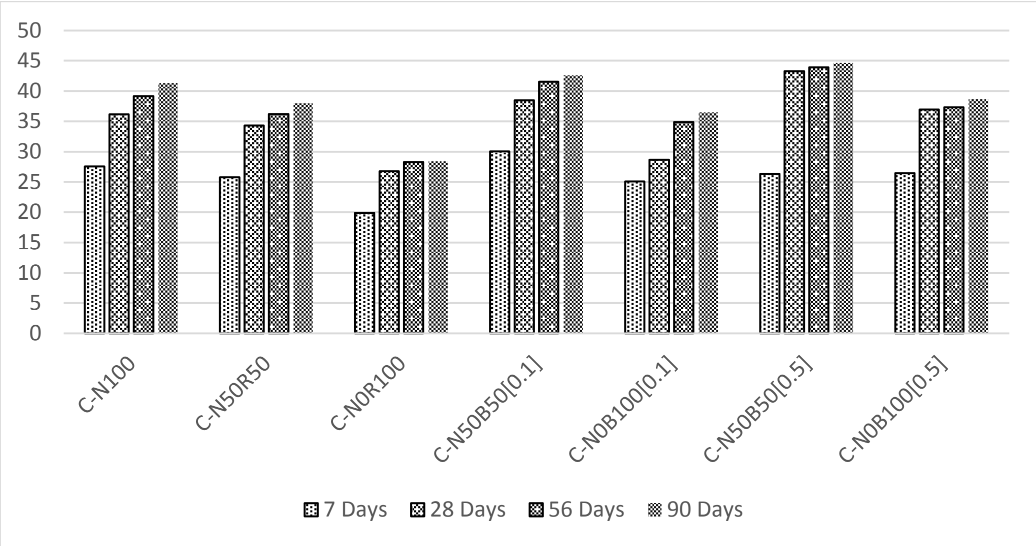

Figure 1 Comparison of compressive strength for all mixes

The results show that the strength for the mixes with the NA replaced with BRCA is better than the mixes with NA replaced with RCA. This is because of the removal of adhered mortar from RCA by the process of beneficiation. Line graph (*Figure1*) also indicates the same. It is observed that the concrete mix which gives overall good results for compressive strength is C-N50B50[0.5].

Split Tensile Strength Test Results

The results showed that there was a general decrease in the split tensile strength of concrete with partial as well as full replacement of NA with RCA compared to control mix at all curing periods.

Table 8- Split tensile strength test results of concrete

MIXES	7 DAYS (MPA)	28 DAYS (MPA)	56 DAYS (MPA)	90 DAYS (MPA)
C-N100	2.58	2.85	3.42	3.79
C-N50R50	1.94	2.29	2.76	2.79
C-N0R100	1.48	1.93	2.03	2.10
C-N50B50[0.1]	2.03	2.88	2.90	3.14
C-N0B100[0.1]	1.50	1.90	2.17	2.44
C-N50B50[0.5]	1.57	1.66	3.04	3.37
C-N0B100[0.5]	1.64	1.93	2.71	2.90

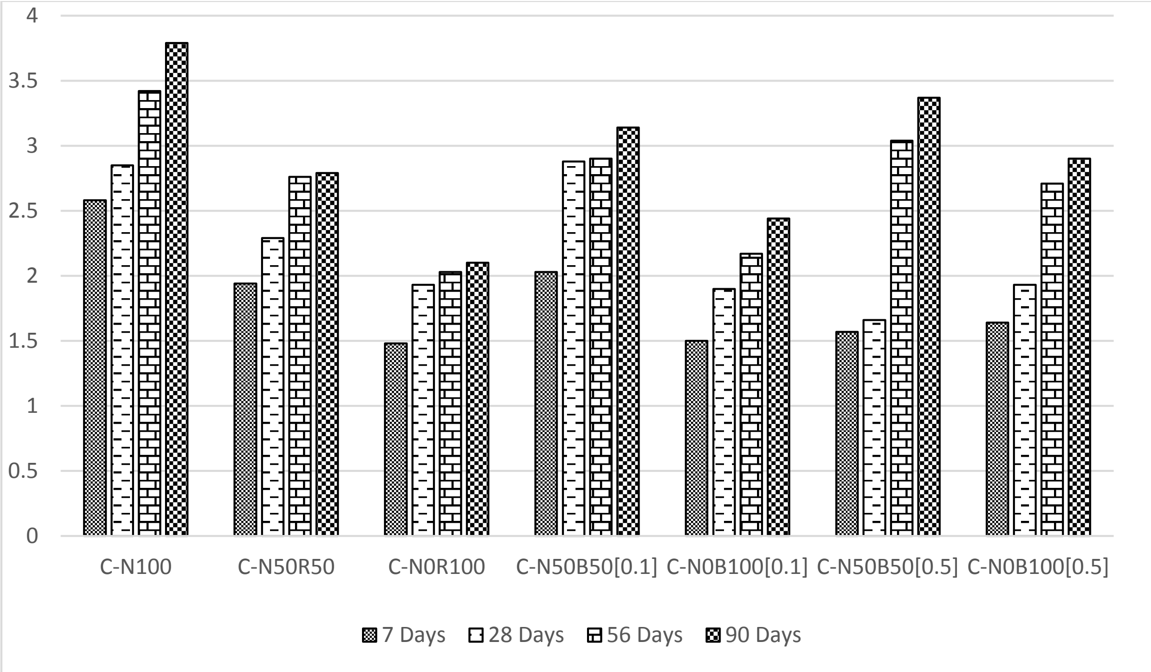

Figure 2 Comparison of split tensile strength for all mixes

The reduction in split tensile strength for concrete mix with full replacement of NA with BRCA[0.5] observed was 36.4%, 32.3%, 20.8% and 21.6% for concrete mix C-N0B100[0.5] in comparison to the control mix C-N100 for curing periods of 7, 28, 56 and 90 days, respectively. The reduction in strength for mixes C-N50B50[0.5] and C-N0B100[0.5] is there which can be due to the presence of remaining adhered mortar present in RCA. The compressive strength test results for mix C-N50B50[0.5] is more. The more the compressive strength of the concrete the more brittle concrete is and hence the split tensile strength is less. Also, the split tensile strength of C-N0B100[0.5] is less than C-N50B50[0.5] which should be the other way around as per compressive strength results. The reason for this trend can be the remaining adhered mortar in the BRCA.

Acid Resistance Test Results

Table 9- Percentage loss in compressive strength due to acid attack

Mixes	Loss in Compressive strength (%)	
	28 Days Average Values (%)	56 Days Average Values (%)
C-N100	8.91	8.18
C-N50R50	16.19	15.23
C-N0R100	24.42	17.50
C-N50B50[0.1]	6.31	5.97
C-N0B100[0.1]	12.41	7.58
C-N50B50[0.5]	4.91	2.18
C-N0B100[0.5]	9.31	7.19

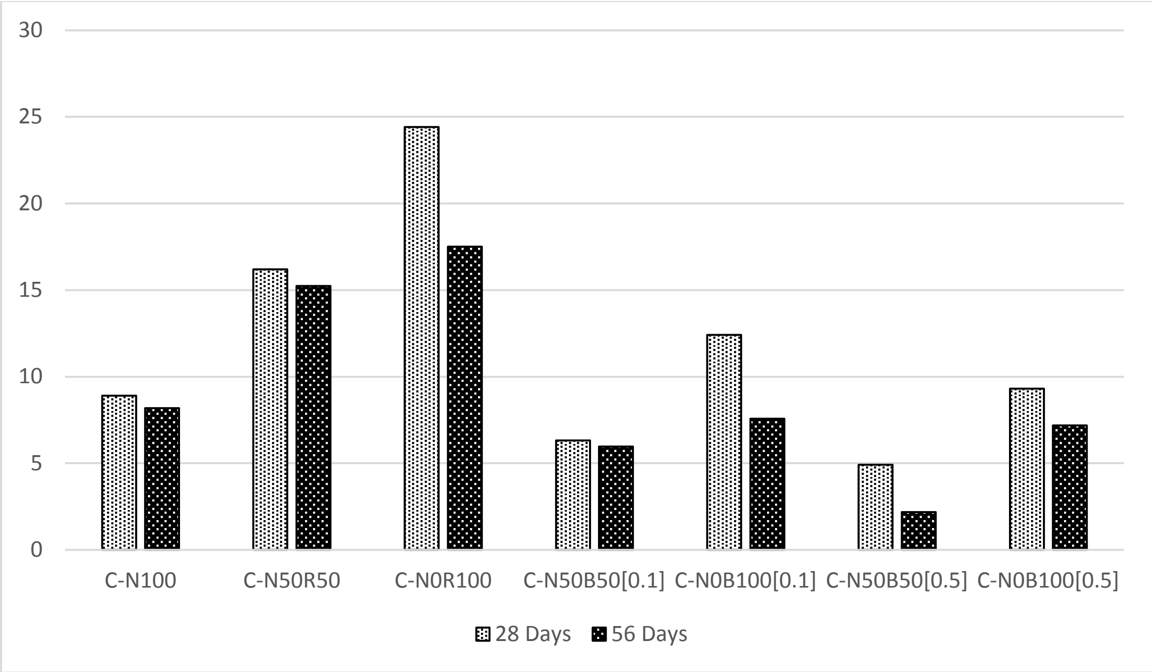

Figure 3 Loss in compressive strength due to acid attack for all mixes for curing periods of 28 and 56 days

The results show that there is a loss of compressive strength when it is subjected to acid attack. The loss is significant when NCA is replaced with RCA partially or completely. The loss in compressive strength is 16.19% and 15.23% with 50% replacement of NCA with RCA for 28 and 56 days respectively. This loss becomes more significant, 24.42% and 17.50% for 28 and 56 days respectively, with the 100% replacement of NCA with RCA. The loss of strength may be because of the porosity of the recycled aggregate concrete which allowed the acid solution to permeate through pores and react with calcium hydroxide crystals present in the mix.

CONCLUSIONS

The percentage removal of mortar content of RCA increases with the increase in the molarity of acid. The percentage removal of mortar content also increase with increase in the duration of soaking. The rate at which the adhered mortar is removed from RCA decreases with the duration of soaking. The impact value of RCA beneficiated with 0.7 M HCL crosses 20% which makes it unsuitable for structural concrete. So, among the chosen molarities the maximum molarity with suitable impact value for treated RCA is 0.5M (I day).

Compared to the control mix (C-N100) made with NCA, the mixes which were made with RCA showed decrease in compressive strength. The mixes which were made with BRCA showed improvement over the mixes made with RCA. Among the mixes in which NCA was replaced with treated RCA (BRCA), C-N50B50[0.5] and C-N50B50[0.1] showed better results and the compressive strength was more than Control mix.

In comparison to control mix (C-N100), every mix showed a decrease in the tensile strength but the concrete mixes made with partial replacement of treated RCA showed better results.

REFERENCES

1. BAIRAGI, N. K., AND KISHORE, R., Behaviour of concrete with different proportions of natural and recycled aggregates.” Resour. Conserv. Recycl., 1993, 9(1–2), pp109–126.
2. RAVINDRARAJAH, R. S., STEWARD, M., AND GRECO, D., Variability of recycled concrete aggregate and its effect on concrete properties: A case study in Australia. 2000.
3. SARAVANAKUMAR, P., AND DHINAKARAN, G., Strength and durability characteristics of recycled aggregate concrete. Int. Conf. on Sustainability Challenges & Advances in Concrete Technology (SCACT 2012), Dept. of Civil Engineering, PSG College of Technology, Coimbatore, Tamilnadu, India, 2012, pp 197–202.
4. TAVAKOLI, M., AND SOROUSHIAN, P., Strengths of recycled aggregate concrete using field-demolished concrete as aggregate. ACI Mater. J., 1996, 93(2), pp178–181.
5. AJDUKIEWICZ, A., AND KLISZCZEWICZ, A., Influence of recycled aggregates on mechanical properties of HS/HPC. Cem. Concr. Compos., 2002, 24(2), pp 269–279.
6. RAHAL, K., Mechanical properties of concrete with recycled coarse aggregate. Build. Environ., 2009, 42(1), pp407–415.
7. SARAVANAKUMAR, P., AND DHINAKARAN, G, Strength and durability characteristics of recycled aggregate concrete. Int. Conf. on Sustainability Challenges & Advances in Concrete Technology (SCACT 2012), Dept. of Civil Engineering, PSG College of Technology, Coimbatore, Tamilnadu, India, 2012, pp197–202.
8. PADMINI, A. K., RAMAMURTHY, K., AND MATHEWS, M. S., Influence of parent concrete on the properties of recycled aggregate concrete. Constr. Build. Mater., 2009, 23(2), pp829–836.
9. RAO, M. C., BHATTACHARYYA, S. K., AND BARAI, S. V., Influence of field recycled coarse aggregate on properties of concrete.” Mater. Struct., 2011, 44(1), pp 205–220.
10. KHAITAN, C. K. Construction and demolition waste; Regulatory issues and initiatives of MoUD. Proc., Workshop on C&D Waste Recycling, Organized by Indian Concrete Institute-Central Public Works Dept., New Delhi, India, 2013, pp 20–23.
11. POON, C. S., SHUI, Z. H., AND LAM, L. Effect of microstructure of ITZ on compressive strength of concrete prepared with recycled aggregates. Constr. Build. Mater., 2004, 18(6), pp 461–468.
12. S.F.U. AHMED, Properties of concrete containing recycled fine aggregate and fly ash, J. Solid Waste Technol. Manage. 2014, 40 (1), pp 70–78.
13. R.V. SILVA, J. DE BRITO, R.K. DHIR, Performance of cementitious renderings and masonry mortars containing recycled aggregates from construction and demolition wastes, Constr Build Mater. 2016, 105, pp 400–415.
14. R.V. SILVA, J. DE BRITO, R.K. DHIR, Availability and processing of recycled aggregates within the construction and demolition supply chain: a review, J. Clean. Prod. 2017, 143, pp 598–614.