

Evaluation of the Feasibility of Recycled Concrete Aggregate for Producing Structural Concrete

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Abstract. When sustainability has become a primary measure of the selection of the building materials in the construction industry over the past decades, researchers all around the world have been looking upon for alternatives to reduce the overall environmental impact of the construction materials while not compromising the strength and durability. The factors like manufacturing, reusability, recyclability, disposal etc, are the criteria of utmost attention affecting the overall life cycle impact of the construction materials. In this prospect the Recycled Concrete Aggregate (RCA) has shown up as an exceptionally viable contender for the manufacturing of concrete with several environmental benefits over the Natural Aggregate (NA) and has already been identified by industry and several government agencies across the globe. The efficient material use of RCA can potentially deliver an inferior though competent concrete in comparison to the NA while averring the criteria of sustenance. The present study delves into the calculation of the proportion of the RCA in a mix design for achieving maximum compressive strength. The experimental setup constituted the casting of concrete cubes of control mix design of M40 grade with proportions of RCA varying from 0-100 percent spread over a space of 10% with NA which were later put to tests. The thorough investigation on the casted concrete cubes lead to the conclusion that the mix design with 50% proportion of RCA in addition to 50% proportion of NA delivered the maximum compressive strength, an average value of 8.23% higher than that of the normal concrete and the highest Rebound Number, an average value of 53.92 for the M40 grade concrete thereby showcasing the feasibility of producing structural concrete with RCA. The results are asserted to be governed by the better bonding between the RCA and NA and due to the significant increase in the water retention capacity by the provision of RCA in the mix.

1 Introduction

As we know today's world is facing major environmental problems i.e. global warming, ozone layer depletion, waste accumulation, etc. Over the last few decades the research indicates that the global climate is changing rapidly (IPCC, 2001) and also un-reveals the fact that this change will continue with time (Morgan, 2004). The increase in emissions from the building sector worldwide is estimated to rise from 8.6 gigatons of carbon dioxide (GtCO₂) in 2004 to 14.3 GtCO₂ by 2030 (Y. Hossain & Marsik, 2019). The building sector is responsible for over 40% of overall energy consumption, making a significant contribution to CO₂ emissions (Ardente et al., 2008; Zabalza Bribián et al., 2009) (D, 1999; United Nation Environment Programme, 2007) and the percentage can be as high as 70% for developing countries such as China (Hu et al., 2012). The exploitation of natural resources, in particular non-renewable resources, for

the construction purpose lead to generation of millions of tonnes of construction and demolition wastes (CDW) every year. The Environmental Protection

Agency of the United States estimated the generation of debris, from the construction, demolition, and renovation of residential and non-residential buildings close to 170 million tonnes in 2003. According to Eurostat, the total amount of waste generated in the European Union in 2010 was over 2.5 billion tonnes, of which almost 35% (860 million tonnes) was derived from construction and demolition activities and 27% (672 million tonnes) belonged to mining and quarrying operations. Without any specific processing plan for these materials, this waste is sent to landfills instead of being reused and recycled in new construction (Silva et al., 2014). The social, economic and environmental indicators of sustainable development are drawing attention to the construction industry, which is a globally emerging sector, and a highly active industry in both developed and developing countries (Ortiz-rodriguez et al., 2009).

To create a deeper sense of the amount of environmental impact that is linked with the usage of building materials a review has been presented in **Ошибка! Источник ссылки не найден.**, whereby a number of commonly used building material elements have been analyzed for the Embodied Energy and

Table 1. Embodied Energy and Embodied Carbon of typical construction materials-Comparative Data based on LCA (Christoforou et al., 2016).

Assembly/Material	Ref	Embodied energy	Unit	Embodied carbon	Unit	Info.
Adobe Brick	(Christoforou et al., 2015)	0.033	MJ/kg	1.76E-3	kgCO ₂ e/kg	Cradle-to-site, On-site production, use of straw as fibre material
Adobe Brick	(Christoforou et al., 2015)	0.078	MJ/kg	5.41E-3	kgCO ₂ e/kg	Cradle-to-site, On-site production, use of straw as fibre material
Adobe Brick	(Christoforou et al., 2015)	0.170	MJ/kg	1.29E-2	kgCO ₂ e/kg	Cradle-to-site, Off-site production, use of straw as fibre material
Adobe Brick	(Christoforou et al., 2015)	0.033	MJ/kg	1.70E-3	kgCO ₂ e/kg	Cradle-to-site, On-site production, use of sawdust as fibre material
Adobe Brick	(Christoforou et al., 2015)	0.077	MJ/kg	5.30E-3	kgCO ₂ e/kg	Cradle-to-site, On-site production, use of sawdust as fibre material
Adobe Brick	(Christoforou et al., 2015)	0.169	MJ/kg	1.28E-2	kgCO ₂ e/kg	Cradle-to-site, Off-site production, use of sawdust as fibre material
Common Brick	(Hammond & Jones, 2011)	3.0 6.9	MJ/kg MJ/brick	0.24 0.55	kgCO ₂ e/kg kgCO ₂ e/brick	Cradle-to-gate Cradle-to-gate
Ceramic Brick	(Andrew Alcorn, 2001)	2.7 5310	MJ/kg MJ/m ³	-	-	
Concrete Block	(Andrew Alcorn, 2001)	0.9 12.5	MJ/kg MJ/block	-	-	
Fired Clay Brick	(Venkatarama Reddy & Jagadish, 2003)	4.25	MJ/brick	-	-	
Fired Clay Brick	(Cabeza et al., 2013)	2.0-3.4	GJ/m ³	-	-	
Fired Clay Brick	(Praseeda et al., 2015)	1.2-4.05	MJ/kg	-	-	Fired clay bricks (i.e. table moulded, wire cut, country brick)
Stabilized Rammed Earth Wall	(Cabeza et al., 2013)	0.45-0.60	GJ/m ³	-	-	
Hollow Concrete Block	(Venkatarama Reddy & Jagadish, 2003)	1.32-1.62	MJ/block			7-10% cement

Embodied Carbon content based on LCA assessment. This impact can however be reduced by the help of reusable construction with a low demand for primary resources. Reusable blocks with recycled brick aggregate, reusable blocks with recycled aggregates (RA), reusable blocks with natural aggregate (NA), and regular concrete wall have great potential in reducing the overall construction and demolition impact (Pešta et al., 2020; Vázquez & RILEM Technical Committee 217-PRE, 2013). A study (M. U. Hossain et al., 2016) revealed that the use of coarse recycled aggregates obtained from the CDW in Hong Kong reduced the greenhouse gases footprints up to 65% and saved up to 58% of the energy consumption. To encourage and promote the use of RA, government agencies the world over have often introduced levies and legislation in an attempt to overcome barriers, with varying degrees of success. The European Union Directive No. 2008/98/CE (Council, 2008) encourages the reuse and recycling of waste materials.

1.1 Recycled Concrete Aggregate (RCA)

There is a reuse market for RA derived from CDW in landscaping, road construction (unbound sub-base and base layers, hydraulically bound layers, bituminous surface pavements), cementitious mortars and concrete (Hansen, 1992). The application of RCA derived from CDW, as shown in **Ошибка! Источник ссылки не найден.** and **Ошибка! Источник ссылки не найден.**, in the construction work has become a subject of priority throughout many places especially in USA and several EU countries. Critical studies are being made to understand the characteristics of RCA to encourage the optimum and wide use of this potent sustainable option as an economic concrete ingredient and as one of the solutions in preserving the environment. Generally, the obstacles to using recycled aggregate concrete (RAC) for realistic structures are lower mechanical and durability properties in comparison with that of natural

aggregate concrete (NAC) (Bui et al., 2018; Dimitriou et al., 2018; McGinnis et al., 2017). The use of 100% RCA for replacing natural coarse aggregates in new concrete, unless carefully managed and controlled, is likely to have a negative influence on most concrete properties due to the presence of adhered old cement mortar on the surface of RCA, which could contain a significant amount of fully hydrated cement paste leading to its lower density, higher porosity, higher water absorption, lower strength and lower abrasion resistance (Bui et al., 2018; Silva et al., 2014; Xuan et al., 2016; Zhan et al., 2019). The adhered and loose mortars contribute to the angularity, rough surface texture and high absorption of fine RCA particles (Evangelista & de Brito, 2014).

RCA also contain more micro-cracks caused by the crushing process, and more interfacial transition zones (ITZs) in the matrix between the old cement mortar and the virgin aggregate in RCA (Kong et al., 2010; Kou et al., 2011; Lotfi et al., 2014; Poon et al., 2004; Tam & Tam, 2008).

Many studies have reported that the strength development rate of RCA concrete is higher than that of NA, especially at the later age (e.g. 28 days) due to the remnant of non-hydrated old cement adhered on the surfaces of RCA particles which react with water (Evangelista & de Brito, 2007; Gesoglu et al., 2015; Kurad et al., 2017; Poon et al., 2004). It has been reported that the influence of RCA replacement level on concrete compressive strength is significantly influenced by the initial moisture condition of RCA. Previous studies have reported a significant increase in water permeability, sorptivity and water absorption capacity for the concrete when over 50% of NA was replaced by RCA (Alexandridou et al., 2018; Zaharieva et al., 2003). Depending on the moisture level the compressive strength can be reduced by up to 30% or increase up to 20% for 100% aggregate replaced by RCA. In their study (Etzeberria et al., 2007) reported that the use of 100% recycled coarse aggregates results in 20-25% less compression strength, 2-10% less tensile strength and 16-17% lower modulus of elasticity than conventional concrete at all ages with the same effective w/c ratio. Lowering the w/c ratio improves the compressive strength of concrete containing RCA (Beltrán et al., 2014; Gesoglu et al., 2015). Some studies have also indicated the benefits of the use of TSMA (two-stage mixing approach) in producing concrete with high compressive strength (Brand et al., 2015; Tam & Tam, 2008).

The creep of concrete containing RCA is found to be proportional to the amount of RCA as the higher amount of RCA in concrete mixture increased the degree of potential creep (Tam & Tam, 2007). In their study (Zaharieva et al., 2003) proposed the use of fine recycled aggregate to be restricted and to use extended curing using a moist environment as another way of increasing the durability of RAC. A possible use of admixtures such as fly ash or silica fume could decrease significantly porosity and permeability of RAC (Verian et al., 2018).

2 Experimental Study

2.1 Goal

The strength evaluation of concrete blocks casted using RCA as coarse aggregates is carried upon in this study to propose the suitability of usage of RCA in producing structural concrete. The study targets the comparison of compressive strength and hardness of sixty-six concrete blocks with varying concentrations of RCA and NA as coarse aggregate. This includes the comparison of test results for addressing and ascertaining the impact of adding RCA in concrete and to calculate the optimum concentration of RCA with NA to achieve substantial amount of strength for a defined grade of concrete to be put to use as structural concrete.



Fig. 1. Demolished Concrete.



Fig. 2. Dismantling of Building.

2.2 Materials

Coarse Aggregate-

- RCA- The aggregates (Ошибка! Источник ссылки не найден.) are recycled and derived after demolishing old concrete blocks of size 150 mm of varying strengths used for testing concrete in the concrete lab in Jamia Millia Islamia University, New Delhi, India, in the past and were discarded after their testing as shown in Ошибка! Источник ссылки не

Table 2. Varying proportions of RCA with NA as coarse aggregates.

S. No.	Recycled Coarse Aggregate (%)	Fresh Coarse Aggregate (%)	Designation	Total No. of Concrete Cubes
1.	0	100	S0	6
2.	10	90	S10	6
3.	20	80	S20	6
4.	30	70	S30	6
5.	40	60	S40	6
6.	50	50	S50	6
7.	60	40	S60	6
8.	70	30	S70	6
9.	80	20	S80	6
10.	90	10	S90	6
11.	100	0	S100	6

найден.. The concrete cubes were dismantled using a hammer (**Ошибка! Источник ссылки не найден.**) and the aggregates were screened and graded afterward ([Bureau of Indian Standards \(BIS\), 1963](#)).

- NA- The natural aggregates used are of fineness modulus of 7.71 ([\(BIS\), 1970](#); [Bureau of Indian Standards \(BIS\), 1963](#)) **Ошибка! Источник ссылки не найден.**



Fig. 3. Recycled Concrete Cubes.



Fig. 4. Crushing of Concrete Cubes using Hammer.



Fig. 5. Recycled Concrete Aggregate (RCA).

Fine Aggregate- Natural river sand of fineness modulus value of 2.486 ([\(BIS\), 1970](#); [Bureau of Indian Standards \(BIS\), 1963](#)) **Ошибка! Источник ссылки не найден.** is used as fine aggregate.

Binding Material- Ordinary Portland Cement (OPC) Wonder 43 grade cement ([Bureau of Indian Standard\(BIS\), 2013](#)) was selected and used as the binding material for the casting of concrete blocks. The tests conducted on cement includes normal consistency test ([IS 4031- Part IV, 1988](#)), setting time test ([IS 4031- Part V, 1988](#)) including initial and final setting time measurements and the compressive strength test of cement ([IS: 4031 \(Part 6\), 2005](#)). The results of the tests conducted have been tabulated in **Ошибка! Источник ссылки не найден.**

2.3 Experimental Setup

The present study in its intended goal involves the casting of concrete blocks (of size 150 mm) with varying percentages of RCA (as coarse aggregate) spaced over an interval of 10% from 0-100% with NA (as coarse aggregate) and fine aggregates combined together using a binding material shown in **Ошибка! Источник ссылки не найден.** The concrete mix design of M-40 grade concrete ([STANDARDS, 1982](#)) was selected and a total number of sixty-six concrete blocks were casted, six cubes for every concentration of RCA, placed in a separate designated group as shown in **Ошибка! Источник ссылки не найден.** The constituent materials put to use in the mix design were subjected to

different tests to assure the quality and strength of the concrete cubes.

After casting the concrete blocks were de-molded and half of the concrete cubes (33 cubes) were cured for duration of 28 days and the other half for duration of 90 days as shown in **Ошибка! Источник ссылки не найден.** The cubes cured for 28 days were air dried for 24 hours, shown in **Ошибка! Источник ссылки не найден.**, and at first put to Non-Destructive Test (Rebound Hammer Test) ([Indian Standards, 1992](#)) as shown in **Ошибка! Источник ссылки не найден.**, to study the behavior of RCA, added in different proportions, on the hardness of the concrete cubes. These cubes were later put to the compression strength test ([IS 456, 2000](#); [IS 516:2014, 2004](#)), as shown in **Ошибка! Источник ссылки не найден.**, to calculate the compressive strength of the blocks at 28 and 90 days of curing interval to visualize the impact of RCA on the concrete cube strength. The results have been compiled in **Ошибка! Источник ссылки не найден.** and **Ошибка! Источник ссылки не найден.** respectively for concrete cubes after curing time of 28 days and 90 days.



Fig. 6. Casting of concrete cubes of size 150 mm.



Fig. 7. Curing of concrete cubes.



Fig. 8. Rebound Hammer T.



Fig. 9. Compressive Strength Test using Compression Machine.



Fig. 10. Concrete blocks left for air drying.

3 Results & Discussion

3.1 Compressive Strength

The results obtained from compressive tests on concrete samples after curing duration of 28 days and 90 days are given in **Ошибка! Источник ссылки не найден.** and **Ошибка! Источник ссылки не найден.** These results are also depicted graphically in **Ошибка! Источник ссылки не найден.** showing a comparison of the compressive strengths after different curing time durations. These results show an incremental variation mainly from 10-50% of RCA replacement and a decrement in strength from 60-100 % of RCA replacement in the concrete matrix. As can be observed from results and as seen in **Ошибка! Источник ссылки не найден.** and **Ошибка! Источник ссылки не найден.**, the compressive strength of concrete at 28 and 90 days having 10% RCA is more than the compressive strength of M-40 grade normal concrete with a value of 0.39% and 5.28% respectively which rises up to 8.32% and 13.98% respectively for the concrete with a 50% RCA replacement. A peak average value of 52.3 MPa and 55 MPa respectively for S5 designation specimens is reached for 50% RCA. However, it was anticipated that the increase in the RCA content will eventually cause the compressive strength of the concrete cubes to fall due to the high water absorption of RA that creates a porous interfacial transition zone (ITZ). The true reason for the

Table 3. Test results of Cement mortar.

S. No.	Cement Type	Normal Consistency (%)	Initial Setting Time (min)	Final Setting Time (min)	Compressive Strength (MPa)
1.	Wonder Cement OPC 43 Grade	33	35	312	44.32

Table 4. Results of Sieve Analysis of coarse aggregates ((BIS), 1970; Bureau of Indian Standards (BIS), 1963).

S.No	Sieve Size (mm)	Weight Retained (gm)	Percentage wt. retained (%)	Cumulative percentage wt. retained	Percentage wt. passing
1.	40	0	0	0	100
2.	20	3550	71	71	29
3.	10	1450	29	100	0
4.	4.75	0	0	100	0
5.	2.36	0	0	100	0
6.	1.18	0	0	100	0
7.	0.6	0	0	100	0
8.	0.3	0	0	100	0
9.	0.15	0	0	100	0
		Total= 771		Fineness Modulus= 7.71	

Table 5. Results of Sieve Analysis of fine aggregates ((BIS), 1970; Bureau of Indian Standards (BIS), 1963).

S.No	Sieve Size (mm)	Weight Retained (gm)	Percentage wt. retained (%)	Cumulative percentage wt. retained	Percentage wt. passing
1.	10	11	0.55	0.55	99.45
2.	4.75	74	3.70	4.25	95.75
3.	2.36	80	4.00	8.25	91.75
4.	1.18	158	7.90	16.15	83.84
5.	0.6	254	12.70	28.85	71.15
6.	0.3	1234	61.70	90.55	9.45
7.	0.15	189	9.45	100.00	0
		Total= 248.60		Fineness Modulus= 2.486	

justification of this pattern of elevation of compressive strength is not yet confirm and could be attributed to a better concrete mix with lower void ratio due to a better grading of aggregates. A further research is proposed on the account of the physical and chemical properties of the virgin concrete used for recycling of aggregates.

The compressive strength of concrete having 60% RCA at 28 and 90 days is more than the compressive strength of normal concrete which was rather already predicted. The percentage increase in the strength of concrete having 60% RCA with the normal concrete at 28 and 90 days is 2.61% and 10.88% respectively. But the strength is less than 50% RCA made concrete. The fall in compressive strength continues at a varying pace for the concrete blocks with 60-100% proportion of RCA in the matrix. The compressive strength of concrete having 100% RCA comes out to be the least which is an inevitable result because of the inferior quality of the aggregates. The percentage decrease in the strength of concrete having 100% RCA with the normal concrete at 28 and 90 days comes out to be 11.85% and 0.62% respectively from **Ошибка! Источник ссылки не найден.** and **Ошибка! Источник ссылки не найден.**. The inferior concrete though has a significant compressive strength. The drop in the compressive strength is attributed to the rise in the content of the RCA with hydrated cement leading to improper mixing and bonding of aggregates with the fresh cement and fine aggregates, adding further to the voids in the concrete matrix.

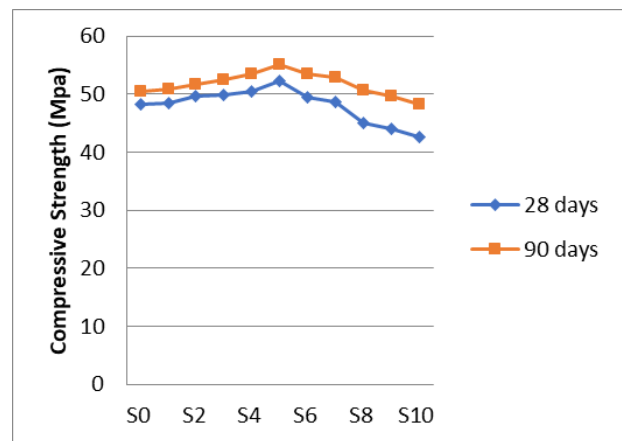


Fig. 11. Variation of compressive strength of concrete cubes with varying proportions of RCA for different curing duration.

Table 6. Results of Compressive Strength test of concrete cubes after 28 days of curing.

S.No	Sample	Cube 1	Cube 2	Cube 3	Average (KN)	Average (N/mm ²)	Percentage Variation
1.	S0	1141	1107	1010	1086	48.27	0.04
2.	S1	1090	1100	1080	1090	48.44	0.39
3.	S2	1120	1105	1130	1118.33	49.70	3.0
4.	S3	1130	1122	1110	1120.83	49.81	3.23
5.	S4	1144	1130	1125	1133.16	50.36	4.37
6.	S5	1170	1205	1155	1176.67	52.30	8.32
7.	S6	1240	1060	1042	1114	49.51	2.61
8.	S7	1173	1108	1001	1094	48.62	0.76
9.	S8	1020	1005	1010	1011.67	44.96	-6.8
10.	S9	986.3	1037	950	991.10	44.05	-8.7
11.	S10	970	960.5	940	956.83	42.53	-11.85

Table 7. Results of Compressive Strength test of concrete cubes after 90 days of curing.

S.No	Sample	Cube 1	Cube 2	Cube 3	Average (KN)	Average (N/mm ²)	Percentage Variation
1.	S0	1135	1155	1125	1138.3	50.5	4.66
2.	S1	1129	1145	1160	1144.6	50.8	5.28
3.	S2	1145	1167	1175	1162.3	51.6	6.94
4.	S3	1155	1175	1210	1180	52.4	8.60
5.	S4	1205	1210	1190	1201.6	53.4	10.67
6.	S5	1245	1220	1250	1238.3	55.0	13.98
7.	S6	1170	1195	1235	1200	53.5	10.88
8.	S7	1215	1195	1160	1190	52.8	9.43
9.	S8	1160	1175	1090	1141.6	50.7	5.07
10.	S9	1130	1090	1140	1120	49.7	3.0
11.	S10	1085	1135	1035	1085	48.22	-0.62

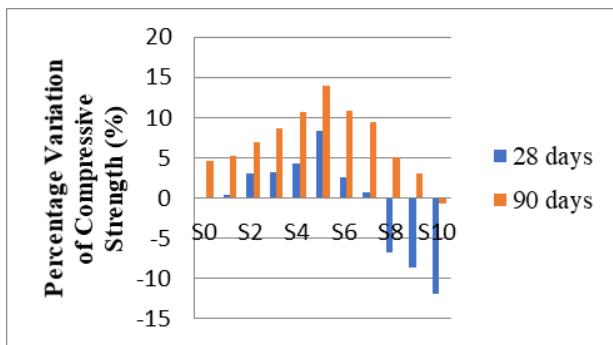


Fig. 12. Percentage variation of compressive strength of concrete cubes with varying proportions of RCA with respect to M-40 grade concrete.

3.2 Rebound Hammer Number

Result of NDT conducted on 33 concrete cube specimens of size 150 mm are given in **Ошибка! Источник ссылки не найден.** and are represented graphically in **Ошибка! Источник ссылки не найден.**. The hardness of the concrete blocks are in alignment with their compressive strength portraying a similar trend of an increase in the bond strength from 10-50% concentration of RCA, from RH number value of 47.27 extending to a peak value of 53.92 for a S5 (50% concentration of RCA) concrete group. The value drop for concrete blocks with the RCA proportions of 60-100% from 53.32 to 47.12 respectively. Rebound Hammer Test also validates the Compressive Strength Test, as the variation between rebound hammer number

(RH number) and compressive strength values in the **Ошибка! Источник ссылки не найден.** is almost less than 10% in all the cases.

Their is still no affirm reason for the dominating results and the kind of variation shown of the hardness for a 10-50% proportion of RCA mix concrete and is part of further research. However, the drop in the RH number value can be reasoned with certainty and could be attributed to the lower grade of the aggregates with high porosity and lower strength. The cement mortar adhered to the aggregates causes a poor bonding with large ITZ, altogether resulting in the decline of the bond strength of the concrete specimen.

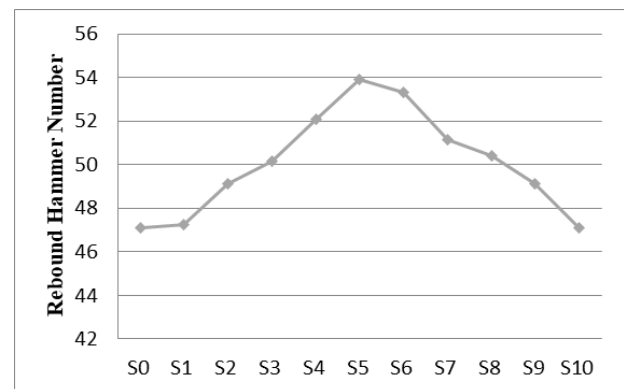


Fig. 13. Variation of Rebound Hammer Test of concrete cubes with varying proportions of RCA.

Table 8. Results of Rebound Hammer Test on concrete cubes.

Sample	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Surface 1	49.5	41.5	42.5	43.5	47	48	45	43.5	48.5	42.5	48.5
	34.5	40.5	45	44.5	51	50.5	51.5	44.5	54	45	50
	43.5	49.5	40.5	41.5	43	49.5	43	41.5	49.5	40.5	49.5
	53.5	49	49.5	43.5	63	57.5	45	43.5	50	49.5	50
	45	44.5	44	43	48	52.5	47	57	49.5	44	49.5
Surface 2	49.5	52.5	55	49	40	57	49.5	49	45.5	55	45.5
	50	49.5	53	48.5	45	56.5	50	48.5	51.5	53	48
	52	38.5	58.5	50.5	54	54	49.5	50.5	45.5	58.5	45.5
	53	49	52	50	52	60.5	49.5	50	48.5	52	48.5
	53.5	52	57.5	49.5	50	54	71	49.5	56	57.5	49
Surface 3	41	38	53.5	51.5	51	53	50	51.5	57	53.5	44
	38	48	49	49	58.5	52.5	57.5	55	48.5	49	48.5
	45	53	54	59.5	56	57.5	49	59.5	55	54	43.5
	50.5	52	54	52	56	49.5	51	52	45	54	45
	52	46.5	50	51	54.5	54.5	54	51	51.5	50	41.5
Surface 4	42	48	41.5	57	69.5	49	55	57	52.5	41.5	45
	52	54	40.5	64	59	53.5	50	64	50	40.5	50
	33	49	46.5	52.5	43	54	47	52.5	50	46.5	50
	52.5	45	49	50.5	50	55.5	63	50.5	50	49	48
	52.5	45.5	47.5	53	51.5	59.5	69	53	50	47.5	43
Average RH No.	47.125	47.275	49.15	50.175	52.1	53.925	52.325	51.175	50.4	49.15	47.125

Table 9. Variation of RH No. and Compressive Strength.

Average RH No.	47.125	47.275	49.15	50.175	52.1	53.925	52.325	51.175	50.4	49.15	47.125
Compressive Strength (28 days)	48.27	48.44	49.70	49.81	50.36	52.30	49.51	48.62	44.96	44.05	42.53
Variation (%)	2.4297	2.414	1.114	-0.723	3.334	3.0203	5.3777	4.9883	10.788	10.379	9.7593

4 Conclusions

The erudite based on the tests conducted on the concrete cubes delivers a number of qualitative and quantitative conclusions. The tests delivered unexpected results of compressive strength and hardness of the concrete manufactured via proportioning of RCA as coarse aggregate in varying quantities in the concrete matrix. The concrete blocks in the vicinity of 50% RCA did exceptionally well in the qualitative analysis marking the highest values of compressive and bond strengths (even higher than normal concrete) for M-40 grade. An increase up to more than 8% has been observed for concrete cube specimens having 50% RCA as compared to the normal concrete cube. Both the compressive strength and the hardness properties go analogous to each other showing similar characteristics for the concrete specimens. On the basis of the present study the authors were able to draw the following conclusions:

- It can be stated that the recycled aggregate concrete; for lean concrete < M-40 grade (IS 456, 2000), has a convenient compressive strength and bond strength, which means a convenient concrete for structural elements in concrete structures where the extent of desirable strength is not too high.
- By decreasing the water/cement ratio, recycled aggregate can achieve higher compressive strength

concrete. But the workability will be very low. Therefore, it is recommended to add admixtures such as super plasticizer and silica fume, etc, into the mix.

- Selective demolition should be promoted and enacted whenever possible. This is an absolute necessity for obtaining RA with minimum level of contamination, thereby adding value to the RCA produced for its use in construction.

Old concrete and RA composition seem to play an important role on the recycled concrete's performance, though a limited chemical and mineralogical characterization of RA is available (Alexandridou et al., 2018; Limbachiya et al., 2007). The physical and chemical properties of the RCA like void ratio, hardness, strength, etc, are affected by the grade of the concrete of origin and upon the methods and level of screening and grading. To employ RCA as fine and coarse aggregates in the concrete mix design demands the determining and standardizing of the best practices for RCA and a controlled citation of these properties to address the strength requirements. The variability of building construction methods naturally means that RA sourced from construction and demolition activities will vary in quality and composition, which will indubitably produce new construction materials of varying quality (Silva et al., 2014).

5 Scopes for Future Research

While the present study has shown that recycled concrete aggregate can be used as aggregate for new concrete, there is a need to obtain long-term in-service performance and life cycle cost data for concrete made with recycled aggregate concrete to assess its durability and performance. If additional research supports the use of concrete buildings then existing specification should be revised to permit and encourage the use of recycled concrete as aggregate. Using recycled aggregate in concrete mixes lead to conserve existing supplies of natural aggregates and to reduce the amount of solid waste that must be disposed of in landfills. Further testing and studies on the recycled aggregate concrete is highly recommended to indicate the strength characteristics of recycled aggregates for application in high strength concrete. Below are some of the recommendations for further studies:

- More investigations and laboratory tests are required to understand the strength characteristics of recycled aggregate. It is recommended that testing can be done on concrete slabs, beams and walls. Some mechanical properties such as creeping, shrinkage and abrasion are also recommended.

- The authors propose a further detailed study of the physical and chemical properties of the RCA recycled from the discarded concrete cubes, as part of this research, to deliberately investigate into the reason of the impact of the true parameters resulting in the observed variation of the compressive strength and hardness of the concrete.

- More trials with different particle sizes of recycled aggregate and percentage of replacement of recycled aggregate are recommended to get higher feasible strength characteristics in the RCA.

- The influence of contaminants in the demolished concrete from buildings should be carefully studied and investigated to extend life time of concrete made with recycled aggregate concrete.

- The fire-resistant property of recycled aggregates should be carefully studied with economic aspect of concrete processing and recycling.

As natural aggregate specification have been specified in building codes and are being utilised all over the world, similarly, specifications and standards are a key to the future use of recycled aggregates. Work is required to develop specifications and standards in order to create opportunities for the increased and efficient use of recycled aggregates.

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