An Experimental Study on Recycled Coarse Aggregate with Carbon Black as a Source of Cementitious Material

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Abstract— To obtain good quality concrete using recycled aggregate it is necessary to follow the minimum requirements defined by the respective Building Standards. Acceptable properties of aggregates are an elemental base for concrete quality; however adequate mix proportions and concrete production methods are highly important in concrete quality too. Recycled aggregates composed of original aggregates and adhered mortar. The physical properties of recycled aggregates depend on both adhered mortar quality and the amount of adhered mortar. The adhered mortar is a porous material; its porosity depends upon the w/c ratio of the recycled concrete employed. When structures made of concrete are demolished or renovated, concrete recycling is an increasingly common method of utilizing the rubble. Concrete was once routinely trucked to landfills for disposal, but recycling has a number of benefits that have made it a more attractive option in this age of greater environmental awareness and the desire to keep construction costs down.

Key words: Concrete Recycling; Crushing Process; Recycled Aggregate; Sustainable Concrete; Durability

I. INTRODUCTION

The construction industry contributes substantially to the generation of solid waste in almost all the countries. In North America the construction and demolition waste contribute around 25 – 40% of the total waste generated depending upon the region. The Construction Materials Recycling Association (CMRA) has conducted a study on construction and demolition waste, related to the buildings and it was estimated to be around 136 million tonnes of waste material. Also, it was reported that apart from the building waste, a million of tonnes of waste is coming from road, bridge, and airport construction and renovation. In developed countries the annual per capita building and construction waste generation were 500 – 1000 kg and in the European countries the building and construction waste was estimated to be around 175 million tonnes per year. The construction and demolition waste generation scenario in Asian countries is also in the same trend. It was reported that Asia alone generates about 760 million tonnes of construction and demolition waste every year. According to the annual report of Dubai municipality's Waste Management Department, there was about 27.7 million tonnes of construction waste, generated from various construction sites in the city in 2007. This was recording growth in construction waste generation of 163% in comparison to the waste generated in 2006. Like other developing countries, India too is generating a huge quantity of construction and demolition waste due to rapid growth in construction industry. According to 11th five year plan the construction industry is second to agriculture in terms of magnitude. It is one of the largest employers in the country. The employment figures have shown steady increase from 14.6 million in 1995 to 31.46 million in 2005. The construction industry in India significantly affects the economic growth of the country. During 2004 – 2005, over US$ 100 billion has been invested in this sector. Due to the Government of India's (GOI) recent initiative to allow 100% foreign direct investment in real estate development projects, the construction sector likely to continue to record higher growth in the coming years . The contribution of the construction industry in total gross domestic product (GDP) has risen from 6.4% in 2000 – 2001 to 7.2% in 2004 – 2005 (TIFAC Ed). Technology Information, Forecasting and Assessment Council (TIFAC) indicate that the total construction work is equivalent to $847 billion during the period 2006 – 2011 (TIFAC Ed). According to the tenth five year plans the materials cost was around 40 – 60% of the total project cost. The construction and demolition waste in India was estimated to be approximately 14.5 million tonnes per year. The Central Pollution Control Board (CPCB) had estimated the total solid waste generation as 48 million tonnes per year for the year 2001 and out of which 12 – 14.7 million tonnes from the construction industry alone and by 2010, this was expected to be around 24 million tonnes. In addition, the new zoning bye-laws, legitimization of squatter settlements and increase in the urban population due to industrial development have led to the demolition of structures in the larger cities. Insufficient capacity of old road bridges for present and future growing traffic and modernization of highway bridges needs the demolition of old bridges too. Also, structures are destroyed due to either natural disasters like earthquakes, cyclones etc. or man-made disasters. Hence, the entire world is facing the problem of handling the waste material generated from the demolition. On the other side, there is a huge requirement of raw materials in the construction sector in India. Projections for building material requirement of the housing sector indicate a shortage of aggregates to the extent of about 55,000 million cubic meters. For achieving the target for road development up to 2010, an estimated 750 million cubic meters of coarse aggregate as sub-base material shall be required. Recycling of aggregate material from the construction and demolition waste may reduce the demand-supply gap in both these sectors. The use of old construction materials in new constructions is not a new technique. Many civilizations have used and reused the construction materials of earlier civilizations or their own destroyed architectures either due to war or due to natural disaster to construct new structures. The best example is that the construction of Vatican Basilica with the stones of ruined Romanesque. Though the '3R' formula i.e. Reduce, Reuse, recycle is one of the best policies to achieve the sustainable construction, due to partial implementation of this technique in most of the countries still lots of quantities of construction and demolition waste is lying in the site and deposited on landfills. The European Demolition Association estimates that about 200 million tonnes of waste generated annually, out of which 30% of this quantity being recycled. However, there was large difference in the quantities of recycling in the region wise. For example, Netherlands and Belgium achieve recycling rates of about 90%, whereas, other European countries like Italy and Spain, the recycling rate was below 10%. The Japan and Germany have also reached the recycling rates of around 96% and 86% respectively. The CMRA estimate that 25% of the construction and demolition waste was recycled and most of these recycled materials were used as base materials for road construction. In India, the construction and demolition waste is not being recycled currently. Although there is a considerable potential for using the construction and demolition waste as aggregates in concrete, considerable amount are either remain in site or land filled, the "last resort" in the waste management hierarchy . Most of the developed/developing countries, the construction waste treated as inert waste, harmless and bulky, which does not give rise to problems. However, this waste consists of mixture of various materials of different characteristics that are often deposited (dumped on land) without any considerations, causing many problems and encouraging the illegal dumping of other kinds of waste. This puts an additional burden to the solid waste management. Also, there is a shortage of dumping sites in the developed countries. Further, there is increase in the cost of transport to dispose waste to the dumping sites. Additionally, there is a need to preserve the depletion of natural resources from the environmental pollution point of view and also it is essential for the sustainable development. Therefore, there is no wonder that the recycling is one of the best solutions sought. The recycling technology not only solves the problem of waste disposal, but reduces the cost and preserves environment also. In addition, the recycling and proper management of construction and demolition waste gives better opportunities to handle the other kinds of waste, as less land is used for dumping of construction and demolition waste.

II. Literature Review

Animesh Awasthi et al (2018) [1] studies the effect of adding Recycled Aggregate Concrete Containing Silica Fume as Partial Replacement for Cement and found that the higher water absorption capacity of recycled aggregates has great influence on the water added to the mix, which can affect concrete's workability. They also found that it is possible to gain the same compression and split tensile strength as conventional concrete up to 30% replacement of natural aggregate with recycled ones. But both the compression and split tensile strength values are decreasing with the increase in replacement levels of recycled aggregates. The increase of recycled aggregates content beyond 30% has a negative effect on compressive strength of recycled aggregates concrete. The reduction in compressive strength after 28 days is about 10% when 50% recycled aggregates are used.

Anurag Gautam et al (2017) [2] presented the effect of replacing river sand partially by quarry dust. The proportions of quarry dust replacing by 0%, 25%, 35%, 45% and 55%. The materials testing, workability, compressive and tensile strength of concrete were examined at 7th, 14th and 28th day of curing of M20 grade of concrete. They examined that the results are comparatively good by replacing partially with natural sand. The replacement of quarry dust up to 45% gives better result. The compressive strength and tensile strength of 45% replacement gives 31.92 N/mm^2 and 3.85 N/mm^2 respectively at 28th day of curing.

Prabhat Kumar et al (2016) [3] presented a review of existing literature work for understanding thoroughly about RCA and the concluded from various studies that Natural aggregate can be used with recycle aggregate with a ratio of 80:20 and 70:30. Higher ratio of Recycle aggregate can worsen the properties and strength of mix and due to use of recycled aggregate in construction industry it can slow the impact of waste on environment. Also, it will promote sustainable growth.

Jitendra Kumar Tanaji Mohite et al (2015) [4] studied about the different test on the natural aggregate, recycle aggregate and blended aggregate and compare results and found that the strength of the recycled aggregate concrete is slightly less for the same condition as that of the natural aggregate. The amount of the reduction depends on the parameters such as amount of blending of the recycled aggregate, w/c ratio, quality of the processed recycled aggregates.

Akansha Tiwari (2015) [5] studied about water absorption of RCA and found that water absorption is higher than the natural aggregate also the compressive strength of concrete containing 50%of RCA has strength approximately to that of normal concrete. Also, her study tells that Concrete has good tensile strength when replaced up to 25-30%.

Vinod Sunhere and Rajesh Joshi (2015) [6] suggested that as the percentage of Natural Aggregate decreases by replacing the Recycled Concrete Aggregate, the corresponding strength goes on decreasing, yet up to 60% replacement it achieves target mean strength.

Jitender Sharma et al (2014) [7] studied about the introduction and production of recycled concrete aggregates and its various applications in the construction industry and they found that when the water cement ratio used in recycled aggregate mix is reduced, tensile strength and modulus of elasticity are improved.

Prof. Dharmesh K. Bhagat et al (2013) [8] from their study it can be concluded that, RCA exhibits comparatively less specific gravity than NA. As the water absorption of RCA was found greater than NA, because of adhering mortar and cement paste. Also their result for compressive strength tells that, the use of RCA up to 40% affect the functional requirements of concrete structure.

Vaishali. G. Ghorpade (2013) [9] found that considerations of both shear strength and workability, it is recommended to limit the replacement of natural coarse aggregate with recycled coarse aggregate up to 20% limit.

Prof. Chetna M Vyas and Prof. (Dr.) Darshana R Bhatt (2013) [10] in their studies the experimental results show that 0% to 40% replacement of Recycled Coarse Aggregate with the Natural Coarse Aggregate give enough compressive strength as per required and also full fills the requirement. In their studies 0% to 40%replacement can take place with recycle aggregate.

Katrina Mc Nei et al (2013) [11] studied about the properties of the RCA, the effects of RCA use on concrete material properties, and the large-scale impact of RCA on structural members and found that aggregate properties are most affected by the residual adhered mortar on RCA due to less density and more porosity of the RCA. They also investigated that the RCA particles are more round in shape and have more fines broken off in L.A. abrasion and crushing testes.

Parekh D. N. et al (2011) [12] studied the basic properties of recycled fine aggregate and recycled coarse aggregate. He also compares these properties with natural aggregates and resulted that recycled aggregate concrete has better resistance to carbonation than natural aggregate concrete.

Mirjana Malešev et al (2010) [13] performed comparative analysis of the experimental results of the properties of fresh and hardened concrete with different replacement ratios of natural with recycled coarse aggregate and the author found the results on the basic properties of concrete with three different percentages of coarse recycled aggregate content (0%, 50% and 100%). He found that workability of concrete with natural and recycled aggregate is almost the same if water saturated surface dry recycled aggregate is used. Bulk density of fresh concrete is slightly decreased with increasing quantity of recycled aggregate.

III. EXPERIMENTAL PROCEDURE

Raw materials required for the concrete use in the present work are

- Cement
- Coarse Aggregates
- Recycled Aggregate
- Carbon black waste
- Fine aggregate
- Water

A. Recycled Aggregate

Obtained from nearby disposal of residential construction.
Specific gravity = 2.62
Water absorption = 2.5

B. Carbon black

Carbon black used for the present study is finely divided powder. The specific gravity of carbon black was determined by density bottle approach, and it was once found to be 1.03. The pH value is 6 and this indicates that carbon black is almost an inert material. The sources of carbon black are mainly from rubber industry, petrochemical plant and oil plant.

Element	Content (%) of weight
Carbon	96 – 99.5
Hydrogen	0.2 – 1.3
Oxygen	0.2 – 0.5
Nitrogen	0 – 0.7
Sulphur	0.1 – 1.0
Residual Ash	< 1

Table 1: Carbon Black Composition

Mix no.	Cement (kg)	W/c ratio	C B (Kg)	C.A (Kg)	F.A (Kg)	RCA (Kg)	% RCA	Water (litres)
1	492.5	0.4	-	1024	678	-	-	197
2	394	0.4	98.5	921.6	678	102.4	10	197
3	394	0.4	98.5	896	678	128	12.5	197
4	394	0.4	98.5	870.4	678	153.6	15	197
5	394	0.4	98.5	844.8	678	179.2	17.5	197
6	394	0.4	98.5	819.2	678	204.8	20	197

Table 2. Mix Proportion

Property	Test	Specification
Mechanical	Compressive Strength	IS 516 – 1959
	Split Tensile Strength	IS 5816 - 1999
	Flexural Strength	IS 516 – 1959
Workability	Slump	IS 1199 - 1959

Table 3: Test Methods and standards adopted

IV. RESULTS

A. Fresh properties:

In all samples of RCA concrete with different weight percentages recycled aggregate (0%, 10%,12.5%,15%,17.5% and 20%) were cast to study the effect on mechanical properties of concrete at 7,14 and 28 days.

Carbon black was effectively used to achieve economy in cement. The Indian standard mixed proportioning guide line as mentioned in IS 10262:2009 has been used for mix proportioning.

Mixture type	0% RCA	10% RCA	12.5% RCA	15% RCA	17.5% RCA	20% RCA
Slump (mm)	5	17.5	17	17.5	17.5	19
Air content (%)	4.0	5.8	3.5	4.0	5.5	4.0

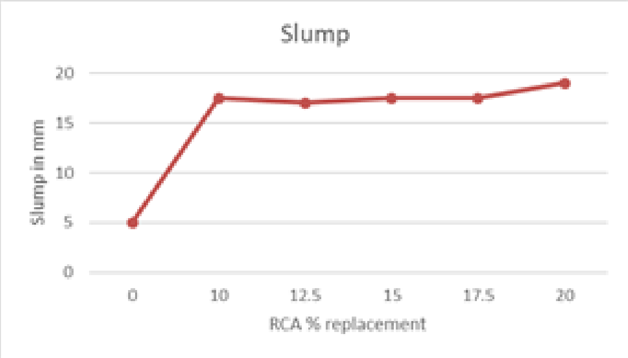

Fig. 1: Workability Properties

Mix	10% RCA	12.5% RCA	15% RCA	17.5% RCA	20% RCA
A	2.0	0.0	6.5	3.1	4.0
B	0.02	0.0	0.08	0.04	0.05
C	60	55	65	60	50

Table 5: Results of Bleeding Measurements

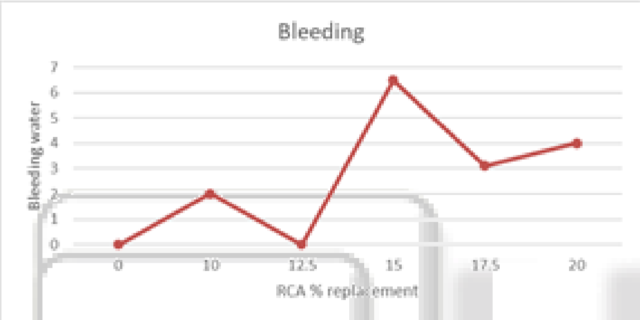

Fig. 2: Bleeding Results

B. *Mechanical Properties of Concrete:*

Mix	Compressive Strength(N/mm²)		
	7 Days	14 Days	28 Days
0	28	37.4	42.4
10	27.5	36.2	42.6
12.5	29	38	40.4
15	28.4	35.4	42.8
17.5	26.8	37.4	43.5
20	27	35.8	42

Table 6: Compressive Strength Results

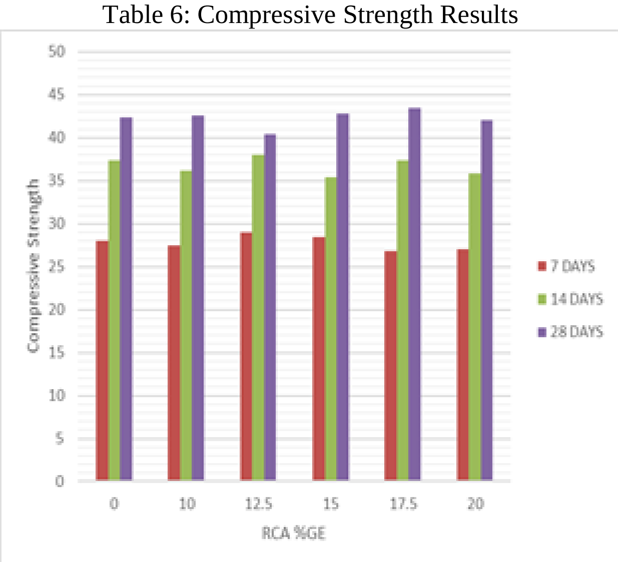

Fig. 3: Compressive Strength results

C. *Split Tensile Strength*

Mix	Split Tensile Strength(N/mm²)		
	7 Days	14 Days	28 Days
0	3.02	4.05	4.47
10	3.12	3.93	4.85
12.5	3.35	4.02	5.12
15	3.32	3.85	4.95
17.5	3.55	4.15	5.25
20	3.42	4.24	4.96

Table 7: Split Tensile Strength Results

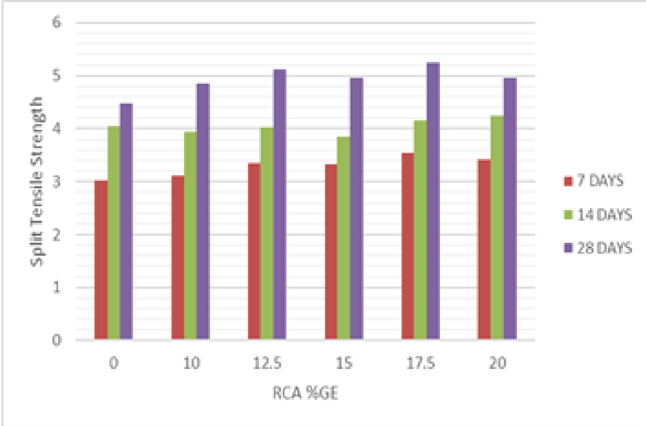

Fig. 4: Split Tensile Strength results

D. *Flexural Strength*

Mix	Flexural Strength(N/mm²)		
	7 Days	14 Days	28 Days
0	3.62	4.27	4.64
10	3.76	4.39	4.52
12.5	2.87	3.35	4.42
15	3.56	4.42	4.36
17.5	3.60	4.38	4.54
20	3.42	4.40	4.02

Table 8: Flexural Strength Results

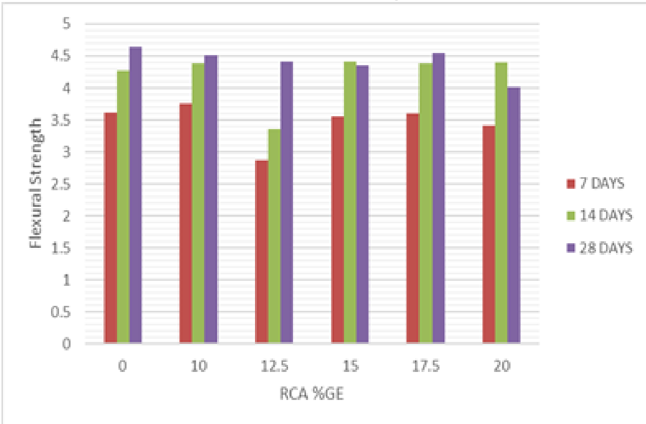

Fig. 5: Flexural Strength results

V. CONCLUSION

Based on the results obtained in the chapter IV the following conclusions were drawn

1) There was not a significant difference between the fresh properties of the reference and the concrete mixtures made with RCA replacements up to 20%.

2) The RCA made in the study was a laboratory-based material. The mixture proportion of the parent concrete used for producing the RCA was similar to that of a conventional mixture with a w/c=0.4. This results in producing a high-quality RCA.
3) There was not a significant difference in compressive strength of the concrete mixtures made with RCA replacements up to 17.5% and 20%.
4) However, due to the higher air content, the mixtures made with 12.5% and 20% RCA replacement had lower compressive strength compared to the reference and other mixtures.

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