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Strength and Deformation Behavior of Concrete Made with Recycled Concrete Aggregates

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ABSTRACT

With the development and modernization of societies, lot of construction activities are seen everywhere. These construction activities are increasing at a faster rate by a large amount. Also, the destruction of existing structures, which have reached their service life, runs parallel to the construction activities. It is not essential that the structures need to be demolished only after when they have completed their service life, but also due to change in fashion and the ongoing trend of reconstruction of even healthy structures just for creating more space in order to meet the present demand. All such activities are generating waste in bulk, and this waste is called the Construction and Demolition (C&D) waste. Disposal of such C&D waste in a sustainable manner is a hard nut to crack for the builders, developers, and owners. While the disposal of C&D waste is a challenge, on the other hand, there is a severe shortage of naturally available aggregates for construction of structures. Reduction of this demand in a small way is possible with the recycling or reusing of construction and demolition waste generated from the construction activities. Hence, the recycling of demolished waste is a sustainable solution of C& D waste.

Recycled concrete aggregate has limited application as fill and sub grade material below the foundation of structures, pavement etc. these applications are non-structural applications. However, research has been ongoing all over the world especially in Japan, China, European countries and some part of India also, from last 50 year in order to find the potential implement of recycled aggregates as a structural grade concrete.

The research work on "Strength and Deformation Characteristics of Fiber Reinforced Concrete made with RAC" is presented here and is one such attempt to establish the RAC as a structural grade concrete. This research work focus on mainly four structural properties of concrete i.e. Compressive Strength, Split Tensile Strength, Flexural performance, and Flexural toughness. In this present study, the experimental part is divided into two different series viz. Series-A (without fibers concrete mix) and Series-B (1% by volume Steel fibers in concrete mix). The natural coarse aggregates are replaced with Recycled coarse aggregates at different replacement ratios. Four replacement ratios are considered in this present study 0% (control specimens), 20%, 40% and 80% M-20 grade of concrete mix are considered in this study. In order to predict the flexural performance of RAC, 16 reinforced concrete beam specimens were prepared. The section was designed as under-reinforced section and tested on UTM for flexural behavior under two-point loading.

Based on the results obtained it is found that on the addition of steel fibers there is an increase in almost all the structural properties of normal concrete and concrete made with recycled aggregates. The investigation indicated encouraging results for RAC beams, cube and cylindrical specimens in all respect, thus pointing to recycled aggregate concrete as potential alternative structural grade concrete of the 21st century.

Keywords: *Workability, Compressive Strength, Tensile Strength, Flexural Strength.*

1. INTRODUCTION

Concrete is the single most widely used construction material in the world, far exceeding other materials as the production of the concrete required much less energy and had a lower net environmental impact. Humans have been using concrete in their pioneering architectural and structural feats for millennia. The global concrete industry will annually require 8 to12 billion tones of natural aggregates after the year 2010 (*Keun-Hyeok et al., 2008*). This huge demand for concrete seems to increase at a much faster rate in 2020 due to the modernization of cities, rehabilitation of old buildings, expansion of concrete pavements etc. Each construction material is manufactured from some combination of raw materials, and the basic ingredients of concrete are –sand and gravel (aggregate), a cement-like binder, and water out of this cement can be manufactured in industries but natural aggregates are usually obtained by mining and cannot be manufactured in industries. As aggregates, the raw material of concrete, are non-renewable and scarce therefore there is an urgent need to find the sustainable solution to get an alternative of natural aggregates.

On the other hand, due to renovations and refurbishments for reasons such as deterioration, alteration of needs, or change in fashion, much concrete structures and its components are changed and thus resulting in Construction & Demolished wastes. These processes sometimes occur frequently. It is estimated that 30-50% of overall construction waste results from renovation activities (*Construction and Demolition Waste Practices and Their Economic Impact-Report, 1999*). Sometimes waste is generated due to the structural problems of individual buildings like the collapse of a building, due to earthquakes, illegal structuring, and urban transformation processes etc. For example, in turkey, 13 million tons of waste was generated due to the Marmara Earthquake of 1999. These wastes were left in empty spaces and fill areas and some of them were dumped at sea (*Solid Waste Control Sub Commission Report –Ankara, 2000*). As per the report of Central Pollution Control Board (CPCB) Delhi, in India, 48 million 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.

India is currently the second fastest-growing economy in the world. Its construction industry plays a vital role in the overall economic development of the country, with investment in construction accounting for approximately 11 percent of GDP and growth rates anticipated at 15 percent. India's development dictates the country needs to build suitable infrastructure to support the current economic growth and to attract continued inward investment. The public sector will continue to be a significant investor in the construction industry with suggested figures ranging from US$320bn to US$485bn to upgrade the nation's roads, railways, ports, airports and power stations. This data represents the increase in concrete demand at an alarming rate. New studies from *The Freedonia Group*, a market research firm, forecasts world demand for construction Aggregates to grow at a faster rate of 4.7 percent annually from 2011 to 26.8 billion metric tons.

In addition, sales of construction aggregates in the Asia/Pacific region are forecast to climb 5.7 percent per annum to 32.6 billion metric tons in 2015, slowing from the torrid 2005-2010 paces but maintaining the regional market's position as the fastest growing worldwide.

2. MATERIALS USED

2.1 Cement

Ordinary Portland cement grade- 43 (Shree Ultra tech cement) conforming to Indian standards IS: 8112-1989 has been used in the present study. The results of the various tests on cement properties are presented in Table 1.

Table-1: Physical Properties of Ordinary Portland cement (Grade-43)

Characteristics	Units	Result Obtained	Permissible Range Specified (IS: 8112-1989)
Specific gravity	**--**	3.15	3.10 - 3.15
Fineness (specific surface)	**cm^2/gm**	2340	2250 (minimum)
Soundness (expansion by Le-Chatelier test)	**mm**	3	10 (maximum)
Normal Consistency (percent of cement by weight)	**%**	34	30 - 35
Setting time	**Minutes**		
Initial		65	30 (minimum)
Final		410	600 (maximum)
Compressive strength	**MPa.**		
3-days		23.02	23.00 (minimum)
7-days		34.50	33.00 (minimum)
28-days		44.10	43.00 (minimum)

2.2 Fine Aggregate

IS: 383-1963 Defines the fine aggregate as the aggregate most of which will pass 4.75 mm IS sieve the fine aggregate is usually termed as Sand. The sand is generally considered to have a lower size limit of 0.007 mm. usually, natural sand is used as a fine aggregate. The sand used for the experimental work is locally available and conformed to grading zone III.

2.3 Course Aggregate

The coarse aggregate is defined as an aggregate most of which is retained on 4.75 mm IS sieve. The broken stone is generally used as a coarse aggregate. Locally available coarse aggregate having the maximum size of 12.5 mm was used in the present work.

2.4 Recycled Course aggregate

A large amount of tested concrete specimens e.g. cubes, cylinders, beams etc. were lying in the concrete testing laboratory of LNCT Bhopal. These specimens were used as a source of Recycled concrete aggregate. To obtain RCA, these specimens were broken down into small pieces manually using hammer. The broken pieces of concrete specimens were sieved, the larger fraction passing through 20 mm IS sieve but retained on 10 mm IS sieve. The fraction passing through 4.75 IS sieve was discarded.

2.5 Steel Fibers

Steel fibers provide a significant bridging effect on the cracking behavior of concrete and can control the crack width and enhance the shear capacity of RC members. Dramix Glued Hooked end type steel fibers Fig. 3.7, with diameter 0.5mm were used in the present investigation. The fibers were added in a proportion of 1% by volume of concrete. The aspect ratio of the fiber adopted was 65

2.6 Super-plasticizer

In this study Master, Glenium SKY 51 was used as a Super plasticizer to improve the workability of concrete. It is polycarboxylic ether based, high range water reducing new second generation super plasticizer concrete admixture. It meets the requirements of TS EN 934-2, ASTM C 494 Type F and IS 9103: 1999. Optimum dosage of Master Glenium SKY 51 should be determined with trial mixes

3. MIX PROPORTIONS

M-20 grade of concrete was considered for the present study. The mixture proportioning was carried out as per the guidelines laid by the Indian standards specification [IS: 10262-1982]. Twenty days compressive strength of cement was considered for the concrete mix proportioning. To achieve the required amount of workability, water reducing admixture i.e. super plasticizer namely Gelenium Sky 51 is added to concrete at a desire dosage rate. The mix proportion of corresponding mixes was prepared by replacing the natural coarse aggregate with the recycled coarse aggregates. In this, mixture proportions for the natural coarse aggregate and the recycled coarse aggregate concretes were nominally kept the same, except for replacement of NCA with recycled coarse aggregate, depending upon the desired recycled coarse aggregate replacement percentage. The aggregates were kept in water for 24 hours and then kept in room temperature in order to obtain surface dry condition. The following four weight combinations of NCA and recycled coarse aggregate are adopted: 100% NCA (control mixture), 80% NCA + 20% recycled coarse aggregate, 40% NCA +60% RCA, 80% RCA. The concrete mixture proportions and the corresponding mix designations are presented in Table 3.12. In concrete batching, first the natural coarse aggregates and RCA are added in the mixer, subsequently, fine aggregates and cement are added to the mixer the ingredients are dry mixed in the mixer for 2 minutes. Then half of water is added and again mixed for 1 minute. After this, the rest of the water along with the quantity of required super plasticizer is added and mixed for another 2 minutes. The mixture is now ready to be poured in the moulds.

4. RESULT AND DISCUSSION ON EXPERIMENTAL TESTS

4.1 Compressive Strength

Three cubes of 100 mm dimension are casted and cured for 28 days to evaluate the compressive strength of concrete made with RCA. The cubes are tested on 200T capacity compression testing machine as shown in Fig.4.1. The direct weight to weight replacement of natural coarse aggregate are carried out with the Recycled concrete aggregates at different replacement ratio of 0% (control specimens), 20%, 40% and 80%. In the present investigation the water-cement ratio is kept constant. Steel fibers, 1% by volume, are also added to SERIES-B specimens. The specimens are placed centrally in testing machine and load w as applied continuously, uniformly he load was increased until the specimen fails. The maximum load taken by the specimen was noted. Experiment was repeated for three specimens of the same mix. The results of the strength tests conducted on concrete specimens of different mixes are presented in Table 2. for SERIES-A and SERIES-B, further these data are presented through graphs Fig.4.2 and Fig. 4.3, the results obtained are discussed in the following section.

Table-2: Cube Compressive Strength at 28 Days

Series	Specification- Id	Replacement Ratio (%)	Average Compressive Strength of 3 cubes at 28 days(N/mm^2)
SERIES-A(Without Fibers)	NC-0	0	18.26
	NC-20	20	17.21
	NC-40	40	16.63
	NC-40	40	16.63
	NC-80	80	14.68
SERIES-B (With Fibers)	RC-0 (1)	0	31.67
	RC-0 (2)	0	33.54
	RC-20 (1)	20	29.69
	RC-20 (2)	20	28.42
	RC-20 (2)	20	28.42
	RC-40 (1)	40	25.13
	RC-40 (2)	40	26.49
	RC-80 (1)	80	23.67
	RC-80 (2)	80	22.81

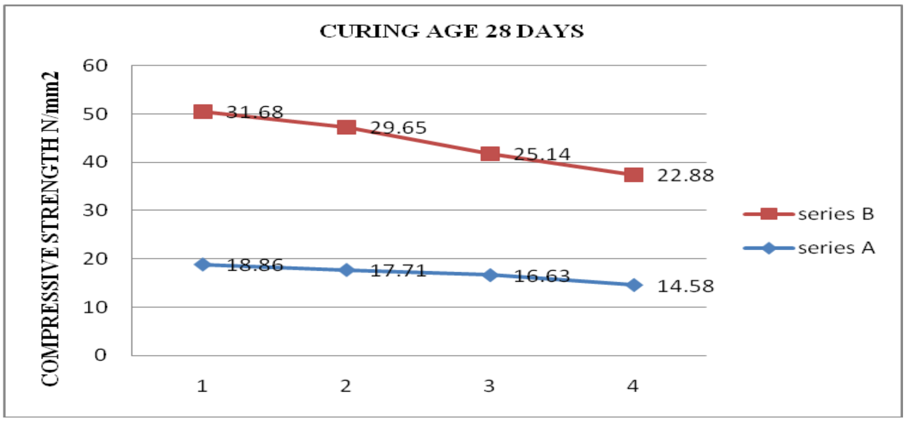

Fig-1: Cube Compressive Strength at 28 days

Series-A (Without Fibers): Fig. 4.2 shows that with an increase in replacement ratio of coarse Recycled Aggregate in the natural aggregate mix there is a decrease in the compressive strength. However, the decrease in compressive strength, up to 20% replacement ratio, is very less and of the order of 5-10% of natural aggregates. It is clear from the test results that there is 20-25% reduction in compressive strength of concrete with 80% replacement of natural aggregates with recycled one.

Series-B (Steel Fibrous Concrete): Fig. 4.3 represents the details of compressive strength of steel fiber concrete. It can be seen from the Table 4.1, in case of no fiber concrete also there is a decrease in strength with increase in replacements of RCA in NA

4.2 Splitting Tensile Strength

Two cylindrical specimens of 100 mm diameter and 200 mm height are cast and cured for 28 days to evaluate the split tensile strength of concrete made with RCA. The cylindrical specimens are tested on the 200T capacity compression testing machine in Fig.4.1. The direct weight to weight replacement of natural coarse aggregate is carried out with the Recycled concrete aggregates at different replacement ratio of 0% (control specimens), 20%, 40% and 80%. In the present investigation, the water-cement ratio is kept constant. Steel fibers, 1% by volume, are also added to SERIES-B specimens. The specimens are placed centrally in the testing machine and the load was applied continuously, uniformly the load was increased until the specimen fails. The maximum load taken by the specimen was noted. The experiment was repeated for three specimens of the same mix. The results of the strength tests conducted on concrete specimens of different mixes are presented in Table 2 for SERIES-A and SERIES-B

Table-3: Split Tensile Strength at 28 days

Series	Specification- Id	Replacement ratio	Splitting Tensile Strength at 28 days
SERIES-A(Without Fibers)	NC-0	0	2.71
	NC-20	20	2.77
	NC-40	40	2.73
	NC-80	80	2.69
SERIES-B (With Fibers)	RC-0 (1)	0	2.93
	RC-0 (2)	0	2.85

	RC-20 (1)	20	2.93
	RC-20 (2)	20	2.89
	RC-40 (1)	40	2.89
	RC-40 (2)	40	2.83
	RC-80 (1)	80	2.81
	RC-80(2)	80	2.83

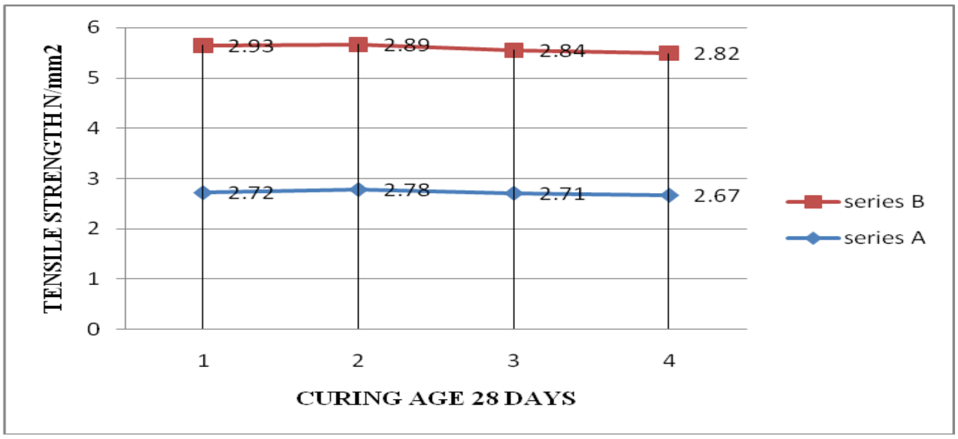

Fig-2: Split Tensile Strength at 28 days

4.2.1 Effect of Recycled coarse aggregates on Split Tensile strength

Fig. 6.1 shows the variation of tensile strength with different replacement ratio. It is clear from the graph that as compare to compressive strength, split tensile strength of RAC is very less affected by the presence of recycled aggregates in the mix. The results show that the tensile strength of the RAC is comparable to the natural concrete. This improvement in the result is due to the increased absorption of the attached mortar and effective interfacial transition zone which indicate a good bond between aggregate and mortar matrix. However this residual mortar creates a weakened spot for compressive failure to occur, limited quantities improve the tensile capacity by creating a smoother transition between mortar and aggregate.

4.2.2 Effect of Steel Fibers on Split Tensile Strength

The effect of adding steel fiber in concrete mix shows an increment in tensile strength of concrete at all the replacement ratio.

5. FLEXURAL STRENGTH TESTS

To investigate the flexural strength of the beam specimens, two-point transverse load test were performed on UTM (2000 kN capacity). The results obtained after 28 days of curing are shown in Table 4.4 it can be noted from the results that with the increase in replacement of natural coarse aggregates from recycled aggregates, there is a decrease in the flexural strength of specimens. Further on the addition of steel fibers to the concrete mix (Series-B), the improved results have been obtained. Also, the value of flexural strength to the square-root of fck is higher in case of fibrous concrete mix. A comparison of flexural behavior As per IS: 516-1959.

Table-3: Flexural Strength of Concrete Specimens at 28 days

Series	Beam specification Id	% of Replacement	Flexural strength at 28 days(N/mm^2)	Flexural strength
Series-A	NC-0	0%	10.52	2.35
	NC-20	20%	9.69	2.17
	NC-40	40%	8.86	1.98
	NC-80	80%	8.12	1.81
Series-B	RC-0	0%	14.02	3.13
	RC-20	20%	13.38	2.99
	RC-40	40%	12.55	2.806
	RC-80	80%	11.44	2.56

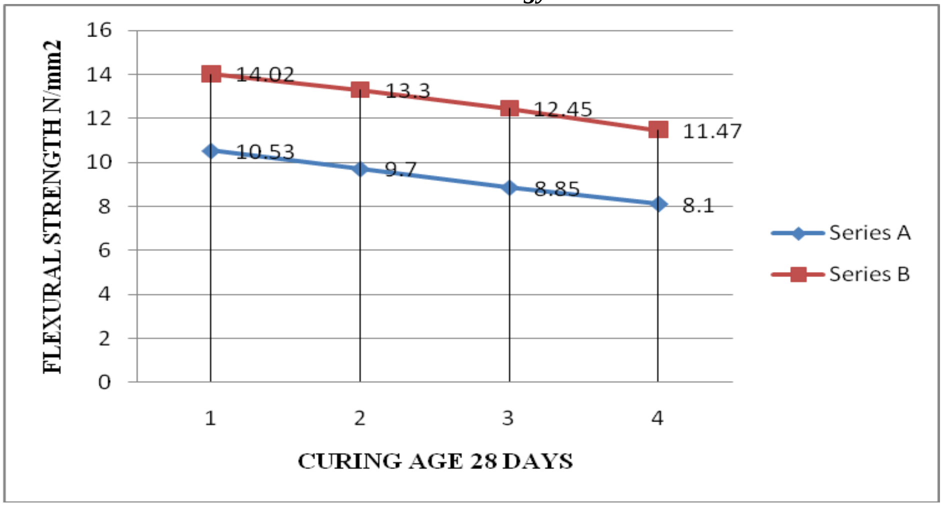

Fig-3: Flexural Strength at 28 Days

6. CONCLUSIONS

Experimental works on the use of recycled aggregates have proven that good quality of concrete could be produced with recycled aggregates. Based on the experimental investigation reported in the present work, the following conclusions are drawn:

- The 28 days compressive strength of concrete made with recycled concrete aggregate decreases with the increase in replacement ratio for same w/c ratio. However, for replacement ratio up to 30%, the compressive strength of RAC is comparable to that of NAC.
- The reduction in compressive strength of concrete made with recycled concrete aggregate is in the range of 5% to 10% for 25% replacement ratio. And this reduction for 80% replacement ratio is in the range of 20-25%.
- The addition of steel fiber (1% by volume) in concrete mix shows an improvement in compressive strength for all replacement ratios. This improvement is in the range of 20-22% than without fibers.
- The results show that the tensile strength of the RAC is comparable to the natural concrete. This result is due to the increased absorption of the attached mortar and effective interfacial transition zone which indicate a good bond between aggregate and mortar matrix.
- On addition of steel fibers to RAC, the increase of tensile strength of RAC with 80% replacement ratio is 19% for 28 days. The increase of tensile strength for 40% and 20% replacement is 24% and 27% respectively for 28 days.
- The flexural strength of concrete with 80 % recycled concrete aggregate decreased 20% for 28 days. And for 40% and 20% this reduction is 11% and 7% at 28 days.
- On addition of steel fibers to RAC, the increase in flexural strength for 80% replacement is 10% for 28 days. For 40% and 20% replacement, the increase in flexural strength due to fibers is 15% and 19% respectively at 28 days.
- A maximum of 7% to 25% reduction in ultimate load and the ultimate moment is observed for RAC beam specimens.
- On addition of steel fibers, RAC beam performs well and shows the higher value of the ultimate load and ultimate moment as compared to the conventional one.
- It has been observed that beam specimens of RAC show higher deflections, wider cracks and closer crack spacing at ultimate load.
- On addition of steel fibers, the flexural performance of RAC beams performs well and satisfactory as a whole.
- Compressive strength, Tensile strength and Flexural strength results of RAC show decrease in strength with increase in percentage replacement of conventional aggregates by recycled aggregates, However, RAC with fibers showed improvement in mechanical properties when compared to RAC.
- In view of the other advantages such as conservation of natural resources, free the recycled material from landfills and elimination of disposal problems, the Recycle

7. FUTURE SCOPE

- The study can be carried out on high strength concrete with RAC.
- The study can be carried out to evaluate the shear performance of beam specimens made with recycled concrete aggregates.
- More investigations and laboratory test should be done on the strength characteristics of recycled aggregate. It is recommended that testing can be done on concrete slabs, beams, and walls.
- The study can be carried out to investigate the behaviour of concrete specimens with the different replacement of natural sand with fine recycled aggregates.
- As natural aggregate specification in all codes and building specification all over the world. Work is required to develop specifications and standards in order to create opportunities for the increased use of recycled aggregates.

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