



Application of Recycled Coarse Aggregate in Steel Tubular Members

Gajalakshmi Pandulu†, Revathy Jayaseelan and Mohana Priya

Department of Civil Engineering, B. S. Abdur Rahman Crescent Institute of Science & Technology, Chennai, Tamil Nadu, India

†Corresponding author: Gajalakshmi Pandulu; gajalakshmi@crescent.education

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ABSTRACT

Recycled aggregate from the demolition of buildings provides a sustainable solution in reducing the space required for dumping demolished waste as landfill and also reduces the consumption of natural aggregate. A percentage of recycled coarse aggregate can be used in structural members which can be economical and environmentally useful. This experimental study consists of three phases. In Phase I, an attempt was made to use Recycled Coarse Aggregate (RCA) in place of Natural Coarse Aggregate (NCA) in concrete. Experimental results of concrete for various combinations of RCA with NCA were analysed numerically for the optimum value using Taguchi's method. In Phase II, the confirmation study was conducted to study the strength and durability characteristics of concrete made with the optimized value of recycled aggregate. In Phase III, the application of optimized recycled coarse aggregate concrete was done by conducting a study on the load-carrying capacity of recycled coarse aggregate concrete-filled steel tube members. The results revealed that there is a marginal increase in load-carrying capacity of recycled coarse aggregate concrete-filled steel tube members than natural coarse aggregate concrete-filled steel tube members. This application proves to be eco-friendly and environmentally sustainable by using the demolished concrete in the structural member.

INTRODUCTION

Concrete is a man-made product which consists of large chunks of cement, coarse and fine aggregate mixed with water and/or admixture. Concrete is the most widely used construction material across the world in all types of construction. In a concrete mixture, aggregate occupies the major part. In conventional construction, coarse aggregate from quarries and sand from river beds play a vital role. The availability of these natural sources is decreasing at a larger scale due to overconsumption and increased development in the field of construction (Tiwari 2015, Chakradhara Rao 2011). The supply of the aggregates has emerged as a major problem in many cities across India. For this purpose, recycling of demolition waste is gaining importance (Matias 2013, Vieira 2016). Also, beams cast with RCA rather experienced greater deflections under a service load and smaller cracking moments (Ganesh 2014). The recycled coarse aggregate can be used only after reducing it to the normal size and standards. While universally accepting the need to promote the use of RCA in the wider application, it must be remembered that the aggregate for the concrete application must adhere to the requirements set in the relevant specification for its intended use (Kazuhisa 2014, Alexandre Bogas 2014). The effect of recycled aggregate must be assessed and worked out for the optimum percentage to produce a concrete of good quality.

In the case of composite construction, the concrete and steel are coupled in such a manner that the advantages of both the materials are utilized effectively in composite members. Concrete-filled steel tubular (CFT) members have evolved to become popular structural members used in buildings, bridges etc., due to their outstanding structural performance characteristics such as high strength, high ductility, savings in formwork, smaller cross-section over reinforced concrete structures and high fire resistance over the steel structures (Gajalakshmi 2011). RCA filled stainless steel tube stub columns and beams under short-term loadings exhibit stable load versus deformation responses and the performance of core RAC was usually enhanced to the appreciable extent due to the confinement of the outer stainless steel tube (Wang 2015, YouFu 2006, Youfu 2013). The variation in compressive strength for the columns filled with RCA is noticeable (Vivian 2016, Kou 2012). In this study, an attempt is made to study the performance of CFT members filled concrete prepared by partially replacing NCA with RCA. This application renders to maintain a sustainable environment.

MATERIALS AND METHODS

Phase I - Experimental Study on Materials

In Phase I, an experimental study was conducted on testing of material properties, development of mix design for M25

and M35 grade concrete and testing of hardened properties such as compressive and split tensile strength. The optimum value of RCA has been found out by Taguchi's approach by using these experimental results in Phase I.

Material properties: The physical properties of natural coarse aggregate and recycled coarse aggregate are compared and are given in Table 1. The cement of grade OPC 53 is used for testing. The concrete mix was designed for the cube compressive strength of 25MPa and 35MPa at 28 days with mix ratios of 1:1.37:2.6 @ 0.45 w/c ratio and 1:1.8:2.7 @ 0.5 w/c ratio respectively with 12.5mm (max) size of natural and recycled coarse aggregate and 2.36mm (max) size fine aggregate based on ACI committee 211.1.1991 recommendations. From the concrete mixes, cubes and cylinders were cast for various percentages of recycled coarse aggregate (RCA) (40%, 60%, 80%, and 100%) with and without admixture (modified polycarboxylic ether) and were tested to obtain the optimum percentage of RCA using Taguchi method.

Taguchi's approach- Analysis of results of compressive and tensile strength: Taguchi (1986) (Ganesan, 2011) developed a method based on orthogonal array for designing experiments to investigate how different factors affect the response especially the mean and variance. Taguchi has coupled design of experiments with optimization of control factors to ensure the best optimal results. He also introduced the concept of signal to noise ratio (S/N), where the signal is the mean response and noise is variation due to uncontrolled

factors. The signal to noise ratio is nothing but log functions of desired response and also serve as an objective function for optimization in experimental data analysis. Taguchi has tabulated 18 basic orthogonal arrays called 'Standard Orthogonal Array'. The process of fitting an orthogonal array to a specific experimental study has been made easy by employing one of the standard orthogonal arrays. The average S/N ratio for each factor and levels were calculated. Keeping in mind the objective of the experiment, viz., maximization or minimization of the performance measure, the best level for each factor can be selected and as per Taguchi's approach S/N ratio is given by-

$$S/N \text{ ratio} = -10 \log \left[\frac{1}{N} \sum Y_i^2 \right]$$

where N is the number of experiments and Y_i is the mean of all the experiments.

Analysis of Results Using the Taguchi Approach

Based on Taguchi method, the suitable array for the compressive test results selected for the analysis is 4^2 (L8), where 4 represents the factors and 2 represents the levels which are shown in Table 2 with four factors as percentage replacement of natural coarse aggregate with recycled coarse aggregate (A1-40%, A2-60%, A3-80% and A4-100%) and two levels of different grades (C1-M25 and C2-M35) and admixtures (B1-0% and B2-0.6%). The S/N ratios were calculated for both compressive strength and tensile strength as shown in

Table 1: Physical properties of Aggregates.

Physical properties	Water absorption (%)	Specific gravity
NCA	1.48	2.68
RCA	5.8	2.2
Fine Aggregate (Zone II)	-	2.65

Table 2: Array table.

	C1		C2	
	B1	B2	B1	B2
A1	33.35	40.4	38.66	45.42
A2	34.51	38.73	38.27	43.37
A3	29.24	34.78	35.36	38.97
A4	28.80	29.07	30.76	33.16

Table 3: S/N ratio of compressive strength of cube.

% of Replacement	% of Admixture	Compressive strength results (N/mm ²)		S/N ratio	
		M25	M35	M25	M35
0	0	24.4	35.16	27.75	30.92
0	0.6	27.42	40.13	28.76	32.06
40	0	33.35	38.66	30.46	31.75
40	0.6	40.4	45.42	32.12	33.14
60	0	31.57	38.27	31.66	31.66
60	0.6	38.73	43.37	31.76	32.14
80	0	29.24	35.36	29.32	30.97
80	0.6	34.78	38.97	30.83	31.81
100	0	28.8	30.76	29.19	29.75
100	0.6	29.07	33.16	29.27	30.41

Tables 3 and 4. The 40% replacement of RCA for NCA has shown improved strength in both compressive and split tensile strength. Hence the optimum value of RCA mixed with NCA is 40% and 0.6% admixture which in turn is applied in the casting and testing of structural members. These members, which were cast for this optimum value, were compared with the control member of M35 grade with 0% RCA and 0.6% admixture.

RESULTS AND DISCUSSION

Phase II - (Confirmation Test)

In Phase II, the confirmation test has been done by studying

the strength and durability performance of M25 and M35 grade concrete made with the optimum percentage of RCA and admixture determined by Taguchi’s approach.

Strength Performance

From the Figs. 1 and 2, maximum strength was obtained for the grade M35 with 40% replacement of natural aggregate with recycled concrete aggregate and 0.6% of admixture. It is observed to be an 11% increase when compared with conventional concrete cubes. From the split tensile strength test results, maximum strength was obtained for the grade M35 with 40% replacement of natural aggregate with recycled concrete aggregate and 0.6% of admixture. It was observed

Table 4: S/N ratio of the tensile strength of cylinder.

% of Replacement	% of Admixture	Tensile strength results (N/mm ²)		S/N ratio	
		M25	M35	M25	M35
0	0	2.70	2.99	8.63	9.513
0	0.6	2.82	3.05	9.00	9.69
40	0	2.85	2.99	9.09	9.513
40	0.6	2.96	3.19	9.43	10.08
60	0	2.72	2.81	8.69	8.97
60	0.6	2.80	2.91	8.94	9.28
80	0	2.70	2.64	8.63	8.43
80	0.6	2.85	2.82	9.09	9.00
100	0	2.56	2.84	8.16	9.07
100	0.6	2.71	2.99	8.63	9.51

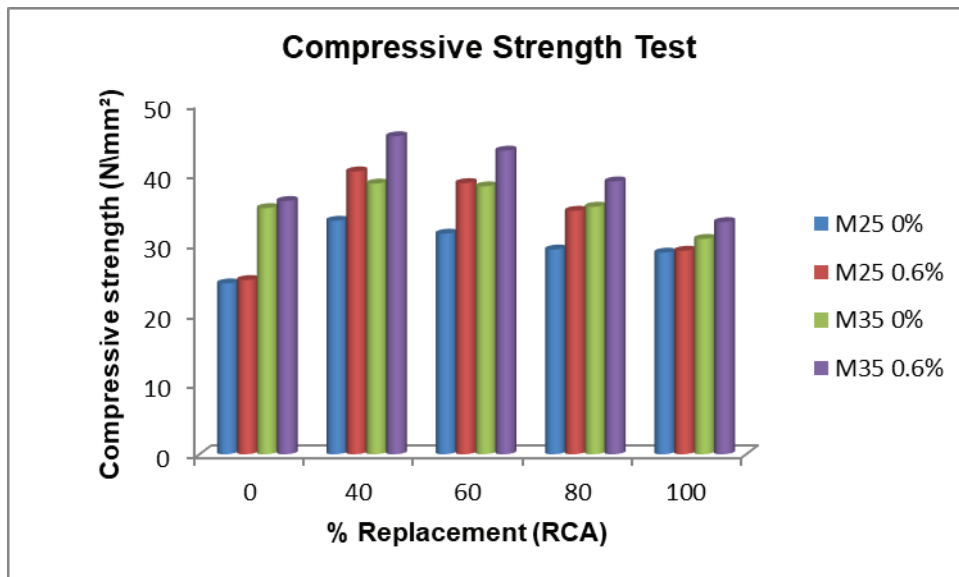


Fig. 1: Compressive strength test results.

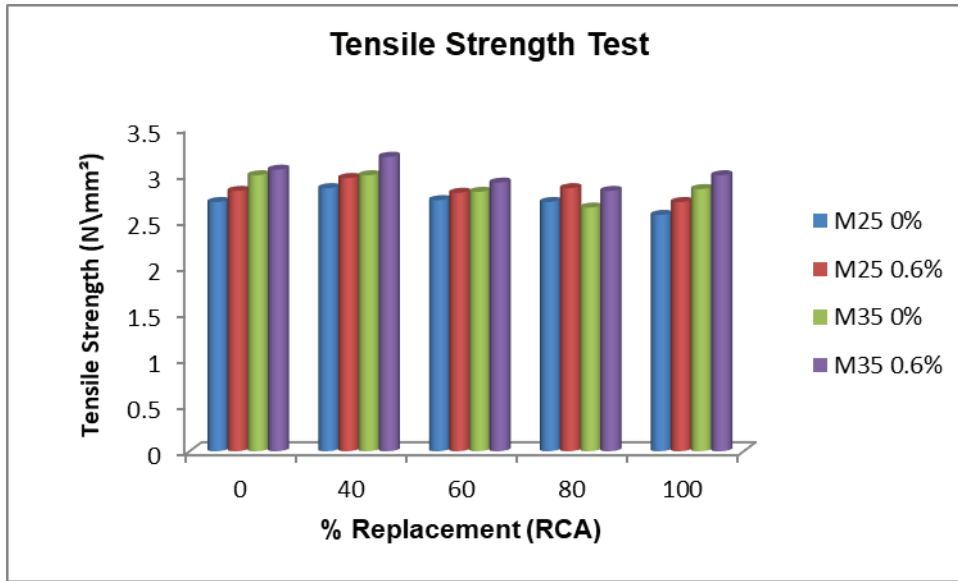


Fig. 2: Tensile strength Test results.

to be a 7.2% increase when compared with the conventional concrete cylinders.

Durability Performance (Confirmation Test)

Rapid chloride penetration: The Rapid Chloride Penetration Test (RCPT) is conducted using the cells and the values are recorded for 6 hours at 30 minutes interval with NaOH and NaCl on either side of the cell for the specimen of 100mm diameter and 50mm height. The specimen is kept in the testing apparatus where one end of the specimen is exposed to sodium chloride and the other end is exposed to sodium

hydroxide. A constant potential voltage of 60 V was applied across the specimens. The current across the specimen was measured every 30 minutes for the complete 6-hour test. The total charge passing through the specimen was calculated in coulombs. Higher the value, higher is the permeability. The chloride ion penetrations are measure in terms of the current passed through the specimen. The current passage will be more if the resistance offered by the specimen is less. Based on the test results given in Fig. 3, the chloride penetrating rate is “Moderate” as per ASTM C1202 for all grades of concrete with natural coarse aggregate and recycled concrete aggregate.

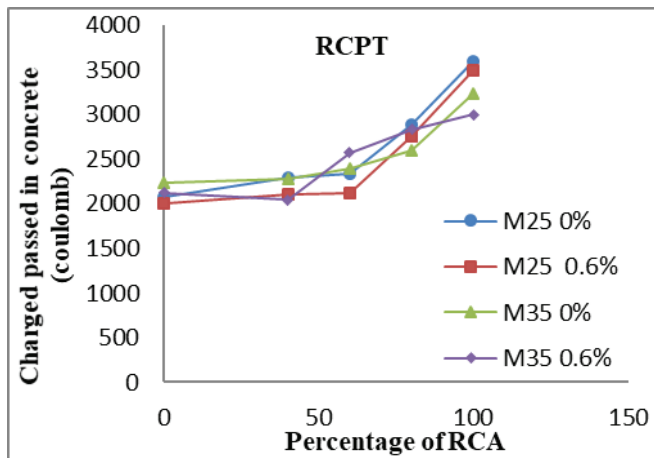


Fig. 3: RCPT test results.

Sorptivity: Sorptivity test is done to measure the capillary rise absorption rate of concrete. The cylindrical specimen of diameter 100mm was cut into pieces of thickness 50mm. These specimens were kept in an oven at 100° Celsius for 24 hours. Waterproofing coating needs to be done on the sides of the specimen. Dry weight has to be taken and the specimen is dumped in water for 30 minutes with 5mm above the specimen surface. The wet weight of the specimen was measured. From Figs. 4 and 5, RCA 40% in M25 grade of concrete shows about 33% and 33.5% higher sorptivity values without and with admixture respectively. Similarly, in case of M35, it was found to be 33.2% and 33.7% higher sorptivity value than RCA 0%. But still, RCA 40% satisfies the same range requirements as 0% RCA. Old mortar in RCA increases the sorptivity of the concrete. Sorptivity values increase with the increase of RCA in new concrete.

Correlation evaluation of the results: The correlation expression is developed between the ratio of the compressive strength of concrete with recycled aggregate and percentage of replacement of recycled concrete is shown in Fig. 6. The value of the regression coefficient (R²) and its corresponding linear equation are presented in Fig. 8. The R² coefficient is 0.98, which is greater than 0.85 (Montgomery & Peck 2015) exhibiting a remarkable correlation between the chosen parameters. The correlation expression can be adopted in the mix design of concrete made with recycled concrete.

Phase III - (Application of RCA in Steel Tube Members)

The main objective of this work is to utilize the construction and demolition concrete waste from which coarse aggregate is extracted for the use of the manufacturing concrete. The

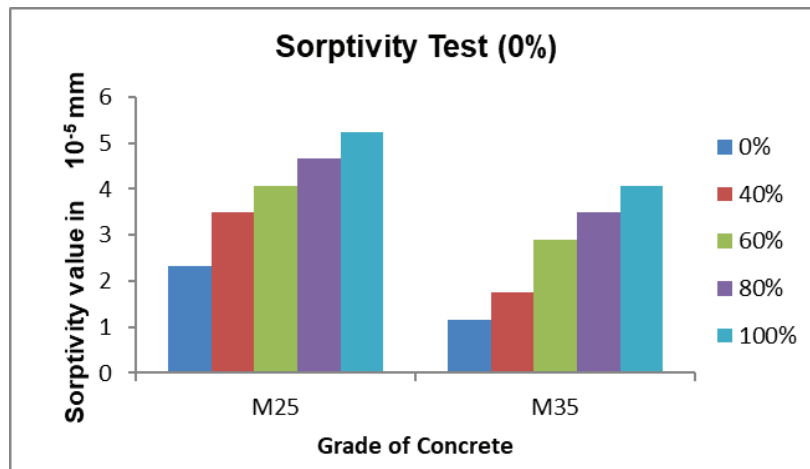


Fig. 4: Sorptivity test results for specimen without admixture.

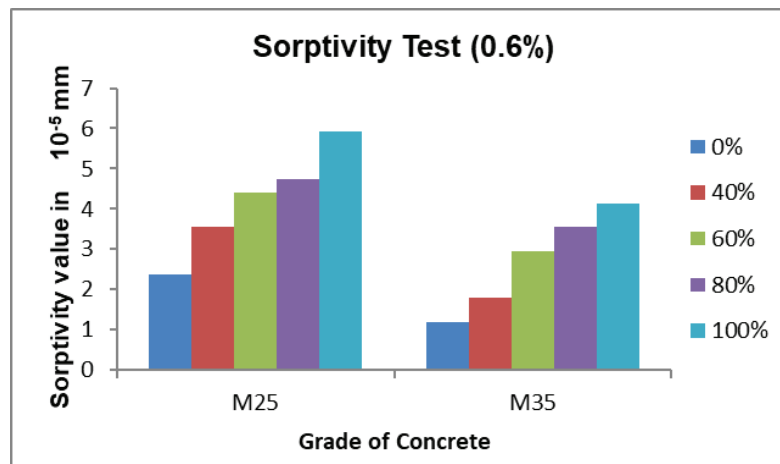


Fig. 5: Sorptivity test results for the specimen with admixture.

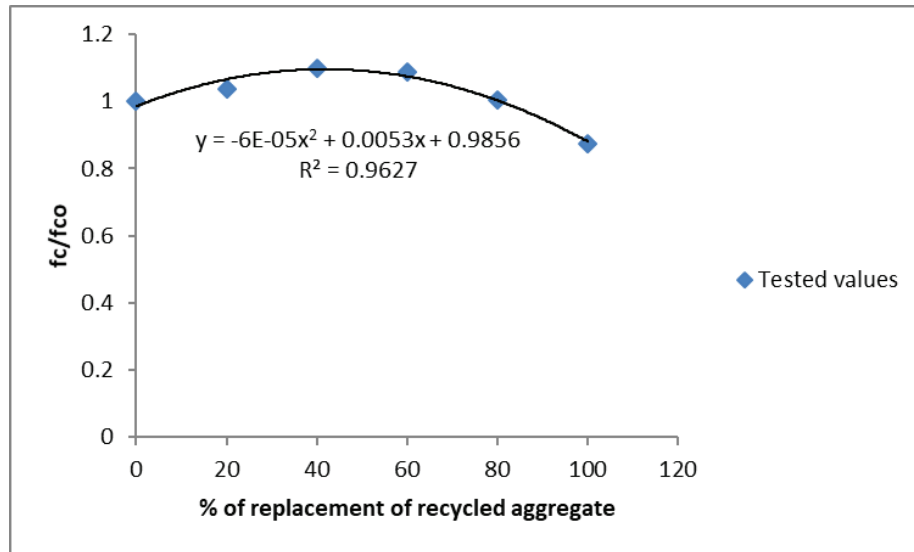


Fig. 6: Correlation evaluation of the results.

optimum percentage of recycled coarse aggregate is obtained from the results of compressive strength and tensile strength tests conducted. The durability of the concrete specimens for the various percentages of RCA in different grades of concrete is observed. In phase III, the experimental program consists of tests on CFT circular columns of diameter 114mm and rectangular columns of cross-section 98x48mm, both members of length 500mm with the thickness of the steel tube being 2.5mm. The CFT circular and rectangular sections of diameter to thickness ratio of 45.6 and 39.2 respectively.

The first part consists of testing of recycled coarse aggregate filled rectangular and circular sections of columns under axial loading. The second part consists of testing of recycled coarse aggregate concrete-filled rectangular beams under two-point loading with simply supported condition. The cross-sections of the beams were 98x48mm and the length 1m. The specimens tested are observed for the maximum load-carrying capacity, axial shortening, strain in column and beam, deflection in beams and failure modes. The specimen labels are given in Table 5.

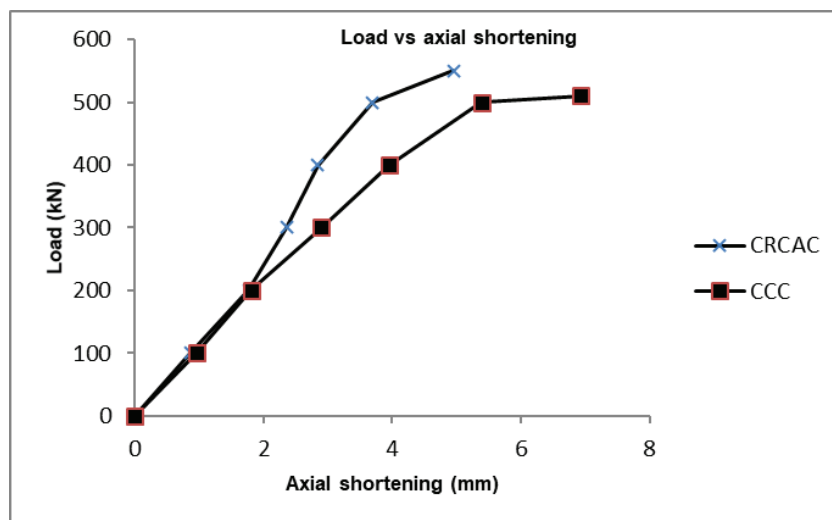


Fig. 7: Load vs axial shortening in the circular column.

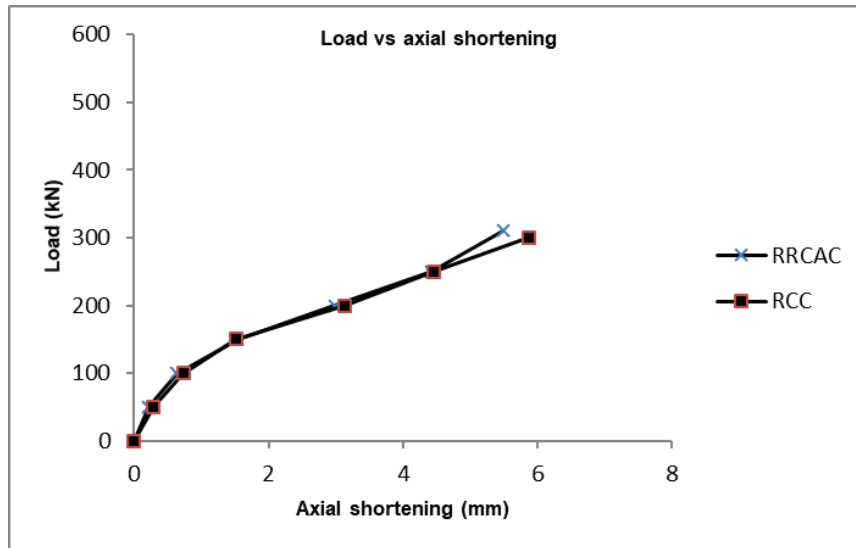


Fig. 8: Load vs axial shortening in rectangular column.

Failure modes and behaviour of RCA concrete-filled steel columns:

The test specimens behaved in a ductile manner and testing proceeded in a smooth and controlled fashion. Typical failure modes of concrete filled with normal concrete and recycled coarse aggregate concrete were local buckling in column are shown in Fig. 9. The columns were tested and the crushing of concrete inside the filled tube was heard when 70% of the load was applied to CCC and 80% of the load was applied to CRCAC. Similarly, in the case of rectangular columns, the crushing of concrete was observed at 75% of the load in RCC and 70% of the load in RRCAC. The buckling in columns occurred at 120mm from bottom in both CCC and CRCAC, whereas the buckling occurred at 90mm from the top in RCC and 110mm from the top in RRCAC. Typical failure modes of columns are shown in Fig. 9. On testing control and RCA concrete in filled columns, the ultimate load carrying capacity of CRCAC was found to be 558kN which is 7.2% increase than CCC. The axial shortening of CRCAC and CCC was found to be 6.9mm and 4.9mm respectively. Similarly, the ultimate load carrying capacity of RRCAC was found to be 308kN which is 7.2% lower than RCC and their corresponding axial shortening

was found to be 5.5mm and 5.8mm respectively. The load vs axial shortening of the columns are given in Fig. 7 and Fig. 8. The load carrying capacity of CRCAC has shown 7.2% increase in comparison with CCC and RRCAC has shown 3.45% decrease with RCC. Considering the overall ultimate load carrying capacity, CRCAC has shown an increase of 44.8% than RRCAC. Similarly, CCC has a 37.8% increase than RCC which shows that circular columns have higher load carrying capacity than rectangular sections in both control and recycled coarse aggregate concrete infilled column.

Failure modes and behaviour of RCA concrete-filled steel beams:

The failure modes of concrete filled with normal concrete and recycled coarse aggregate concrete was bending in beams. The concrete in filled steel beams exhibited bending at the centre with maximum load transferring at the loading points as shown in Fig. 11. When the load was applied, the bottom face of the steel tube exhibited an elongation allowing the beam to bend completely at the ultimate load. RRCAB exhibited a deflection measuring 60mm, 8.3% greater than RCB. The bending increased with increase in load upto 70% which is shown in Fig. 10

Table 5: Specimen label for columns and beam.

Specification	Specimen label for Column		Specimen label for beam
	Circular	Rectangular	Rectangular
Control specimen	CCC	RCC	RCB
Recycled aggregate specimen	CRCAC	RRCAC	RRCAB

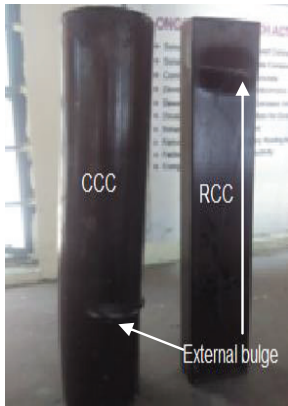


Fig. 9 (a): External buckling in control columns.

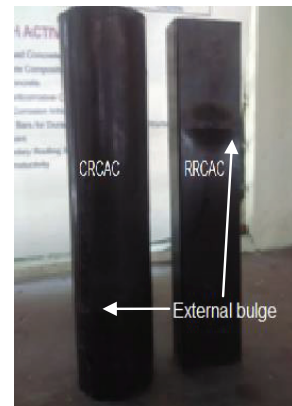


Fig. 9 (b): External buckling in RCA concrete-filled columns.

CONCLUSIONS

Based on the experimental work done, the following conclusions were drawn.

Taguchi method used to analyse a wide range of values was employed to analyse the compressive and split tensile strengths to obtain the optimum percentage as 40% of RCA to be replaced for NCA.

It is observed that as per ASTM C1202, the chloride penetration rate is moderate for 40% RCA in concrete for all grades of concrete.

The correlation expression developed between compressive strength and percentage replacement of recycled

aggregate in concrete and correlation expression exhibits a remarkable correlation between the chosen parameters.

RCA filled circular columns exhibit higher load-carrying capacity than rectangular sections in both normal and recycled aggregate concrete in filled column.

In the case of beams, the load-carrying capacity of RCA filled beams increased upto 3.62% and can be used in construction sites.

Use of recycled coarse aggregate in the concrete mixture is found to have sufficient strength properties close to that of natural coarse aggregate. This would enable many construction companies and developers to effectively use

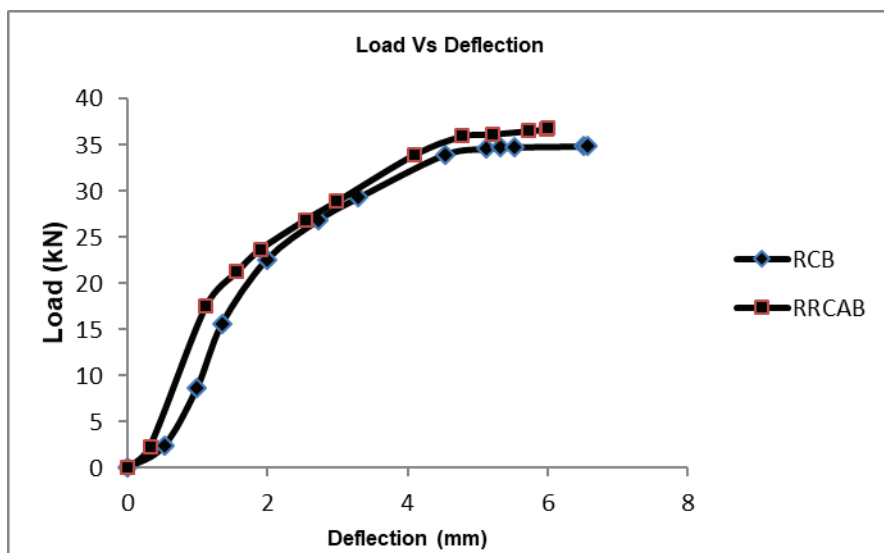


Fig. 10: Load vs deflection curve for beams.



Fig. 11: Failure pattern of beams.

the construction and demolition concrete waste thereby reducing its impact as landfills and provide an eco-friendly and sustainable environment.

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