Compressive Strength of RAC Cylinders Cast with Recycled Aggregates from Different Structural Members

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ABSTRACT

In this research study, the effect on the compressive strength of recycled aggregate members is presented. Demolished waste was collected from five different structural members. Hammering was used to reduce the aggregate size to a maximum of 1 inch. Using a 1:2:4 mix and 0.5 w/c ratio, 55 cylinders in 11 batches were prepared for each source of coarse aggregates. Additionally, one batch of cylinders was prepared with conventional concrete and its results were compared with the others. Altogether, 280 cylinders of standard size were prepared and cured for 28 days. The compressive strength of all specimens was determined in a universal testing machine. The optimum replacement percentage with the least reduction in compressive strength was found to be 35%. Column concrete contributed most to compressive strength with a reduction equal to 6.23%, whereas beam concrete caused a 6.9% reduction. Further, a comparison for mixed aggregates by taking the average of all sources was conducted. It showed that 35% replacement was also the optimum with a reduction in strength equal to 8.63%.

Keywords-recycled aggregates; demolishing waste; parent concrete strength; structural members; compressive strength; green concrete; demolishing waste

I. INTRODUCTION

Concrete is the most widely used material in today's construction industry. Concrete ingredients come from natural sources (fine and coarse aggregates) and factories (cement), posing the problem of depletion of natural resources and bringing a negative impact on the environment. It is reported by [1] that only in India, the consumption of aggregates reached 1.1 billion tons in 2014 and was increasing at the rate of 7.7% per year. The recent global boom of construction has posed the problem of waste generation due to demolishing of old, deteriorated, or short buildings. The debris generated due to demolishing is used in floor and plinth fills and the residual generally goes to landfills. The scarcity of space in metropolitan cities has posed the problem of proper dumping of this waste. Transportation to far locations poses additional financial burden on projects, and if left unattended, it poses serious problems to the environment and the public health. A solution to this problem is making use of demolishing waste in new concrete. Several attempts have been made to use demolishing waste in new concrete as replacement of all three ingredients of the concrete, but most effort have been conducted on using it as coarse aggregates as they occupy the maximum volume of the concrete body.

Coarse aggregates generated from demolishing waste are believed of inferior quality due to the old mortar attached with them, the age of concrete, parent strength, and different mix ratios used for different structural members. Review papers [2, 3] on the issue discuss the problem associated with recycled aggregates, the need of rules and regulations and their proper implementation, and the reasons for deviation in the properties of the aggregates. However, the material has the potential to be used in new concrete with careful consideration of its properties and mix design. Mix demolished waste has been treated to recycled aggregates and has been used in concrete by many researchers. But studies on the effect of recycled aggregates coming from different structural members are scarce.

The use of the demolished waste in new concrete is not new. Various components of the waste have been attempted to replace cement and fine or coarse aggregates in new concrete. However, the use of demolished waste as coarse aggregates is dominant. A review of the published works on the use of demolished waste in concrete [2, 4, 5] highlights the problems associated with demolished waste and the need of encouraging the industry by giving incentives, developing, and implementing the regulations in using the aggregates. The recycling process of the waste into aggregates is also an important aspect in order to acquire quality aggregates. Various recycling processes have been discussed. The properties of recycled aggregates from surface texture to abrasion resistance are important in the determination and ensuring the quality of the product. To this end, authors in [3] reviewed the properties of recycled coarse aggregates from demolished waste published by various scholars. The scatter in reported results shows the need of improvement in the recycling process and more work in the area.

Strength is one of the key properties of hardened concrete and should be properly checked to ensure its safety and serviceability. In this regard, authors in [6] studied the effect of recycled aggregates from demolished waste on the compressive strength of concrete. They used 0, 5%, 15%, 25%, 35%, 45%, and 50% replacement of conventional aggregates to prepare 324 standard size cylinders. The specimens were equally divided to 3 groups and were cured for 7, 14, and 28 days. The comparison of compressive strength test results showed maximum of 26% reduction in the strength for 28-day cured samples containing 50% recycled aggregates. Thus, the authors concluded to 50% as the optimum dosage of the aggregates to be used in new concrete. However, they suggest the use of new materials for low load areas. Authors in [7] used demolished waste as fine and coarse aggregates to study the fresh and hardened properties of concrete. The replacement level of the aggregates was up to 100% in increments of 10%. The results of the basic properties of the aggregates and the hardened properties of concrete showed deviation from the conventional concrete. The compressive strength was 30% less at 35% replacement level. The authors further argue that demolished waste may be used in new concrete up to 40% without any massive damage to light weight works. Authors in [8] used 0%, 10%, 20%, and 30% aggregates along with SP430 superplasticizer while studying the compressive strength of recycled aggregate concrete. From the test results, they observed increase in compressive, tensile, and flexural strength. Thus, the authors argue that the superplasticizer plays a vital role in strength improvement of recycled aggregate concrete. Authors in [9] also used demolished waste in new concrete as full replacement of conventional coarse aggregates. Comparison of strength results of the concrete with conventional concrete and drilled cores in recycled aggregate concrete showed that the proposed concrete exhibited only 2.69% decrease in compressive strength in comparison with conventional concrete and far higher than the strength of the cores. Based on the results, the authors argue that strength decrease less than 5% may be ignored, so the recycled aggregates can be used. Authors in [10] and recommended 50% as the optimum dosage of demolished waste to be used in new concrete with comparable compressive strength. Authors in [11] used 100% replacement of conventional aggregates with recycled aggregates to study the fresh and hardened properties of the concrete. From the test results they found 15.3% reduction at 50% dosage of recycled aggregates for 28-day cured samples. Authors in [12] observed 2.5% increase in compressive strength at replacement level of 20%.

Authors in [13] used waste concrete from paving blocks as recycled aggregates in new concrete and evaluated its strength properties. From the laboratory tests of compressive and flexural strength, they observed 22.3% decrease in compressive strength and 12.9% decrease in flexural strength at 50% dosage of the waste material. Authors in [14] on the other hand observed 9.6% increase in compressive strength at 50% replacement level of conventional aggregates with recycled aggregates from demolishing waste, using varying water cement ratio values. Authors in [15] also used demolished waste to replace conventional aggregates from 0 to 100% with increment of 25% to study the compressive strength at 7-, 14-, 21-, and 28-days curing age. The authors observed deviation in the properties of the aggregates. The strength test results showed that for the 28-day cured samples, the reduction in compressive strength was 15.7% at 25% dosage of the demolished waste. Beyond this dosage the strength reduced drastically. Authors in [16] used 0, 33.3%, 66.7%, and 100% dosage of debris as recycled aggregates. They also used silica fume as admixture to improve the strength properties of concrete. From the test results of 28-day cured samples, they observed that without the admixture (silica fume) the proposed concrete exhibited 6.12% decrease in compressive strength at 100% replacement of conventional aggregates, but when the admixture was added to the concrete it exhibited 9.95% increase in strength. Therefore, the authors favored the use of admixture for strength improvement of recycled aggregate concrete. Authors in [1] used demolished waste as coarse aggregates in preparation of M20 concrete. The replacement levels used to prepare the specimens were 0%, 10%, 20%, 30%, 40%, 50%, and 100%, in curing ages of 7, 14, and 28 days. Compressive, tensile, and flexural strength tests revealed that 30% dosage improves all the strength properties. The recorded increase in compressive strength at that dosage level was 12%.

Different additives have also been attempted in recycled aggregate concrete to check their effect on concrete properties. Among them steel fibers [17, 18], marble dust [19], fly ash [20, 21], curing types [22] are only few examples. Also, the behavior of recycled aggregates exposed to elevated temperature on the compressive strength was studied in [23]. It may be observed from the above summary that good time and effort has been devoted by the research community, but result scattering is still a major hurdle in developing a confidence level for the use of recycled aggregates. Table I shows a summary of the research results on the compressive strength results of recycled aggregate concrete.

This research aimed to check the influence of recycled aggregates from different structural members on the compressive strength of recycled aggregate concrete. The outcome of the work will not only give a clear understanding of the compressive strength when recycled aggregates from different structural members are utilized, but also will pave the way for future researchers for selecting demolished waste to be used in new concrete.

TABLE I. SUMMARY OF COMPRESSIVE STRENGTH RESULTS

Reference	Compressive strength	RCA dosage
[6]	-26.0%	50%
[7]	-30.0%	35%
[8]	+4.00%	30%
[9]	-2.69%	100%
[11]	-15.30%	100%
[12]	+2.50%	20%
[13]	-22.30%	50%
[14]	+9.60%	50%
[15]	-15.70%	25%
[16]	-6.12%	100%
[1]	+12.00%	30%

II. MATERIALS AND METHODS

The demolishing waste used in this research study was collected from five structural members. The details are given in Table II. Large blocks of demolishing waste (Figure 1) were reduced to the maximum of 25 mm size by hammering. Reduced aggregates were then sorted for unwanted substances followed by washing and drying. The process was repeated for all the five sources of aggregates. Conventional aggregates of the same size were also washed and dried in the laboratory. The basic properties of the coarse aggregates were determined by ASTM [24] and are given in Table III. The conventional and recycled aggregates from the all sources were sieved (Figure 4) to ensure well graded aggregates in the concrete mix. Ordinary Portland cement, hill sand, and potable water were used in all the concrete mixes with 1:2:4 mix ratio and 0.5 water-cement ratio [25]. Conventional coarse aggregates were replaced in dosages of 5%, 15%, 25%, 35%, 45%, 55%, 65%, 75%, 85%, 95%, and 100%, in a total of 11 batches (B1 – B11). Additionally, one batch of specimens was prepared with conventional aggregates (CC) only. In each batch, 5 cylinders of standard size (6"/12") were prepared. This process was repeated for all types of demolished waste. Hence, a total of 280 specimens were prepared. In each mix, concrete ingredients were batched by weight and mixed in a concrete mixer. The molds were prepared in the standard fashion by oiling the inner of the molds. Each mold was filled in three layers and compaction was done by a table vibrator.

TABLE II. DETAILS OF DEMOLISHED WASTE

Designation	Aggregates source	Location	Mix ratio
RA1	Roof/slab concrete	University colony Nawabshah	1:2:4
RA2	Beam concrete	Bhangwar colony Nawabshah	1:2:4
RA3	Main gate columns concrete	Line par Nawabshah	1:1.5:3
RA4	Footing concrete	Garib Abad Nawabshah	1:2:4
RA5	Lintel concrete	Makhdoom Shah Nawaz Colony Hala	1:3:6

Fig. 1. Demolishing waste.

Fig. 2. Cylinder specimens.

Fig. 3. Specimen curing.

TABLE III. BASIC PROPERTIES OF THE AGGREGATES

Designation	Specific gravity	Water absorption (%)	Density (kg/m^3)	Soundness (%)
NA	2.6	1.2	1672.2	4.87
RA1	2.4 (-8.36%)	3.14 (+161.67%)	1491.1 (-10.83%)	6.04 (+24.02%)
RA2	2.4 (-8.36%)	3.12 (160.00%)	1486.3 (-11.12%)	6.32 (+29.77%)
RA3	2.5 (-4.56%)	3.05 (+154.16%)	1540.5 (-7.87%)	5.71 (+17.25%)
RA4	2.4 (-6.46%)	3.18 (165.00%)	1411.7 (-15.58%)	6.71 (+37.78%)
RA5	2.3 (-9.80%)	3.17 (+164.16%)	1471.6 (-11.99%)	6.73 (+38.19%)

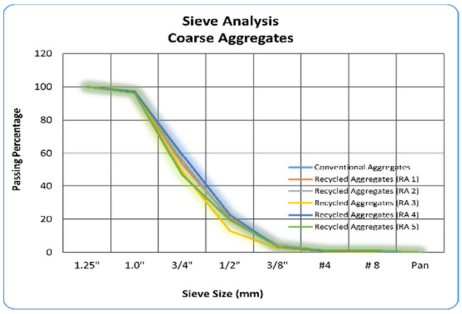

Fig. 4. Sieve analysis of the coarse aggregates.

After 24 hr of filling the cylinders, the molds were opened (Figure 2), and the specimens were cured for 28 days by fully immersing in potable water (Figure 3). After the completion of the curing age, the specimens were taken out of the water and were allowed to air dry for 24 hr, followed by testing for crushing load in a universal testing machine (Figure 5). The load was gradually increased at a rate of 0.5 kN/sec until failure of the specimens. The compressive strength was calculated from the recorded failure load by the standard formula for the purpose.

Fig. 5. Specimen testing.

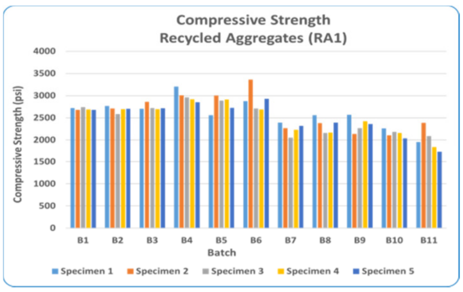

Fig. 6. Compressive strength (RA1).

The computed compressive strength results in each dosage of recycled aggregates were averaged and are plotted in Figures 6-10.

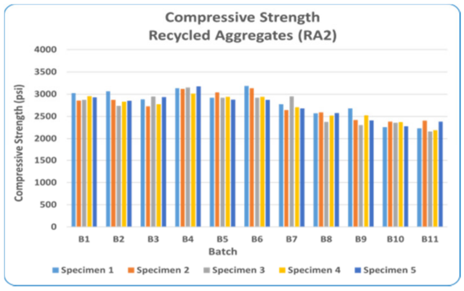

Fig. 7. Compressive strength (RA2).

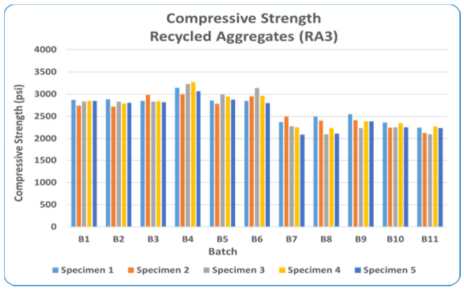

Fig. 8. Compressive strength (RA3).

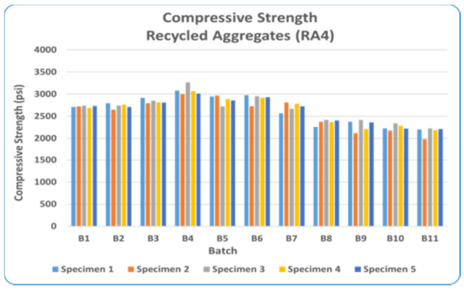

Fig. 9. Compressive strength (RA4).

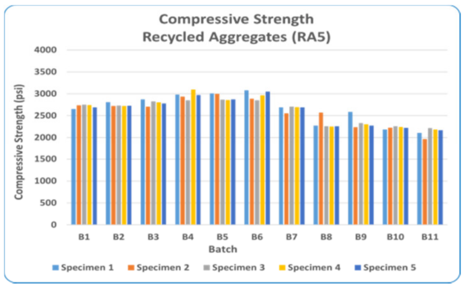

Fig. 10. Compressive strength (RA5).

III. RESULTS AND DISCUSSION

Table III reports the obtained results of the basic properties along with their percentile difference with respect to conventional aggregates. It can be observed that all the evaluated basic properties deviated from those of conventional aggregates. The specific gravity of all recycled aggregates was observed ranged between -4.56% and -9.8% in comparison with conventional aggregates. Similarly, water absorption ranged between +154% and +165%, density of recycled aggregates was recorded in the range of -7.87 to -15.58%, and soundness was observed in the range of +17.25% to 38.19%. All four properties evaluated in this research work deviated from the results of conventional concrete. Although different percentile results were observed, yet the deviation concurred the results published in the literature. The deviation in the properties is due to the old mortar attached to the aggregates whose density, specific gravity, and resistance to wear is weaker than stone's. Also, it absorbs more water than stone giving rise to the water absorption results. These parameters, particularly water absorption, should be considered while deciding the water-cement ratio of the mix to ensure proper workability of the concrete mix utilizing recycled aggregates.

From Figure 2, it may be observed that the grading of recycled aggregates is in good agreement with that of conventional aggregates. The percentage passing from various sieves of both types of aggregates was within the specified ranges of the relevant ASTM standards, ensuring that well graded aggregates were used in the concrete mix. The compressive strength results of each batch were averaged and are compared with the average results of conventional concrete in Figures 11-15.

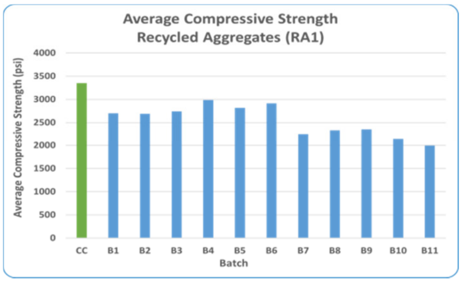

Fig. 11. Average compressive strength (RA1).

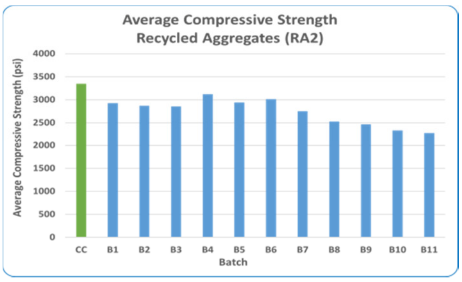

Fig. 12. Average compressive strength (RA2).

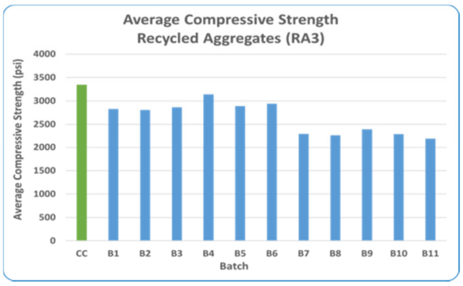

Fig. 13. Average compressive strength (RA3).

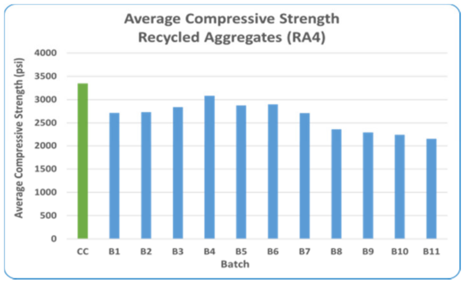

Fig. 14. Average compressive strength (RA4).

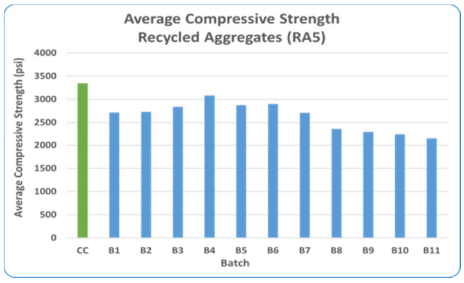

Fig. 15. Average Compressive strength (RA5).

TABLE IV. % DIFFERENCE PERCENTAGE OF THE AVERAGE COMPRESSIVE STRENGTH OF RECYCLED AGGREGATE CONCRETE WITH CONVENTIONAL CONCRETE

Batch	RA (%)	NA (%)	RA1	RA2	RA3	RA4	RA5
CC	0	100	--	--	--	--	--
B1	5	95	-19.36	-12.58	-15.54	-18.81	-18.94
B2	15	85	-19.62	-14.26	-16.16	-18.39	-18.07
B3	25	75	-18.19	-14.82	-14.48	-15.24	-16.45
B4	35	65	-10.80	-6.90	-6.23	-7.83	-11.36
B5	45	55	-15.88	-12.24	-13.66	-14.10	-12.76
B6	55	45	-13.02	-10.11	-12.21	-13.35	-11.40
B7	65	35	-32.79	-17.87	-31.36	-19.06	-20.33
B8	75	25	-30.42	-24.58	-32.27	-29.36	-30.65
B9	85	15	-29.80	-26.33	-28.48	-31.40	-29.96
B10	95	5	-35.85	-30.40	-31.55	-32.86	-33.51
B11	100	0	-40.39	-32.07	-34.46	-35.50	-36.42

From Figures 11-15, it may be observed that the overall pattern of the average compressive strength is decreasing with increase in dosage of recycled aggregates, in comparison to conventional concrete. From the five groups of recycled aggregates, batch B4 showed the highest average compressive strength. The replacement percentage of conventional aggregates of this batch was 35%. Batches B5 and B6 showed a little improvement in strength in comparison with the other batches, but less than batch B4. This should be due to the less attached mortar and thus voids in the recycled aggregates of these batches. The difference of average compressive strength of all batches of all groups was computed and is given in Table IV. It may be observed that the reduction in average compressive strength for batch B4 is the least among the batches of recycled aggregate concrete. At this replacement level, recycled aggregates from different structural members are compared. It is observed that recycled aggregates from beam and column perform better than recycled aggregates from other structural members used in this study. This is due to the proper mix ratio and the strength of the parent concrete. To compare the results further, the average compressive strength of the batches is again averaged for all sources of aggregates to check the impact of mixed aggregates from different structural members. The obtained average is compared with conventional concrete. The percent difference is plotted in Figure 16. It is evident from this Figure that again the decrease in strength is minimum (8.62%) for batch B4. Therefore, the optimum replacement level of the conventional aggregates with recycled aggregates from demolished waste independently from a structural member or mixed from different structural members is 35%.

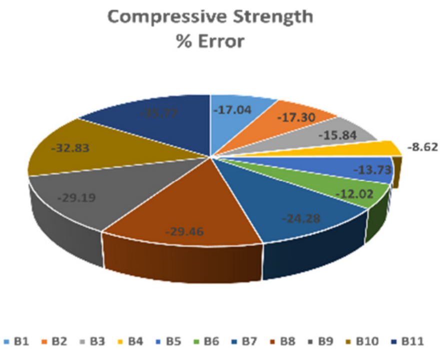

Fig. 16. Average compressive strength of all sources of recycled aggregates.

IV. CONCLUSION

The research presented in this paper studied the effect of recycled aggregates origin and percentage on the compressive strength of concrete. The results can help in selecting the demolished concrete for recycling into coarse aggregates with least possible reduction in strength. Based on the results of this research, the following are concluded:

- The deviation in the properties of recycled aggregates confirms the results of other published studies.
- The grading of the recycled aggregates from all sources was in good agreement with conventional aggregates'. The passing percentage at various sieves was within relevant ASTM ranges.
- Compressive strength results showed that 35% replacement of conventional aggregates with recycled aggregates as the optimum with least reduction in compressive strength.
- The performance of recycled aggregates from beam and column concrete was better than that of recycled aggregates from other structural members.
- Recycled aggregates from beam concrete showed 6.9% reduction in compressive strength.
- Recycled aggregates from column concrete performed better than recycled aggregates from beams, with 6.23% reduction in compressive strength. The difference between the two reductions is minimum and hence may be ignored. But preference should be given to recycled aggregates from column concrete.
- The average compressive strength from all sources (mix aggregates) showed again 35% as the optimum dosage with reduction in compressive strength equal to 8.62%.

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