

Experimental investigation on Utilization of RCA in Low, Medium and High Strength Self Compacting Concrete

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Abstract. Self Compacting Concrete (SCC), owing to its advantages, is now a buzz word in the present construction industry. The application of recycled aggregates in concrete mixes is widely investigated. The present investigation focuses on the use of RCA in SCC. The variables of study include grade of concrete (Normal, standard grade and high strength), RCA content (0 to 100%) and age of concrete (7 and 28 days). The parameters of investigation are fresh and hardened state properties, viz. compressive, split tensile and flexural strengths. The mix design was carried out based on modified Nan Su method. The fresh state properties were satisfied for all RCA contents in all the three grades of concretes tested. The test results were encouraging and the target mean strength could be attained in M30 concrete even with 50% RCA as replacement of natural aggregate. However, a reduction in strength was observed as the grade of concrete increased. Optimum RCA content was arrived at based on the strength for different grades of concretes tested.

1. Introduction

The experimental investigations on the recycling of Construction and Demolition Wastes have long been accepted to have the possibility to conserve natural resources and to decrease energy used in production. In some nations it is a standard substitute for both construction and maintenance, particularly where there is a scarcity of construction aggregate. Researches on Construction and Demolished Waste (CDW) reveal that the behaviour of structural concrete with recycled aggregate is comparable to that of the concrete with conventional natural aggregate Manzi et al. [1,2] (2013). The use of such materials solves the disposal problem, apart from reducing the cost of construction materials.

The Indian construction industry today is amongst the five largest in the world and the supply of natural aggregate has also emerged as a problem in some of the metropolis in India. The requirement of natural aggregates is not only required to fulfil the demand for the upcoming future projects in India but also the needs of extensive repairs or replacements required for the existing infrastructure. The future of construction industry sector seems to be in dark with the likely shortage of natural resources as seen today. Several market constraints and technical challenges exist when developing markets for new products. Notable among these barriers is consumer uncertainty about the quality and consistency of products due to the lack of practical performance and engineering data on recycled materials A.R.Khaloo, et al. [3-5] (1996). Such data is necessary to assist with the development of appropriate design codes to guide product specification and performance information on recycled materials.



The concept of self compacting was proposed in 1986 by Professor Hajime Okamura [6] (1997), but the prototype was first developed in 1988 in Japan, by Professor Ozawwa [7] (1989) at the University of Tokyo. In the current research work, mix design adopted is based on Packing Factor (PF) of aggregate proposed by NAN-SU [8] (2001). PF is the ratio of mass of aggregate of tightly packed state in SCC to that of loosely packed state. The workability tests performed in this research were as per EFNARC [9] (2002). Edamatsu et al. [10] (2003) proposed modifications to mix design approach of Okamura. Experimental investigations on RCA concrete [11-16] indicate that there is no effect on strength of concrete compared to that of Conventional aggregate concrete. Recycled aggregate concrete had 7 to 9% lower relative density and 3 to 5 times higher water absorption than that of natural aggregate concrete while there is no effect on strength of concrete for RCA replacements upto 30%. Ajdukiewicz et al. [17] (2002) considered different grades of concrete ranging from M40 to M70 in their study and found that there is a marginal difference in the tensile strength of Recycled Aggregate Concrete (RAC) and Natural Aggregate Concrete (NAC). They also found that the RAC possesses better durability characteristics compared to conventional concrete though the tensile strength is slightly lesser for the former. A marginal decrease was observed in the compressive strength of RCA concrete.

1.1. C&D Waste Management in India

The Indian construction industry is highly labour intensive and has accounted for approximately 50% of the country's capital outlay in successive Five-Year Plans. Out of 48 million tonnes of solid waste generated in India in a year, C&D waste makes up 25%. Projections for building material requirement by the housing sector indicate a shortage of aggregates to the extent of about 55,000 million m³ [19]. An additional 750 million m³ of aggregates would be required to achieve the targets of the road sector. But there is a significant gap in demand and supply. Estimated C&D waste generation during construction is 40 to 60 kg per m². Similarly, waste generation during renovation and repair work is estimated to be 40 to 50 kg per m² as per C&D waste estimation was done by Technology Information, Forecasting and Assessment Council (TIFAC) [18]. The highest contribution to waste generation comes from demolition of buildings which is between 300 to 500 kg per m². Therefore in the present study it is proposed to develop low, medium and high strength SCC with RCA.

2. Experimental Program

2.1. Materials used

2.1.1. Cement: Ordinary Portland Cement of grade 53 with specific gravity 3.15 was used in this investigation.

2.1.2. Mineral Admixtures: Fly ash conforming to IS 3812 (Part-1):2003 [21] was used. Chemical composition of fly ash is given in Table 1. It was found that the compressive strength (and workability) of RCA concrete can be significantly improved by adding fly ash to the mixture [1, 3, 4].

2.1.3. Fine and Coarse Aggregates: The physical properties of Sand, NCA and RCA used in the present experimental investigations are tabulated in Tables 2 and 3. The maximum size of coarse aggregate was 12.5 mm. Figure 4 shows the raw RCA obtained from C&D waste concrete and the laboratory Jaw Crusher.

2.1.4. Chemical Admixtures: Super plasticizer (Polycarboxylate Ether based) with specific gravity 1.01 and pH:8, and Viscosity Modifying Admixture (Glenium B233 stream 2) with specific gravity 1.1 and pH:6 were used in this work.

2.1.5. Water: Locally available potable water was used.

Table 1. Chemical composition of Fly Ash

Chemical Property	Loss on Ignition	Alumina (as Al ₂ O ₃)	Silica (as SiO ₂)	Iron (as Fe ₂ O ₃)	Calcium (as CaO)	Magnesium (MgO)	Sodium (as Na ₂ O)	Potassium (as K ₂ O)
Result	0.43	16.31	60.82	17.17	4.64	--	0.34	0.08

Table 2. Properties of Sand, Natural and Recycled Coarse Aggregate

Property	Sand	NCA	RCA	Method
Type	Natural	Crushed	Crushed	--
Specific gravity	2.62	2.65	2.45	IS:2386 Part-3-1963 [20]
Total water absorption	1.0%	0.3 %	2.4 %	IS:2386 Part-2-1963
Moisture content	0.15%	0.8%	0.45%	IS:2386 Part-2-1963
Bulk Density (Loose)	1567kg/m ³	1380 kg/m ³	1355 kg/m ³	IS:2386 Part-3-1963
Bulk Density (Compacted)	1713kg/m ³	1532 kg/m ³	1540 kg/m ³	IS:2386 Part-3-1963
Fineness Modulus	2.63 (Zone II)	5.94	4.65	IS:2386 Part-2-1963
Elongation Index	--	7.10%	11.27%	IS:2386 Part-2-1963
Flakiness Index	--	6.15%	7.85 %	IS:2386 Part-2-1963

Table 3. Properties of Coarse Aggregate for various proportions of RCA

Property	Percentage of RCA				
	0%	25%	50%	75%	100%
Specific gravity	2.65	2.60	2.53	2.48	2.45
Packing factor	1.12	1.12	1.13	1.13	1.14
Water absorption (%)	0.3	1.0	1.6	2.0	2.4

2.2. Methodology

Modified Nan Su Mix design was used for the design of mixes and then the mix proportions were modified after conducting the workability tests such as Slump flow test, V-funnel test, and L-box test. The modifications were made according to EFNARC guidelines. The mix proportions are given in Table 4. Compressive, split tensile and flexural strengths at the ages of 7 and 28 days were determined.

Table 4. Quantities of different ingredients of various grades of SCC per cum

Grade of Concrete	W/P	Cement (Kg)	Fly ash (kg)	Coarse Aggregate		Sand (Kg)	Admix-ture (kg)	VMA (kg)	Water (lts)
				CA (Kg)	RCA (Kg)				
M30	0.37	407.14	160.43	737.66	0.00	784.49	6.81	0.68	212.00
M50	0.33	489.29	110.60	737.66	0.00	784.49	7.20	0.72	199.00
M70	0.25	710.00	40.19	737.66	0.00	784.49	9.00	0.90	185.00

(Note: Natural Aggregate is replaced with RCA in increments of 25%, i.e., 0%,25%,50%,75% and 100%)

Table 5. Fresh properties of SCC with Different proportion of RCA

Mix Designation	Slump spread in mm	T50 Slump Flow in sec	V-Funnel (T_0) in sec	L- Box Test (h_2/h_1) Test Results
NASCC-M30-0%	720	2.5	8.00	0.95
RASCC-M30-25%	700	3.5	8.28	0.93
RASCC-M30-50%	690	4.0	8.50	0.90
RASCC-M30-75%	680	5.5	8.80	0.88
RASCC-M30-100%	650	6.0	9.00	0.85
NASCC-M50-0%	800	2.5	6.80	0.95
RASCC-M50-25%	780	3.0	7.20	0.93
RASCC-M50-50%	750	3.5	8.50	0.89
RASCC-M50-75%	720	5.5	8.80	0.85
RASCC-M50-100%	680	6.5	9.00	0.80
NASCC-M70-0%	780	3.0	7.50	0.98
RASCC-M70-25%	750	4.0	7.80	0.96
RASCC-M70-50%	720	5.5	8.50	0.90
RASCC-M70-75%	680	6.0	8.00	0.86
RASCC-M70-100%	650	6.5	9.50	0.80

3. Test Results and Discussion

The fresh state properties are given in Table 5. The compressive, split tensile and flexural strengths, for all the three grades of concrete tested, are plotted in Figures 1, 2 and 3 respectively.

3.1. Workability Properties of M 30, M50 & M70 Grade NASCC & RASCC Concrete

3.1.1. Slump cone test results: The natural aggregate has slump flow of 720 mm for M30 grade concrete while the same for 100% RAC is 650. The slump value is found to decrease as percentage of RCA increased in all the grades of concrete tested. Similar trend was observed in M50 and M70 grades also. The slump values ranged between 800 to 680 mm for M50 and 780 mm to 650 mm for M70 grade respectively.

3.1.2. T-50 Slump Flow Results: The natural aggregate has T-50 slump value as 3 sec. There is no appreciable change in the value of T-50 slump flow for all replacements of aggregate for M30, M50 and M70 grades of concretes.

3.1.3. V-Funnel Test Results: The natural aggregate concrete has V-funnel value of 8 sec and it was found to increase with increased percentage of RCA, indicating reduced workability.

3.1.4. L-Box test results: The values of h_2/h_1 were found to decrease with increased percentage of RCA, indicating reduced workability. This is true for all the grades of concretes tested.

3.2. Compressive strength

The compressive strengths of M30, M50 and M70 Grade concretes is observed to decrease with increased recycled aggregate content at all ages. The reduction in compressive strength of M30 grade concrete is less than 10% for 7 days curing while it is about 15% for 28 days curing. However, for M50 grade concrete, the maximum reduction in strength due to the inclusion of RCA is around 20% for 7 days curing while it is about 25% for 28 days curing. This clearly shows that the loss of compressive strength is more in higher grade concretes. The Target strength is reached for M30 grade concrete up to 50% replacement natural aggregate by RCA and beyond 50% replacement there is

marginal deviation from the target strength. However, for M50 grade concrete the target strength could reach only for natural aggregate concrete. As the deviation of target strength is negligibly small, 25% RCA is recommended for M50 grade concrete. For M70 grade, though the design strength is achieved for all the RCA contents including 100% replacement of NA by RCA, target strength could not be attained.

3.3. Tensile strength: The split tensile strength is also found to reduce as the percentage RCA increased in the mix in all the three grades of concrete tested. However, the variation is within 10 to 15% range for M30 and M50 grades while it is 25% in M70 grade concrete tested at 28 days (Figure 2). This clearly shows that the loss of strength is more in high strength concretes when RCA is used.

3.4. Flexural strength: Increased RCA content reduced the flexural strength in all the grades of concrete tested. The reduction in strength as percentage RCA increased is more in all the three grades of concrete at the age of 7 days compared to 28 days age. In M70 grade concrete, the reduction in flexural strength is marginal when tested at the age of 28 days.

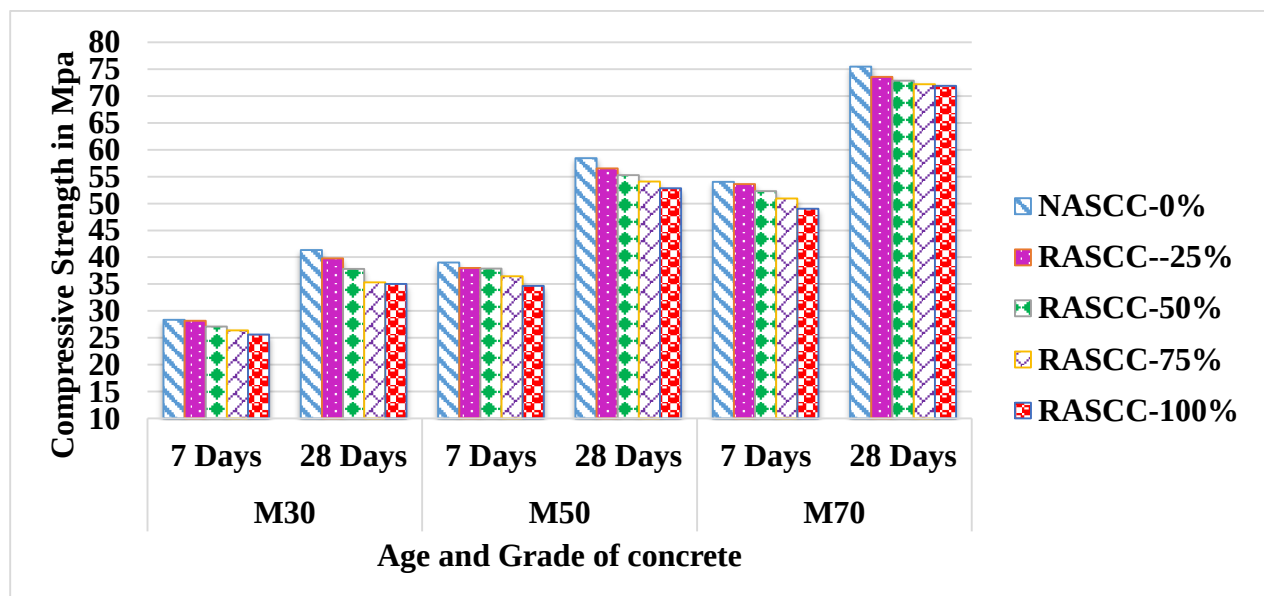


Figure 1. Variation of Compressive Strength with RCA for different grades of concrete and different ages of curing

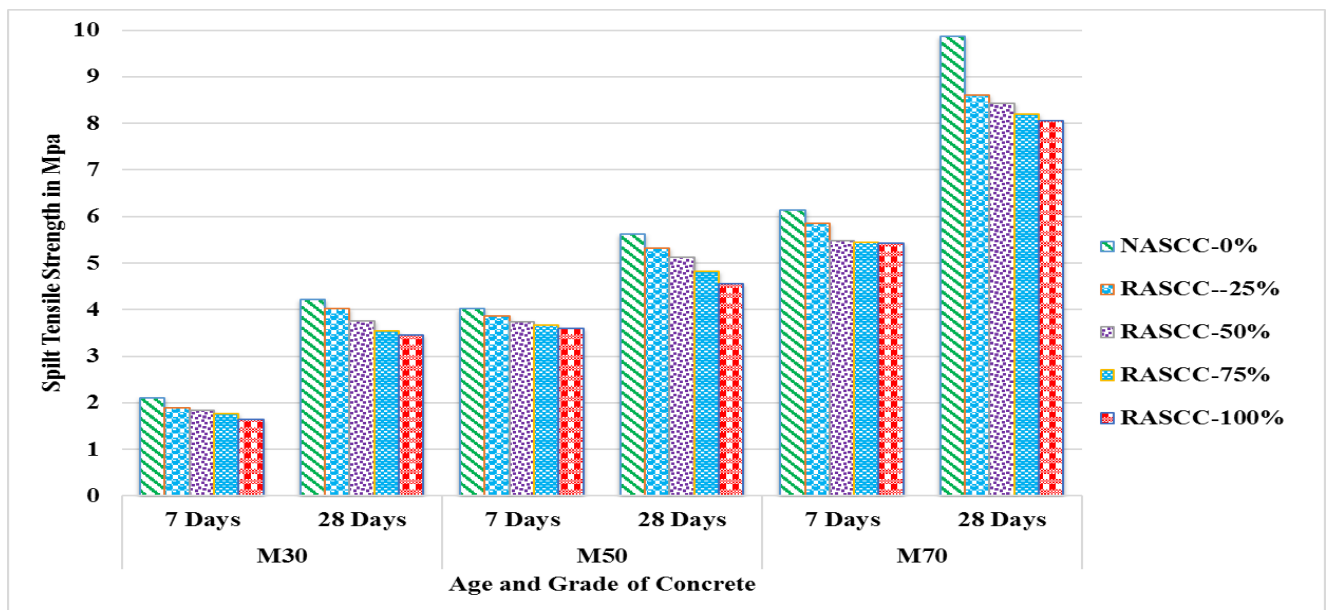


Figure 2. Variation of Split Tensile Strength with RCA for different grades of concrete and different ages of curing

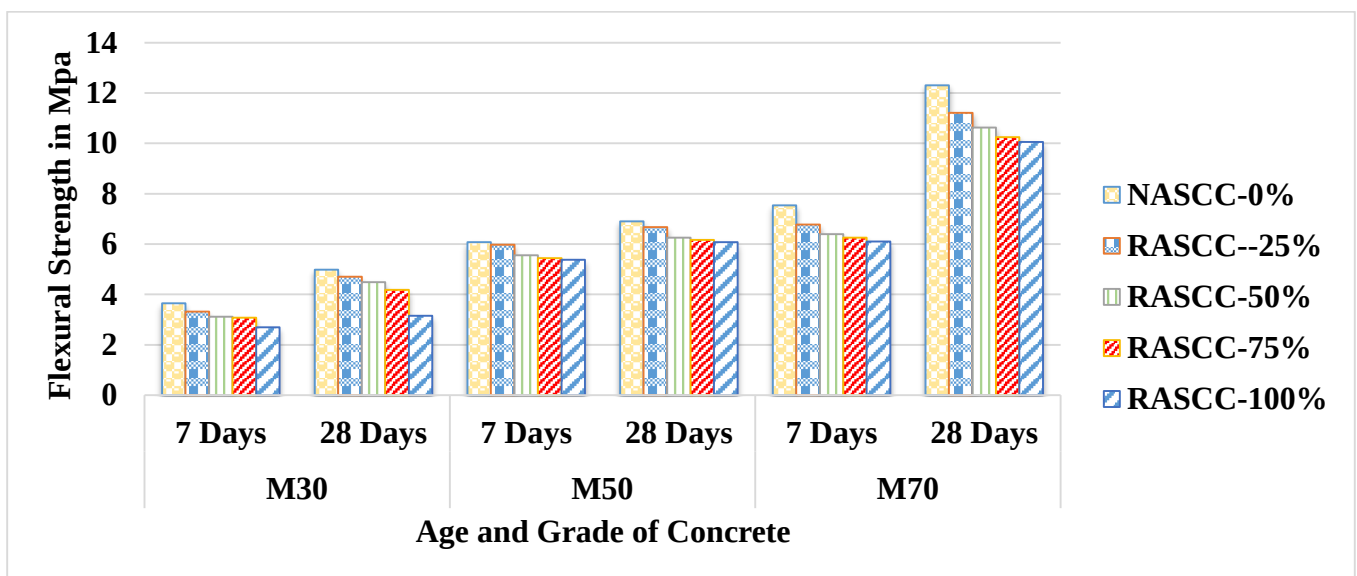


Figure 3. Variation of Flexural Strength with RCA for different grades of concrete and different ages of curing



Figure 4. Demolished Concrete Material and Laboratory JAW crusher



Figure 5. Testing of cubes in UTM



Figure 6. Workability tests for SCC

4. Conclusions

Recycled concrete aggregates can be used for both non-structural and structural concrete. However, based on the studies presented in this paper, it is clear that there is a reduction in the strength of recycled concrete aggregate based concrete and hence it should be blended with natural aggregates for improved properties. The following conclusions are drawn based on the experimental investigations carried out in the present study:

1. The fresh properties requirements of SCC are met with for all the mixes tested, i.e., M30, M50 and M70 grades and all the RCA contents from 0% to 100% as replacement of natural aggregate.
2. The slump spread value reduced with the increase of RCA content in all the grades of concretes tested, indicating reduction in workability.
3. The slump spread value is more for M50 concrete compared to M30 grade. This shows rich mixes are more workable compared to lean mixes. However, higher dosage of super plasticizer is required in high strength concretes to get desired workability.
4. There is not much change in the compressive strengths of RASCC of M30, M50 & M70 grade at 7 days age, for 50% replacement of natural aggregate by RCA. However, the loss of strength of around 14% is observed at the age of 28 days.
5. Split tensile strength and flexural strength of RASCC followed more or less similar trend and the decrease in these values compared to NASCC was found to be around 10%.
6. From the experimental results, it is observed that the optimum percentage replacement of natural aggregate by RCA is 50% to get reasonable strength in compression, tension and flexure.

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