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RESEARCH ARTICLE

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EXPERIMENTAL STUDIES ON MULTIPLE RECYCLING OF CONCRETE WASTE

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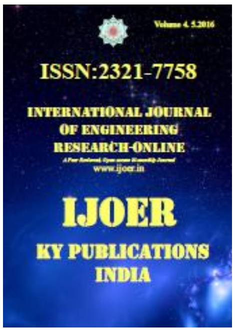

ABSTRACT

In the literature, there are enough number of experimental references which suggest a good performance of Recycled Aggregate Concrete (RAC) even with 100% Recycled Coarse Aggregate (RCA) which are recycled once. However, very few experimental studies are conducted on multiple recycling of concrete waste. A detailed experimental study is undertaken to assess fresh and hardened properties of RAC made with first, second and third cycle RCA. The Control Mix (CM) is designed as per IS 10262:2009, by considering the properties of natural aggregates. Two fractions of coarse aggregates are used in the mix design viz., 60% (< 20 mm and > 10mm) and the remaining 40% (< 10 mm and > 4.75mm). RAC mixes are produced by replacing 20%, 40%, 60% and 100% of Natural Coarse Aggregate (NCA) with first, second and third cycle RCA respectively. The test results with respect to compressive strength at 7 and 28 days, density and split tensile strength are statistically analysed, to determine their correlation as well as the ratio between them.RAC mixes made with first, second and third cycle RCA are found to exhibit similar properties at corresponding replacement level. The study concludes that "concrete waste is many times recyclable like steel without any significant loss in strength.

Keywords –Recycled Coarse Aggregate (RCA), Recycled Aggregate Concrete (RAC), Control Mix (CM), Natural Coarse Aggregate (NCA) compressive Strength, Density, Split tensile strength.

I. INTRODUCTION

Recycling strategy, is the key to achieve sustainability in construction and towards that, it is imperative, that the material, even after repeated recycling process, is still in the recycling loop, without losing its intrinsic material characteristics.In the literature, there are enough number of experimental references, whichsuggest a good performance of RAC made with even 100% RCA which are recycled once. Limited experimental works are reported in the literature [1-3], to ascertain, the ability of concrete wastes to be 'many times recyclable'

II. LITERATURE REVIEW

Iqbal Marie and Hisham Quiasrawi [1], have reported the possibility of multiple recycling of RAC. The first and second generation concrete contained up to 20% replacement of NCA. Fresh and hardened properties of first and second generation concrete are obtained. Second generation RAC mixes

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performed better than first generation both in terms of workability and strength.

Jorge de Brito et al [2, 3], have measured the compressive strength of three series of concrete cubes containing coarse aggregates recycled from previous series.The authors were able to maintain the strength and workability characteristics in successive cycles of RAC.

III. MULTIPLE RECYCLING PROCESS

A. Control Mix: First, the concrete mix with 100% NCA termed as control mix is prepared to cast cubes and cylinders. Test results of control mix are used to compare the strength properties of subsequent RAC mixes.

B. First Generation RCA (RCA-I) :Tested specimens are crushed to recover RCA which are termed as “RCA - I” and used, in varying proportions, as, 20, 40, 60 and 100% replacement for NCA to produce RAC mixes, which are termed as “ First generation concrete”.

C. Second Generation RCA (RCA-II):Tested, cube and cylinder specimens of first generation concrete, made with 100% replacement for NCA by RCA – I, are crushed to recover RCA which are termed as “RCA – II” ,and used in varying proportions as 20, 40, 60 and 100% replacement for NCA, to produce RAC mixes, which are termed as “Second generation concrete”.

D. Third Generation RCA (RCA-III):Tested, cube and cylinder specimens of RAC mixes, made with 100% replacement for NCA by RCA – II, are crushed to recover RCA which are termed as “RCA - III” and used in varying proportions, as 20, 40, 60 and 100% replacement for NCA to produce RAC mixes, which are termed as “Third generation concrete”.

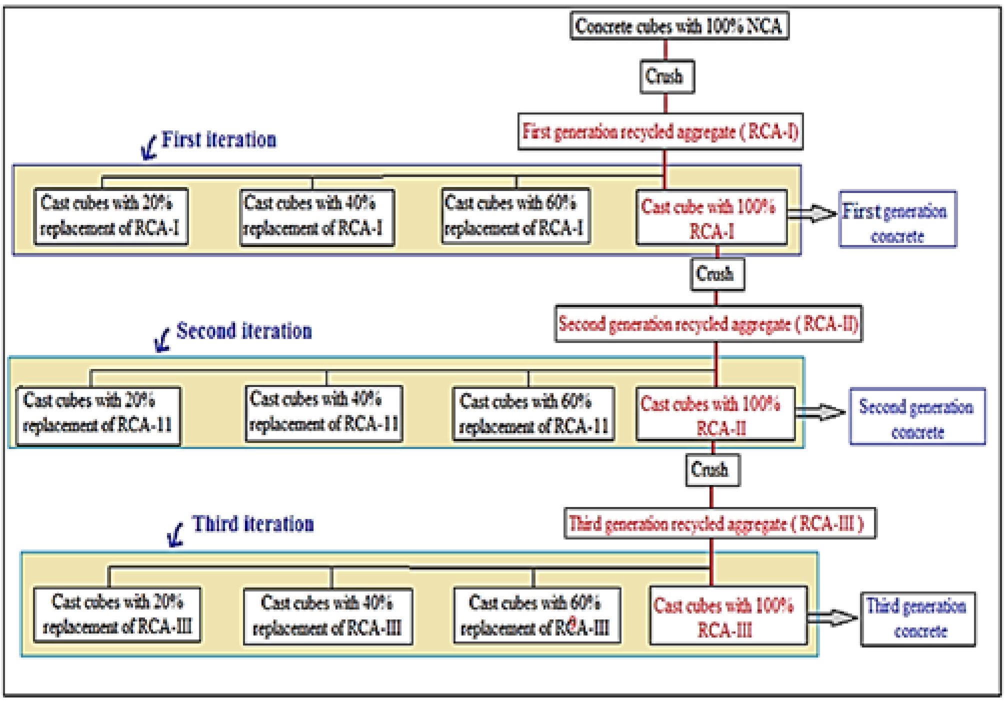

Fig. 1 Block diagram of the process of recovery of subsequent RCA

Fig.1, shows the scheme adopted, to recover RCA from previous concrete mixes to make new generation RAC

IV. PHYSICAL PROPERTIES OF MATERIALS

The physical characteristics of different materials used in the experimental studies are listed in Table 1. The recovered RCA-I, RCA-II and RCA-III are shown in the Fig.2.The reduction in specific gravity and increase in water absorption of RCA are attributed to adhered mortar content. RCA-III exhibits higher adhered mortar content as compared to RCA-I and RCA-II. The weak link between mortar and aggregate in RCA-III, tend to disintegrate during the preparation of concrete. This increases the finer fraction content in the concrete mix.

V. MIX DESIGN

The M20 grade concrete mix is designed as per IS 10262:2009 by considering the properties of natural Aggregates.The mix proportion corresponds 1:1.96:3.26(Cement: Fine Aggregate: Coarse Aggregate) with water-cement ratio as 0.55.Two fractions of coarse aggregates are used in the mix design viz., 60% is passing 20 mm and retained on 10mm sieve and the remaining 40 % is passing 10 mm and retained on 4.75mm IS sieve. The First, second and third generation RAC mixes are produced, with RCA – I, II and III at 20%, 40%, 60%, and 100% replacements for NCA. Table 2, indicates the weight of the ingredients used to produce first, second and third generation RAC mixes.

Table 1: Physical Characteristics of Constituents of concrete mixes

Cement		43 Grade			
1	Specific Gravity	3.04			
2	Fineness (%)	6.43			
3	Standard Consistency (%)	31.25			
4	Initial Setting Time (min)	60			
5	Final Setting Time (min)	210			
6	28Day Compressive Strength, N/mm^2	46			
Natural Fine Aggregate		River Sand			
1	Specific Gravity	2.61			
2	Compacted Bulk Density (kg/m^3)	1601			
3	Fineness Modulus	2.705			
4	Bulking (%)	37.5			
Coarse Aggregate		**NCA**	**RCA -I**	**RCA-II**	**RCA-III**
1	Specific Gravity (20mm>10mm)	2.66	2.49	2.41	2.38
2	Water Absorption (%) (20mm>10mm)	0.7	4.2	5.6	8.6
3	Crushing Value (%) (12.5mm>10mm)	25.47	30.12	34.18	38.35
4	Impact Value (%) (12.5mm>10mm)	22	24.1	30.8	35
5	Fineness Modulus	6.62	6.59	6.58	6.58
6	Bulk Density (kg/m^3) (20mm>10mm)	1551	1480	1394	1338
	Bulk Density(kg/m^3) (10mm>4.75mm)	1524	1472	1375	1304
7	Elongation Index (%) (20mm>16mm,10mm>6.3)	17.27	12.45	11.8	10.12
8	Flakiness Index (%) (20mm>16mm,10mm>6.3)	14.27	11.6	10.7	12.2
9	Angularity Number(20mm>16mm)	10.4	8.8	8.6	9
	Angularity Number(10mm>6.3)	12.62	10.6	10.4	11.1

Fig.2: RCA-I, RCA-II and RCA-III used in the experimental study

TABLE 2: MIX CONSTITUENTS FOR FIRST, SECOND AND THIRD GENERATION CONCRETE MIXES (Kg/m^3)

First generation Concrete mixes					
Contents in kgs	**RCA Replacement levels**				
	0%	**20%**	**40%**	**60%**	**100%**
Cement	350	350	350	350	350
Sand	686	686	686	686	686
NCA (< 20, > 10)	685.8	548.6	438.9	351.1	0
NCA (< 10, >4.75)	457.2	365.8	292.6	234.1	0
RCA (< 20, > 10)	0	127.6	255.1	382.7	637.8
RCA (< 10, > 4.75)	0	85.0	170.1	255.1	425.2
Water	192	192	192	192	192
Second generation Concrete mixes					
Cement	350	350	350	350	350
Sand	686	686	686	686	686
NCA (< 20, > 10)	685.8	548.6	438.9	351.1	0
NCA (< 10, > 4.75)	457.2	365.8	292.6	234.1	0
RCA (< 20, > 10)	0	123.4	246.9	370.3	617.2
RCA (< 10, > 4.75)	0	82.3	164.6	246.9	411.5
Water	192	192	192	192	192
Third generation Concrete mixes					
Cement	350	350	350	350	350
Sand	686	686	686	686	686
NCA (< 20, > 10)	685.8	548.6	438.9	351.1	0
NCA (< 10, > 4.75)	457.2	365.8	292.6	234.1	0
RCA (< 20, > 10)	0	122.1	244.1	366.2	610.4
RCA (< 10, >4.75)	0	81.4	162.8	244.1	406.9
Water	192	192	192	192	192

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TABLE 3: WORKABILITY OF NAC AND RAC

Test Results	NAC	RAC											
	(0% RCA)	20% RCA			40% RCA			60% RCA			100% RCA		
		I	II	III	I	II	III	I	II	III	I	II	III
Slump	78	54	45	48	30	25	30	17	15	18	0	5	5
CF	0.93	0.91	0.91	0.91	0.89	0.89	0.9	0.86	0.86	0.87	0.81	0.86	0.86

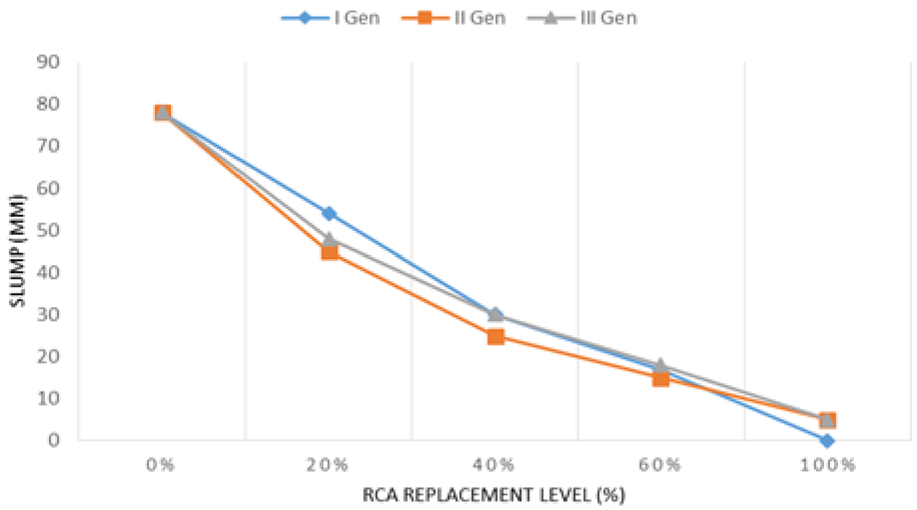

Fig.3: Slump Characteristics of RAC mixes with multiple recycled aggregates

FRESH PROPERTIES OF NAC AND RAC

Slump and Compaction factor tests are conducted to assess the workability of concrete. These are listed in Table 3. The variation of slump for different RCA replacement levels, for all the three generations of RAC mixes are shown in Fig.3. As the level of RCA replacement increases, RAC mix shows reduction in slump for all the three generations of RCA. At any given replacement level, RAC mixes made with all the three generations of RCA, do not show significant differences in their respective slump values. This is in line with observation made by Jorge Manuel Caliço Lopes de Brito et al [3]. The results in terms of workability show that concrete produced after multiple recycling of aggregates, retains more or less, the same characteristics, as that of concrete, produced by using RCA I.

HARDENED PROPERTIES

For different mix variants, tests are performed on cube specimens, to determine the compressive strength at the end of 7 and 28 days of curing. These are statistically analysed, to determine their correlation as well as the ratio between them. Further, individual test results are normalized with respect to control mix and their descriptive statistical parameters are evaluated to infer about the trend. Tests are also performed on cylinder specimens to determine the split tensile strength of RAC at the end of 28 days of curing. Using the aforementioned normalization technique, the influence of prime variants on split tensile strength is quantified. Test results of control mix with NCA, pertaining to 7 days compressive strength of four cubes, 28 days split tensile strength of threecylinder specimens and 28 days compressive strength of thirty nine cubes are listed in Table 4.

A. ***Statistical Analysis of test results of Control mix***

The descriptive statistics of test data presented in Table 4, are evaluated and summary of the results are presented in Table 5.

B. ***Hardened Properties of RAC mix with multiple recycling of concrete waste.***

Seven and 28 days compressive strength, density and split tensile strength of RAC mixes, with RCA-I, II and III, for 20%, 40%, 60% RCA replacement for NCA are reported in Table 6. Test results pertaining to four cubes and three cylinder specimens, for RAC

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mixes with 100%replacement with RCA – I, II and III are reported in Table 7. Additional test results pertaining to density and 28 days compressive strength of RAC mixes with RCA I and RCA II at 100% replacement are listed in Table 8.

TABLE 4: DENSITY AND STRENGTH OF CONTROL MIX

SI.No	7 days Compressive Strength (MPa)	SI.No	28 days Split Tensile Strength (Mpa)
1	20.8	1	2.21
2	19.9	2	2.35
3	19.7	3	2.26
4	21.6		

Sl No	Density kg/m^3	28 days Compressive Strength (MPa)	Sl No	Density kg/m^3	28 days Compressive Strength (MPa)
1	2471	36.4	21	2492	29.6
2	2441	39.6	22	2536	27.1
3	2391	36.5	23	2441	22.7
4	2459	35.1	24	2486	31
5	2524	37.8	25	2359	21.5
6	2483	38.9	26	2350	30.8
7	2385	38.7	27	2456	27.5
8	2430	29.7	28	2507	30.1
9	2492	29.5	29	2456	28.4
10	2436	28.5	30	2498	32.4
11	2450	38.7	31	2403	27.4
12	2483	38.5	32	2498	31.5
13	2492	39.1	33	2566	33
14	2501	37.6	34	2456	25.6
15	2441	37.9	35	2450	25.6
16	2530	35	36	2444	24.9
17	2486	37.7	37	2622	34.1
18	2373	29.8	38	2489	36.3
19	2504	29.5	39	2560	29.6
20	2406	28.3			

TABLE 5: DESCRIPTIVE STATISTICS OF TEST RESULT OF CONTROL MIX

Parameters	Density	Compressive strength (MPa)		Split tensile strength (MPa)
	(kg/m3)	28 days	7 days	
Mean	2468	32.2	20.5	2.27
Standard Error	9.2	0.8	0.4	0.04
Median	2471	31.3	20.4	2.26
Standard Deviation	57.2	5.1	0.9	0.07
Sample Variance	3275	26.2	0.8	0.01
Skewness	0.1	-0.2	0.6	0.82
Confidence Level	18.6	1.7	1.4	0.18

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TABLE 6: HARDENED PROPERTIES OF RAC MIX WITH RCA I, II, III AT 20%, 40% AND 60% REPLACEMENT

Mix Composition-->		Density kg/m^3			Compressive Strength (MPa)						28 days Split Tensile Strength (MPa)		
					28 Days			7 days					
RCA Cycle → / ↓ RAC mixes		I	II	III	I	II	III	I	II	III	I	II	III
With20% RCA	1	2444	2373	2373	31.7	29.7	28.4	17.7	17.4	17.2	2.4	2	2.2
	2	2450	2385	2356	29.3	29.8	29.9	19.3	17.6	17.9	2.2	2.1	1.9
	3	2441	2356	2329	30.7	28.5	27.6	18.3	18.1	17.7	2.3	2.1	2.1
	4	2427	2367	2311	27.5	34.2	28.9	17.4	14.5	18.7		-	
With40% RCA	1	2439	2350	2302	32	29.5	29	19.6	18.7	19.8	2.3	1.9	2.1
	2	2427	2359	2311	31.5	30.8	31.2	19.2	18.5	20.5	2.1	2	2
	3	2397	2370	2361	30.7	32.8	29.4	18.4	18	19.6	2.3	2	1.9
	4	2427	2361	2287	34.5	35.5	25.9	16.2	17.1	20.3		-	
With 60% RCA	1	2379	2323	2290	34.7	33.5	32.8	19.6	21.2	21.9	2.4	2.3	2
	2	2415	2350	2317	35.8	35.1	32.9	19.2	21.5	21.5	2.3	2.1	2.1
	3	2412	2329	2299	32.5	36.6	34.5	20.6	21.9	20.8	2.2	2.2	2.1
	4	-	2326	2284	-	34.1	32.2	-	18.3	20.5		-	

C. Statistical properties of RAC Mixes with multiple recycling

The descriptive statistics of test data presented in Table 6, 7 and 8, are evaluated and summary of the results are presented in Table 9

D.Normalized properties of RAC Mixes with multiple recycling

The performance assessment of RAC mixes with multiple recycling of concrete wastes is attempted, by normalizing the mean values of test results with respect to control mix. These are tabulated in Table 10

E. Inferences

It is observed that, multiple recycling of concrete waste has very little influence on the strength properties of RAC mixes.Hence, RAC mixes made with multiple recycling of concrete waste, possess the same intrinsic properties of concrete mix, made from first cycle RCA.

TABLE 7: HARDENED PROPERTIES OF RAC MIX WITH RCA I, II, III AT 100% REPLACEMENT LEVEL

Mix Composition		**Density kg/m^3**			**Compressive Strength (MPa)**						**28 days Split Tensile Strength (MPa)**		
					28 Days			**7 days**					
RCA Cycle → / ↓ RAC mixes		I	II	III	I	II	III	I	II	III	I	II	III
with 100% RCA	1	2347	2237	2243	25.4	29.7	29.1	15.8	18.1	17.4	2.1	1.8	1.9
	2	2379	2234	2267	29.4	29	30.1	22	19.1	17.6	2.1	2	1.8
	3	2317	2234	2261	29	34.6	29.4	17.1	18.4	18.5	2.2	1.9	1.7
	4	2403	2225	2225	29.9	32.4	33	16.4	17.5	18.7		-	

TABLE 8: HARDENED PROPERTIES OF RAC MIX WITH RCA I, II AT 100% REPLACEMENT

Contd...	**Density kg/m^3**		**28 Days Compressive**	
	I	II	I	II
5	2397	2290	33.4	30.2
6	2364	2311	32	29
7	2427	2273	34.1	29.1
8	2474	2296	33.1	27.3
9	2302	2264	34	29.2
10	2406	2237	27.5	30.4
11	2477	2281	34.4	29.2
12	2412	2231	35.7	28.3
13	2453	2231	34.5	34.3
14	2347	2261	32	30.5
15	2397	2243	32.1	31.6

16	2453	2261	31	32.9
17	2430	2261	34.8	32
18	2427	2264	34.1	30.7
19	2356	2261	30.9	33.5
20	2450	2270	31.5	30.7
21	2418	2279	31.5	31.8
22	2433	2249	28.3	31.3
23	2382	2246	29.9	31.4
24	2391	2279	31	31.8
25	2427	2222	32	34.2
26	2430	2296	30.8	31.9
27	2400	2296	33.3	29.8
28	2418	2290	31	30.7
29	2441	2261	32.4	30.4
30	2397	2279	34.2	29.1
31	2447	2219	31.8	30
32	2418	2225	31.5	30.3

TABLE 9: AVERAGE VALUES OF DENSITY AND STRENGTH

Mix Composition	µDensity (kg/m^3)			µ28 days strength(MPa)			µ7 days strength (MPa)			µTensile strength (MPa)		
	I	II	III	I	II	III	I	II	III	I	II	III
20% RCA	2441	2370	2342	29.8	30.6	28.7	18.2	16.9	17.9	2.3	2.1	2.1
40% RCA	2423	2360	2315	32.2	32.2	28.9	18.4	18.1	20.1	2.2	2	2
60% RCA	2402	2332	2334	34.3	34.8	33.1	19.8	20.7	21.2	2.3	2.2	2.1
100% RCA	2407	2260	2249	31.8	30.9	30.4	17.8	18.3	18.1	2.1	1.9	1.8

TABLE 10: NORMALIZED VALUE OF DENSITY AND STRENGTH

Mix Composition	Normalized Values = µ$_{RAC}$/µ$_{Control\ Mix}$											
	Density			28 days strength			7 days strength			Tensile strength		
	I	II	III	I	II	III	I	II	III	I	II	III
20% RCA	0.99	0.96	0.95	0.93	0.95	0.89	0.89	0.82	0.87	1.01	0.93	0.93
40% RCA	0.98	0.96	0.94	1.00	1.00	0.90	0.90	0.88	0.98	0.97	0.88	0.88
60% RCA	0.97	0.94	0.95	1.07	1.08	1.03	0.97	1.01	1.03	1.01	0.97	0.93
100% RCA	0.98	0.92	0.91	0.99	0.96	0.94	0.87	0.89	0.88	0.93	0.84	0.79

VIII. CONCLUSION

Based on Strength and workability characteristics of RAC mixes with multiple recycled concrete aggregates, it is concluded that, "concrete waste is many times recyclable like steel without any significant loss in strength".

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