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Partially Set Recycled Aggregate Concrete: An Experimental Study

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ABSTRACT
Construction industry is a backbone to the development of humankind with the time and has a major role to play further in up gradation of the existing infrastructure facilities worldwide. Whereas concrete is the most versatile and vitally used material, which consumes natural resources and has maximum environmental impact. Hence, consideration of sustainable development with the environmental preservation is prime focused research domain in recent time. Present studies focus on the use of recycled aggregate obtained from the construction waste as a structural material in concrete. An attempt has been made to investigate; all the physical and mechanical properties of recycled aggregate obtained from various sources and compare those properties with natural aggregates with respect to Indian Standard specifications for utilization in construction projects. Also due to many unforeseen circumstances at the site it may happen that a delay arises from the preparation of the mix to its placing in the formwork; where the concrete mass suffers setting and show a great loss in strength as well as workability, as a result it is declared as unserviceable and considered as waste. Thus the problem arises, whether the partially set mix should always be discarded from structural use. Hence the applicability of selfing concept to Recycled Aggregate Concrete (RAC) has been considered in present study along with investigation of the fresh and hardened properties of concrete by replacing natural aggregate with recycled aggregates, in different proportions like 10%, 20 % and 30% for M20 and M25 grade of concrete.
KEYWORD*: Selfing, Setting time, Workability, Slump and Thermal effect.*

I. INTRODUCTION

Concretes or cement-sand mortars or cement pastes develop strengths in thepresence of water when added to the dry mixture of the ingredients. The gain in the strength commences from the very instant of time when water is just added. This instant of time at t = 0 is identified as 0- hr, and at which the mix which is fresh and possess full workability, attains normally maximum strength. It is advisable that concrete thus prepared should be cast into mould without delay in order to get maximum strength out of it.

The time interval *t* between the preparation of the mix (at t = 0) and casting the same in the mould at elapsed time *t* (henceforth to be termed as time lag) is a very influential parameter which plays a very major role from the point of development of strength in the mix. Such mix is to be termed as time lag concrete or t-hr concrete, the strength as well as workability of which are bound to be affected adversely in comparison to that of the fresh or 0-hr concrete. Needless to mention that concretes instantly prepared at any instant of time *t* show the same strength as that of the 0-hr one, and they are identified by instantly prepared concrete. For a mix type A, thus the strengths of those concretes can be written as A_0, A_i and A_t respectively, and those at $t = t_i$ (initial setting time) and $t = t_f$ (final setting time), are as A_i and A_f, respectively. Broadly termed as partially set concrete, which can be simply identified as the function of the parameter, namely, time lag t as

- ✓ 0-hr as partially set concrete which is, freshly prepared at t= 0
- ✓ T-hr as actual partially set concrete which is, prepared at time lag t.

II. ABOUT SELFING AND CROSSING

Selfing is a term attributed to the blending of two different individual mixes of the same mix type but of different *r* and *t* values into a single composite mass, which henceforth be called as the selfed mass, and the corresponding strength of which be termed as selfed strength. Crossing, on the other hand, is the generalized version of selfing, where the two mixes in blending are of different types, and the corresponding terms are crossed mass and crossed strength. [10]

III. BACKGROUND OF SELFING AND CROSSING

Cement concrete, a carefully controlled mixture of cement, water, coarse aggregates starts gaining strength due to onset of hydration process from the instant when water is added to the dry mass. It is generally considered that if this mixed mass with water is not immediately placed in the form and compacted without any further loss of time, it starts losing its strength. It is exceedingly difficult to alter concrete once placed and if the partially set concrete is allowed to remain in the structural elements, the reduced strength seriously endangers the stability of the entire structure. Hence though concrete is a very versatile and costly building material and therefore widely used, utmost care and caution is warranted in its placement and compaction.

However, at construction sites, partially set mixes are invariably formed due to various unforeseen circumstances, such as displacement of formwork, power failure, breakdown of machinery, accidents etc. If the time gap between the preparation of the mix and its placing in the formwork gets prolonged, the concrete mass suffers setting and show a great loss in strength as well as workability. For the time lag t upto and around the initial setting time t_i, the strength and workability may not be affected appreciably but those particularly towards the final setting time t_f are greatly affected, and often being unserviceable are to be declared as waste. Thus the problem arises, whether the partially set mix should always be discarded for structural use. If not, could such a partially set mix be reused even on blending with some suitable relatively fresh mix in a certain weight ratio? Whether to reuse or to discard totally the concrete in which partial setting has taken place already, it becomes essential, to speak technically, to know the strength level and other various behavioral physical properties of such concretes before such an ultimate decision is taken. Fortunately, Selfing and Crossing concept, developed very recently, aims at providing such answers concerning partially set concretes, their strength, and reuses, which has become a very strong tool in the hands of the field and construction engineers.[10]

IV. MATERIALS USED

Cement

Ordinary Portland cement of 53 grade was used throughout the work. Cement was tested at beginning and end of each phase of work to ensure no deterioration in quality of cement during the interim period. The following tests were carried out for Cement:

Consistency of cement, Initial setting time, Final Setting time, Specific gravity, Fineness, Soundness, Compressive strength. All the above tests were conducted in accordance with relevant IS code of practice. The details of the test result are presented in table 1.

Table 1 Test Results of OPC 53 Grade

Item	Tests	Results Obtained	Requirement as per IS:12269-1987
1	Consistency (%)	30	
2	Specific Surface Area (m^2/kg)	264	> 225
2	Initial Setting Time (minutes)	130	> 30
3	Final Setting Time (minutes)	228	< 600
4	Compressive Strength (N/mm^2)		
	3 days	31	> 27
	7 days	38	> 37
	28 days	54	> 53
5	Soundness (mm) Le-Chetelier Method	2.0	< 10

Fine Aggregate: Natural Sand (NS)

The fine aggregate as river sand available locally in Bardoli, Gujarat has been used. The following tests were carried out for fine aggregate: Sieve analysis, Specific gravity, Water absorption, Bulk density, Silt content. These tests were carried out as the relevant IS code of practice. The test results are presented in Table 2.

Table 2 Test Results of Sieve Analysis and other properties of NS

Item	Tests	% Passing
1	Gradation percent Passing on IS Sieve	
	10 mm	100
	4.75 mm	96.81
	2.36 mm	88.24
	1.18 mm	63.20
	600 micron	38.27
	300 micron	13.32
	150 micron	3.88
2	Fineness modulus	2.96
3	Specific Gravity	2.69
4	Water absorption (%)	2.08
5	Silt Content (% Passing on 75μ)	1.08
6	Bulk Density kg/m^3	1714

Natural Coarse Aggregate (NCA)

The coarse aggregate as crushed basalt available in Chikhli, Gujarat was used. The following tests were carried out for coarse aggregate as per the procedure laid down in the relevant IS code of practice. Sieve analysis, Specific gravity, Water absorption, Flakiness index, Elongation index, Bulk density, Aggregate impact value, Aggregate crushing value, ten percent fine value. The above test results are presented in Table 3.

Recycled Coarse Aggregate (RCA)

The recycled coarse aggregate as from construction waste was used. The following tests were carried out for coarse aggregate as per the procedure laid down in the relevant IS code of practice. Sieve analysis, Specific gravity, Water absorption, Flakiness index, Elongation index, Bulk density, Aggregate impact value, Aggregate crushing value, ten percent fine value. The above test results are presented in Table 3.

Table 3 Test Results of Sieve Analysis and other properties of RCA

Item	Tests	Results obtained % passing	
		For NCA	For RCA
1	Gradation percent passing on IS Sieve		
	40 mm	100	100
	20 mm	95.95	49.49
	16 mm	53.23	18.67
	10 mm	24.99	0.54
	4.75 mm	1.55	0.41
2	Elongation Index (%)	20	22.84
3	Flakiness Index (%)	8	6.28
4	Impact Value (%)	13.89	12.70
5	Specific Gravity	2.832	2.606
6	Water Absorption (%)	1.163	2.076
7	Bulk Density kg/m^3	1321	1446

V. DESIGN MIX PROPORTIONAND FRESH CONCRETE PROPERTIES

Design Mix

With the knowledge of properties of ingredients, necessary design of the mixes was carried out for M20. Table 4 provides the proportion of M-20, and table 5 provides the proportion of M- 25 Grade of Concrete.

Table 4 Mix Proportion of M -20

Sr. No.	Material	Proportion by Weight
1	Cement	330 kg
2	Fine Aggregate (Natural)	693 kg
3	Coarse Aggregate (10 mm down size)	386 kg
4	Coarse Aggregate (20 mm down size)	901 kg
5	Water	174.9 liter

Table 5 Mix Proportion of M-25

Sr. No.	Material	Proportion by Weight
1	Cement	381 kg
2	Fine Aggregate (Natural)	658.6 kg
3	Coarse Aggregate (10 mm down size)	381 kg
4	Coarse Aggregate (20 mm down size)	888 kg
5	Water	171.4 liter

Setting Time Test

To apply selfing concept in present study, setting time of said mixes to be evaluated.

The setting times were determined systematically using penetration resistant method (PRM). The results for setting times for different mixes are given in Table 6 and Table 7 for M20 and M25 mixes respectively with different replacement percentage of natural coarse aggregate (NCA) with recycled coarse aggregate (RCA).

Table 6 Setting time test for M-20 with different % of replacement of NCA with RCA

Sr. No.	Description	Initial time (Minute)	Final time (Minute)
1.	Normal Concrete	240	410
2.	10 % Replacement of NCA with RCA	235	365
3.	20 % Replacement of NCA with RCA	205	310
4.	30 % Replacement of NCA with RCA	190	305

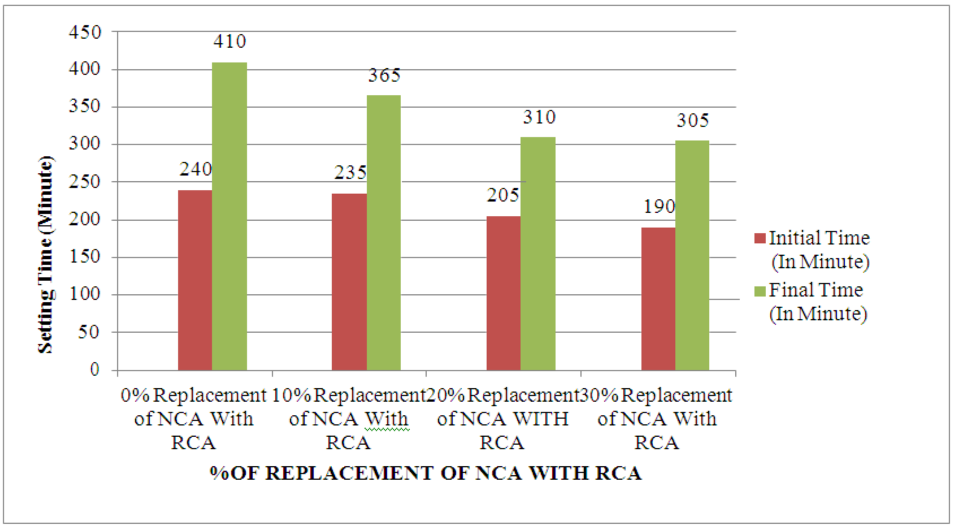

Figure 1 Setting time test various mixes

Table 7 Setting time test for M-25 with different % of replacement of NCA with RCA

Sr. No.	Description	Initial time (Minute)	Final time (Minute)
1.	Normal Concrete	205	395
2.	10 % Replacement of NCA with RCA	200	280
3.	20 % Replacement of NCA with RCA	185	270
4.	30 % Replacement of NCA with RCA	140	235

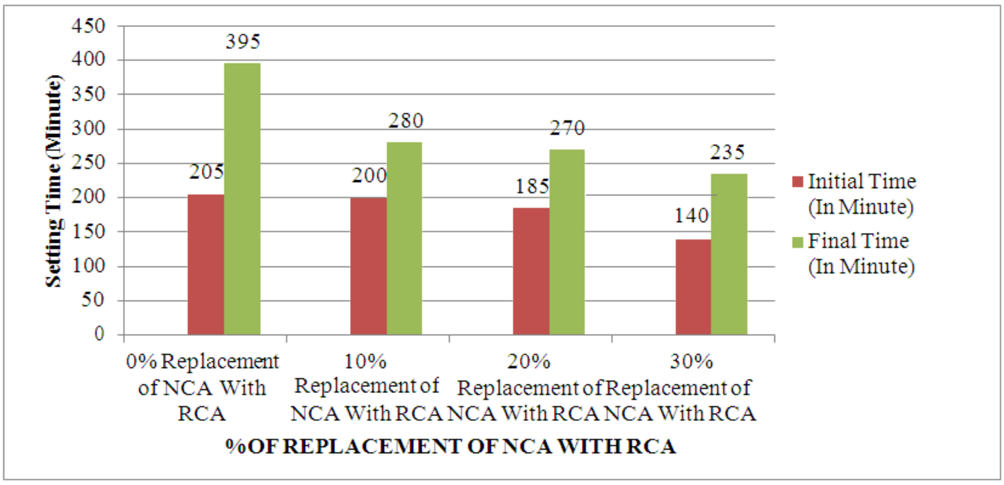

Figure 2 Setting time of various mixes

Workability Test

The Slump test was performed to measure the workability of fresh concrete for both the mixes under investigation i.e. M20 & M25 along with the different % of replacement of NCA with RCA. The result of which are as shown in Table 8.

Table 8 Test results of workability for different % of replacement of CA with RCA

Sr. No.	Mix	% Replacement of C.A with R.C.A	W/C Ratio	Slump Value in mm
1	M-20	0	0.50	94
2	M-20	10	0.50	58
3	M-20	20	0.50	30
4	M-20	30	0.50	0
5	M-25	0	0.48	80
6	M-25	10	0.48	53
7	M-25	20	0.48	32
8	M-25	30	0.48	0

VI. COMPRESSIVE STRENGTH RESULTS

The test was carried out using 200-tonne of compression machine. The specimen cube size of 150 mm is used to determine the compressive strength, was placed between the platens and the load was applied at a standard rate of loading. The maximum load was noted. The test was repeated for three specimens and the average value of compressive strength has been calculated and recorded. The results of each mixes are provided in Table 9 to Table 12.

Table 9 Test result of Compressive Strength partially set mixes (i.e. M-20 & M-25)

Sr. No.	Time interval	Average Compressive strength(N/mm^2)			
		For M-20		For M-25	
		7 days	28 days	7 days	28 days
1	0 hour	17.70	24.50	21.77	30.50

2	1 hour	16.50	22.80	20.88	28.67
3	2 hour	13.60	19.00	18.90	26.80
4	3 hour	11.37	17.83	17.87	24.67
5	4 hour	8.83	12.13	9.13	13.33

Table 10 Test result of Compressive Strength partially set mixes (i.e. M-20 & M-25) 10 % replacement of NCA with RCA at different time interval (Selfing interval)

Sr. No.	Time interval	Average Compressive strength(N/mm^2)			
		For M-20		For M-25	
		7 days	28 days	7 days	28 days
1	0 hour	14.90	21.10	18.23	26.17
2	1 hour	14.50	20.00	16.57	24.87
3	2 hour	12.70	17.30	15.13	22.73
4	3 hour	10.19	15.18	14.30	20.97
5	4 hour	7.70	11.60	8.32	12.37

Table 11 Test result of Compressive Strength partially set mixes (i.e. M-20 & M-25) 20 % replacement of NCA with RCA at different time interval (Selfing interval)

Sr. No.	Time interval	Average Compressive strength(N/mm^2)			
		For M-20		For M-25	
		7 days	28 days	7 days	28 days
1	0 hour	14.20	20.50	17.33	25.60
2	1 hour	13.10	18.80	15.67	22.50
3	2 hour	11.60	17.20	14.00	20.30
4	3 hour	10.08	15.00	13.10	18.50
5	4 hour	6.37	11.28	8.03	11.88

Table 12 Test result of Compressive Strength partially set mixes (i.e. M-20 & M-25) 30 % of replacement of NCA with RCA at different time interval (Selfing interval)

Sr. No.	Time interval	Average Compressive strength(N/mm^2)			
		For M-20		For M-25	
		7 days	28 days	7 days	28 days
1	0 hour	12.80	17.90	15.93	21.17
2	1 hour	11.00	16.30	13.13	18.30
3	2 hour	10.60	15.50	10.67	15.53
4	3 hour	8.70	12.20	8.57	11.33
5	4 hour	6.47	8.72	7.10	10.51

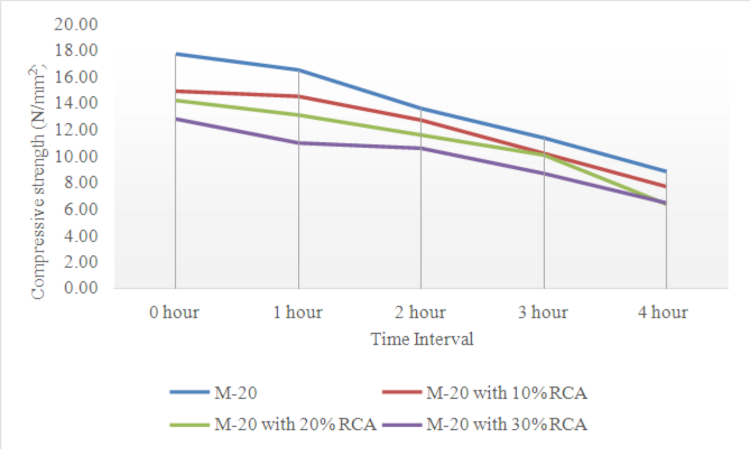

Figure3 Variation of Compressive strength of partially set mix M-20 with various replacement of NCA with RCA at 7-days.

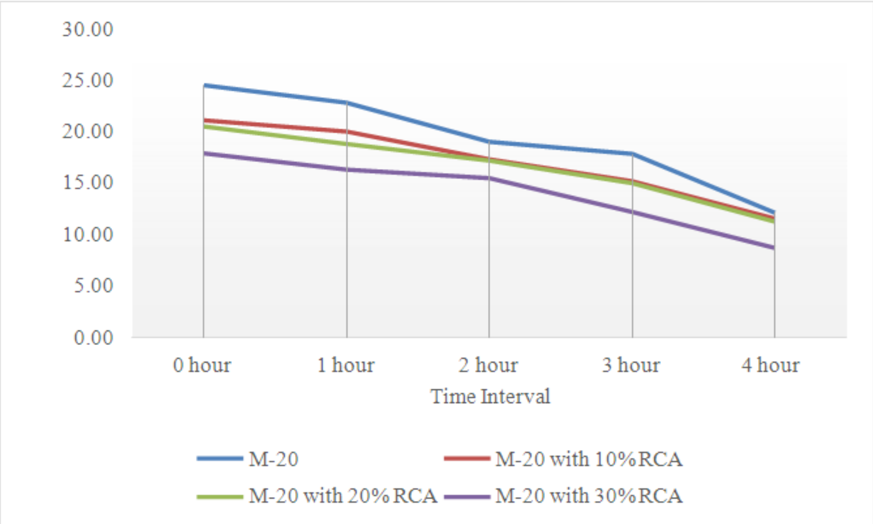

Figure 4 Result Variation of Compressive strength of partially set mix M-20 with various replacement of NCA with RCA at 28-days.

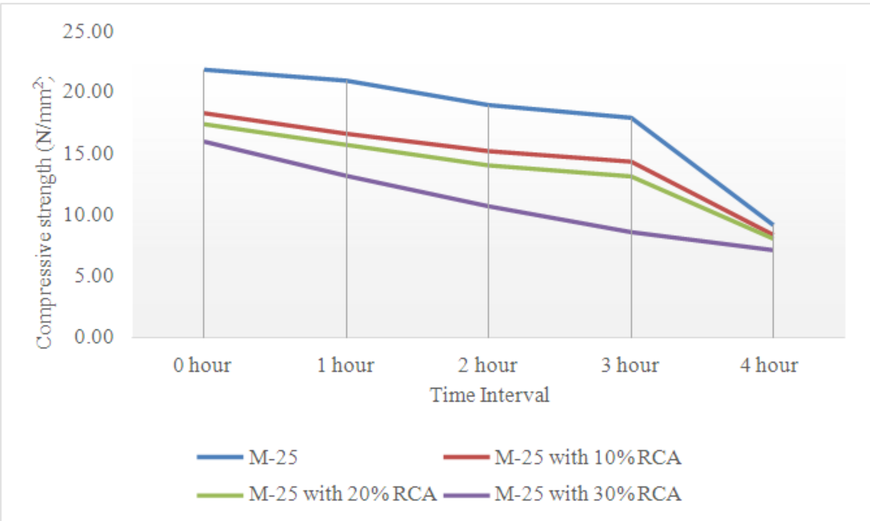

Figure 5 Variation of Compressive strength of partially set mix M-25 with various replacement of NCA with RCA at 7-days.

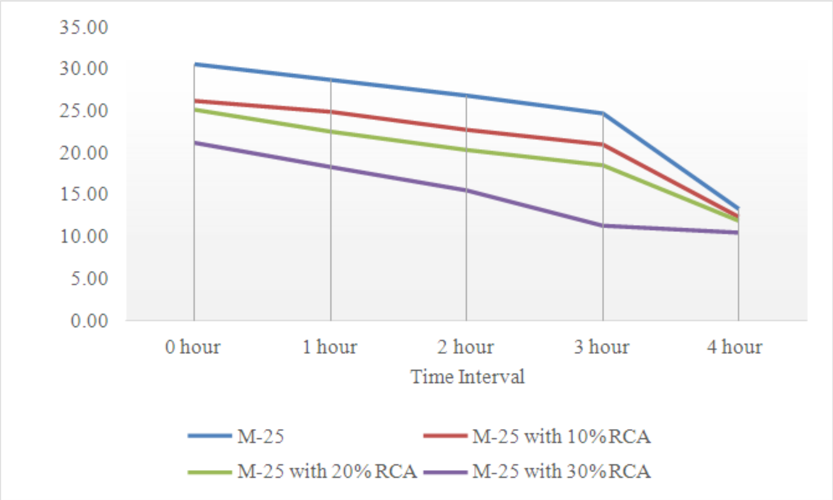

Figure 6 Result Variation of Compressive strength of partially set mix M-25 with various replacement of NCA with RCA at 28-days.

VII. PREDICTION OF COMPRESSIVE STRENGTH THROUGH SELFING THEORY

Data of actual compressive strength are compared with compressive strength obtained from equation (theoretical)for compressive strength of selfing concrete considering time interval between the initial and final setting times of the concrete at the intervals of 30 minutes from the initial setting time up to the nearest 30 minutes to final setting time. Results and compression for M20 and M25 with different trial mixes are as shown in Table 13 and Table 14 respectively.

Table 13 Comparison of test results of compressive strength at 28 days experimentally and analytically for M-20 different mixes.

Conventional Concrete M20			
t	Experimental (N/mm^2)	Analytical (N/mm^2)	% Variation
270	9.85	10.04	-1.96
300	8.70	8.58	1.34
330	7.62	7.49	1.65
360	6.42	6.65	-3.60
390	5.8	5.98	-3.07
10 % Replacement of CA with RCA			
t	Experimental (N/mm^2)	Analytical (N/mm^2)	% Variation
270	7.40	7.52	-1.57
300	6.20	6.02	2.96
330	5.20	5.02	3.55
360	4.20	4.30	-2.38
20 % Replacement of CA with RCA			
t	Experimental (N/mm^2)	Analytical (N/mm^2)	% Variation
210	14.21	14.32	-0.76
240	11.28	11.25	0.27
270	9.4	9.26	1.44
300	7.6	7.88	-3.62
30 % Replacement of CA with RCA			
t	Experimental (N/mm^2)	Analytical (N/mm^2)	% Variation
210	10.3	10.49	-1.86
240	8.72	8.67	0.58

270	7.5	7.39	1.50
300	6.45	6.44	0.23

Table 14 Comparison of test results of compressive strength at 28 days experimentally and analytically for M-25 different mixes.

Normal Concrete			
t	Experimental (N/mm^2)	Analytical (N/mm^2)	% Variation
210	22.6	22.79	-0.84
240	15.49	15.56	-0.48
270	11.4	11.82	-3.66
300	9.54	9.52	0.16
330	7.7	7.98	-3.60
360	7.1	6.86	3.35
390	6.2	6.02	2.89
10 % Replacement of CA with RCA			
t	Experimental (N/mm^2)	Analytical (N/mm^2)	% Variation
210	17.4	17.68	-1.63
240	12.37	12.00	2.99
20 % Replacement of CA with RCA			
t	Experimental (N/mm^2)	Analytical (N/mm^2)	% Variation
210	14.6	14.93	-2.24
240	11.88	12.12	-2.01
30 % Replacement of CA with RCA			
t	Experimental (N/mm^2)	Analytical (N/mm^2)	% Variation
150	12.4	12.00	3.26
180	11.33	11.42	-0.81
210	11.1	10.90	1.80

Sample Calculation for Conventional Concrete M20 at t=270 Minutes.

$$A_{r,t} = \frac{A_r t_i \; A_r t_f (t_f - t_i)}{(t - t_i) \, A_r t_i + (t_{f-t}) \, A_r \, t_f}$$

Where,

A_{rti}=12.1 N/mm^2 t_i=240 Minutes.

A_{rtf}=5.6 N/mm^2 t_f=410 Minutes, and t=270 Minutes.

In selfing all the above values in the equation it can be,

$$A_{r,t} = \frac{12.1 * 5.6 \, (410-240)}{(270-240)12.1+(410-270)5.6} = 10.04 \text{ N/mm}^2 \text{ (Through Analytical)}$$

9.85 N/mm^2 (Through Experiments)

VIII. CONCLUSION

Based on experimental studies, following conclusions are drawn:

- The setting of concrete mix varies from mix to mix. Richer is the concrete mix lower are the setting time. The setting of concrete mixes depends on the water cement ratio, aggregate cement ratio, cement content, percentage of recycled aggregate present in concrete, ambient air temperature etc.
- The fresh property of concrete, i.e. workability decrease as we increase the replacement percentage of RCA with NCA for both M20 & M25 mixes.
- Compressive strength of concrete for different mixes at different time interval is observed. The compressive strength values after initial setting time of concrete for relevant mixes observed lesser.
- Compressive strength values of different concrete mixes indicate 20% replacement of recycled coarse

aggregate with natural coarse aggregate as optimum replacement for both M20 & M25 mixes.

- Comparison of theoretical and actual value of compressive strength at 28 days for both M20 and M25 concrete shows the minimum variation.
- The selfing concept successfully applied for M-20 and M-25 mixes with various replacement of NCA with RCA.

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