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Optimization of Recycled Aggregate Concrete

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Abstract-* The relative properties of concrete are of great importance in terms of the serviceability of buildings. The effects of physical and mechanical properties of Recycled aggregate concretes are explained. Here w/c ratio 0.27, 0.30, 0.33 and 0.36 with replacement of 0%, 30%, 35%, 40%, 45% and 50% of Natural aggregates by Recycled aggregates are considered. Taking 3 factors (w/c 4 nos, % Replacement 5 nos and days 3 nos), we arrived at L25 Orthogonal array. To execute this we needed 25 experimental results. Here total 675 specimens were casted (9Cubes, 9Cylinder and 9prism for each trial mixes 25nos).Mechanical properties were found for all the mixes. Attempt is made to compare with different mixes of recycled aggregate concrete. Optimum mix has been proposed.

I. INTRODUCTION

Concrete is one of the most widely used construction material causing a high demand for it. As a result of this, there is an increase in the demand for its constituents like the coarse aggregates, sand, cement and water. This increase in demand is causing extensive quarrying of natural aggregates as it is required as coarse aggregates in concrete production and also it forms the major constituent by mass in concrete. Recycling concrete is the best option to decrease the demand on high quality natural resources. Globally, the concrete industry consumes large quantities of naturalresources, which are becoming insufficient to meet increasingdemands. At the same time, many old buildings have reached theend of their service life and are being demolished, resulting inwasted concrete; some concrete waste is used as backfill material,and much being sent to landfills. Recycling concrete by using it asnew aggregate in concrete could reduce concrete waste and conservenatural sources of aggregate. Hence this study is carried out mainly to explore the possibilities of use of RAC in structural construction which leads to sustainable economic construction with the best usage of demolished wastes generated.

According to M C Limbachiya, et al workability (slump) decreases and stability (bleeding and segregation) increases with increase in percentage of replacement of coarse aggregates by RA but slump though reduces is well within tolerance of +/-25mm but at RA of more than 50% replacement stability decreases greatly and is just suitable to be used as filler material.Compressive strength at 28 days for 30% replacement by RA has no significant variation with that of NA but beyond that there is gradual decrease in strength.Water absorption is more in RA than NA and it is found to increase with increase in size of RA (Ismail Abdul Rahman et al).Many authors, conclude that for up to 30% replacement, no reduction in compressive strength. RCA have greater water absorption, lesser density and specific gravity than NA. The values of impact and abrasion values are more for RCA. There is reduction in compression strength, split tensile strength and modulus of elasticity of RAC with increased % of replacement. Workability reduces with increase in replacement for constant w/c ratio.

II. MATERIAL AND PROPERTIES

Cement: the grade of cement used in this work is ordinary Portland cement, 43 grade manufactured as per IS 8112. Fine aggregate: Locally available sand free from silt, organic matter and passing through 4.75mm sieve confirming to zone 2 as per IS 383 is used as fine aggregate. Natural Coarse aggregate: the natural coarse aggregate of maximum size 12.5mm passing and retained on 4.75mm sieve is used.Recycled Coarse aggregate: the recycled aggregate size of maximum size 12.5mm passing and retained on 4.75mm sieve is used. The particle size distribution curve is shown in figure 2.1and the properties of materials are listed in Table.2.1

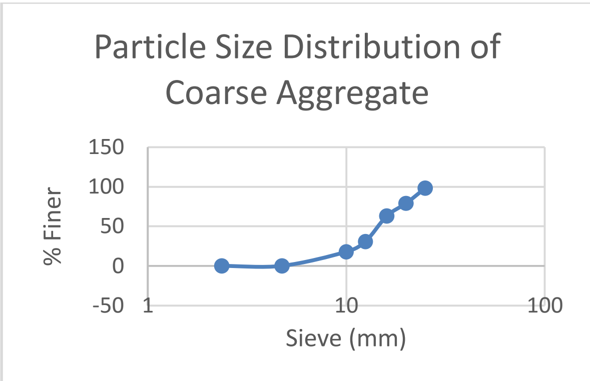

Fig.2.1 Particle size distribution of coarse aggregate

Table 2.1 Properties of materials

Test	Fine Aggregate	Natural Coarse Aggregate	Recycled Coarse Aggregate
Fineness Modulus	2.35	6.25	5.45
Specific gravity	2.492	2.657	2.6
Crushing	-	27.56%	28.10%

Value			
Impact Value	-	21.18%	29.86%
Water Absorption	-	0.31%	1.87%
Moisture Content	0.61%	-	-

III. METHODOLOGY

Table 3.1 Mix proportions for M60 concrete grade

Mix no	% Replacement	w/c	cement (kg/m^3)	Fine aggregate (kg/m^3)	Silica fume (kg/m^3)	NCA (kg/m^3)	RCA (kg/m^3)	Water (kg/m^3)	S.P in (kg/m3)
1	0%	0.27	500	665.535	55.55	1000	0	150	12.5
2	30%	0.27	500	644.11	55.55	700	300	150	12.5
3	35%	0.27	500	640.54	55.55	650	350	150	12.5
4	40%	0.27	500	636.97	55.55	600	400	150	12.5
5	45%	0.27	500	633.4	55.55	550	450	150	12.5
6	50%	0.27	500	629.83	55.55	500	500	150	12.5
7	0%	0.3	450	712.03	50	1000	0	150	11.25
8	30%	0.3	450	690.6	50	700	300	150	11.25
9	35%	0.3	450	687.03	50	650	350	150	11.25
10	40%	0.3	450	683.46	50	600	400	150	11.25
11	45%	0.3	450	679.89	50	550	450	150	11.25
12	50%	0.3	450	676.32	50	500	500	150	11.25
13	0%	0.33	409.09	750.07	45.45	1000	0	150	10.23
14	30%	0.33	409.09	728.64	45.45	700	300	150	10.23
15	35%	0.33	409.09	725.07	45.45	650	350	150	10.23
16	40%	0.33	409.09	721.50	45.45	600	400	150	10.23
17	45%	0.33	409.09	717.93	45.45	550	450	150	10.23
18	50%	0.33	409.09	714.36	45.45	500	500	150	10.23
19	0%	0.36	375	781.77	41.67	1000	0	150	9.375
20	30%	0.36	375	760.34	41.67	700	300	150	9.375
21	35%	0.36	375	756.77	41.67	650	350	150	9.375
22	40%	0.36	375	753.2	41.67	600	400	150	9.375
23	45%	0.36	375	749.63	41.67	550	450	150	9.375
24	50%	0.36	375	746.06	41.67	500	500	150	9.375

3.1. Perumal's Method of Mix Design for High Strength Concrete:

The production of high strength concrete- M 60. Mix proportions are shown in Table 3.1. In the current study the specimens have been casted. Cube specimens for testing compression test, beam specimens for flexure test and cylindrical specimens for split tensile strength casted and kept for curing of 28 days and then tested for their respective strengths.

IV. FRESH CONCRETE PROPERTIES

4.1. WORKABILITY TEST:

Workability is very important property of concrete which will affect the rate of placement and degree of compaction of concrete. The slump test will give an indication of how easily a mix can be placed, it is mentioned in IS: 456-2000 that a slump less than 25mm will indicate a very stiff concrete and a slump more than 125mm will indicate a very runny concrete.

In the current investigation as the concrete is high strength concrete (M60), hence the slump is zero as shown in the figure 4.1.

Figure .4.1: Slump test on RAC

4.1.2. COMPACTION FACTOR RESULTS:

Compacting factor test is also used to determine the workability of fresh concrete. It is not used in site testing as the apparatus is heavy. According to street works info, the compacting factor test gives a more accurate workability of fresh concrete than slump test. It mentioned that compaction factor test is also known as the "drop test", which measures the weight of fully compacted concrete and compare it with the weight of partially compacted concrete. The compaction factor indicates a moderate decreasing trend of workability when the percentage of recycled aggregate is increased. Table 4.1 shows the compaction factor ratio recorded during the experiment. As shown in Figure-4.1.1, Compaction Factor results showed that continuous increase in percentage replacement of natural aggregate with recycled aggregates was accompanied by a continuous decrease in Consistency also Consistency decreases with decrease in W/C. 0% replacement of 0.36 W/C ratio gave the highest compaction factor of 0.892 while 50% replacement gave the least compaction factors 0.819. Also from figure workability is more for 0.36 W/C when compared to 0.27 W/C. This implies that workability decreases as the percentage replacement increases and workability increases with increase in W/C ratio. Thus the use of recycled aggregates in concrete reduces the workability of the concrete.

Table.4.1: Compaction factor results for NAC and RAC

% replacement	**0%**	**30%**	**35 %**	**40%**	**45%**	**50%**
Compaction factor (0.27 w/c)	0.883	0.841	0.83	0.824	0.816	0.811
Compaction factor (0.36 w/c)	0.892	0.867	0.86	0.835	0.824	0.819

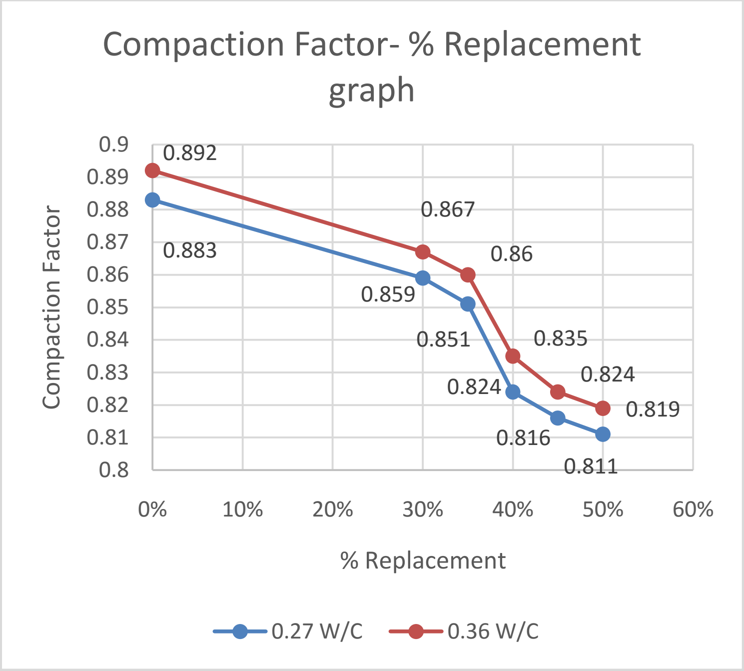

Figure-4.1.1. Graph of Compaction Factor against percentage replacement

4.2. MECHANICAL PROPERTY AND TEST RESULTS:

4.2.1. COMPRESSION TEST RESULTS:

The compressive strength of concrete cubes were determined by using CTM machine as shown in figure 4.2. And the table 4.2 shows that the compressive strength of cubes for various percentage replacement of NA by RA for different curing age of cubes specimens. By observing table 4.2 the compressive strength of RAC is lower than the NAC. Table below shows the compressive strength with age recorded during the test.

Figure .4.2: Compression test on cubes

Table .4.2: Compression test results of concrete cubes

W/C	% replacement	3 days (MPa)	7 days (MPa)	28 days (MPa)
0.27	0%	41.87	50.67	69.78
0.27	30%	41.78	49.96	68.82
0.27	35%	41.69	48.82	67.25
0.27	40%	39.67	47.61	66.12
0.27	45%	35.56	43.02	59.26
0.27	50%	34.72	40.84	57.86
0.36	0%	41.01	49.63	68.36
0.36	30%	40.08	48.98	67.49
0.36	35%	39.81	47.2	66.8
0.36	40%	36.87	44.63	61.48
0.36	45%	34.32	42.1	57.2
0.36	50%	34.14	39.58	56.9

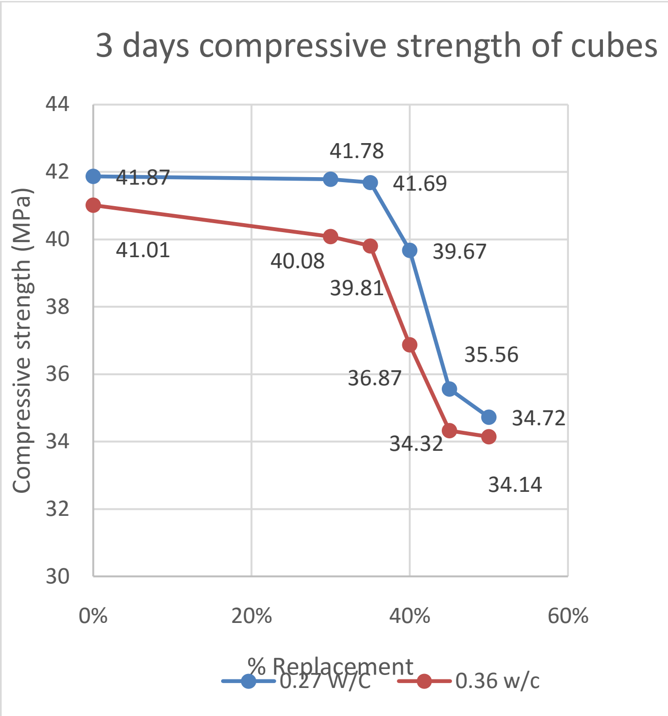

Figure.4.3: 3 days compressive strength of concrete

From the above figure 4.3. Can be observe that for 3 days the maximum strength developed is for NAC of 0.27 W/C and it is 41.87 N/mm^2 and for 0.36 W/C, maximum compressive strength is at 0% replacement I.e., 41.01 N/mm^2. Thus by increase in w/c ratio, compressive strength decreases. Among RAC the maximum 3 days strength developed for 30% replacement (0.27 W/C) it is 41.78N/mm^2 with astrength reduction of 0.21% among. RAC 50% replacement of NA by RA has lesser strength as compared to all replacement ratio. And the strength developed for 50% Replacement (0.27 W/C) is 34.72N/mm2 and it is about 17.08% reduction in strength as compared to NAC and for 0.36 W/C with 50 % Replacement is 34.14 N/mm2 and it is about 16.75% reduction in strength compared to NAC.

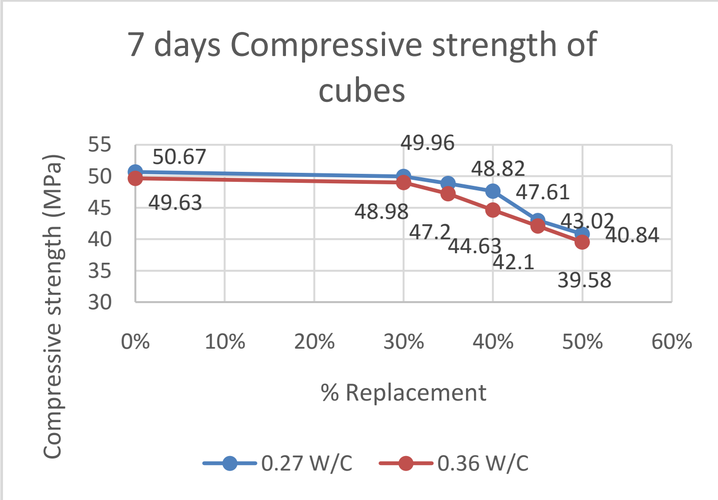

Figure.4.4: 7 days compressive strength of concrete

From the figure 4.4. Can be seen that again the maximum strength developed at 7 days is for NAC of 0.27W/C and it is about 50.67N/mm^2 and for 0.36 W/C, maximum compressive strength is at 0% replacement I.e., 49.63 N/mm^2. Thus by increase in w/c ratio, compressive strength decreases. Among RAC the maximum 7 days strength developed for 30% replacement (0.27 W/C) it is 49.96N/mm^2 with astrength reduction of 1.4% among. RAC 50% replacement of NA by RA has lesser strength as compared to all replacement ratio. And the strength developed for 50% Replacement (0.27 W/C) is 40.84N/mm2 and it is about 19.4% reduction in strength as compared to NAC and for 0.36 W/C with 50 % Replacement is 39.58 N/mm2 and it is about 20.25% reduction in strength compared to NAC.

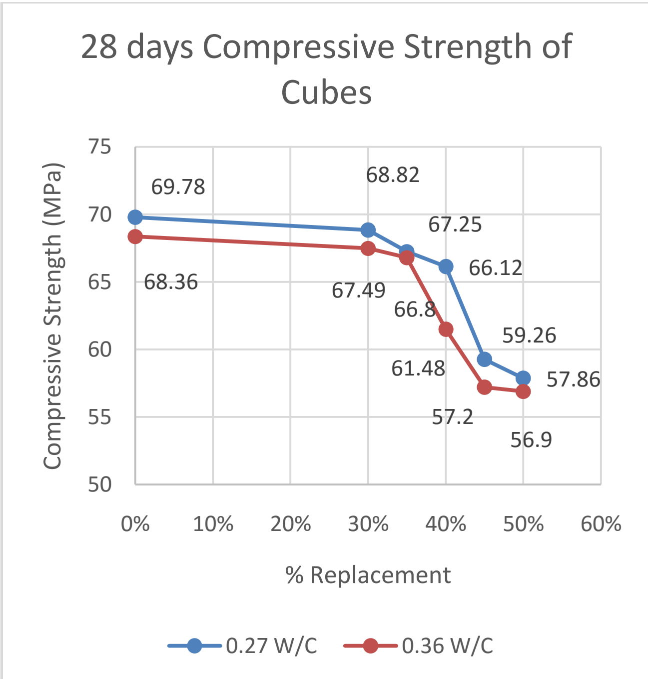

Figure.4.5: 28 days compressive strength of concrete

From figure 4.5. . Can be seen that again the maximum strength developed at 28 days is for NAC of 0.27W/C and it is about 69.78N/mm^2 and for 0.36 W/C, maximum compressive strength is at 0% replacement I.e., 68.36 N/mm^2. Thus by increase in w/c ratio, compressive strength decreases. Among RAC the maximum 28 days strength developed for 30% replacement (0.27 W/C) it is 68.82 N/mm^2 with a strength reduction of 1.38% among. RAC 50% replacement of NA by RA has lesser strength as compared to all replacement ratio. And the strength developed for 50% Replacement (0.27 W/C) is 57.86N/mm^2 and it is about 17.08% reduction in strength as compared to NAC and for 0.36 W/C with 50 % Replacement is 56.9 N/mm^2 and it is about 16.76% reduction in strength compared to NAC.

4.2.2. SPLIT TENSILE STRENGTH RESULTS:

The split tensile strength was carried out by CTM machine as shown in figure 4.6. The indirect tensile strength indicates a decreasing trend of tensile strengthwhen the percentage of RA is increased. Table 4.3 shows the average tensile strength recorded during the test.

Figure.4.6: Specimen subjected to split tensile test

Table.4.3: Split tensile strength results of concrete cylinders

W/C	**% replacement**	**7 day Split tensile strength (MPa)**	**28 day Split tensile strength (MPa)**
0.27	0%	6.17	10.12
0.27	30%	5.87	9.63
0.27	35%	5.67	9.3
0.27	40%	5.64	9.26
0.27	45%	4.52	7.41
0.27	50%	4.23	6.94
0.36	0%	6.05	9.92
0.36	30%	5.75	9.43
0.36	35%	5.7	9.01
0.36	40%	4.69	7.69
0.36	45%	4.18	6.86
0.36	50%	4.09	6.7

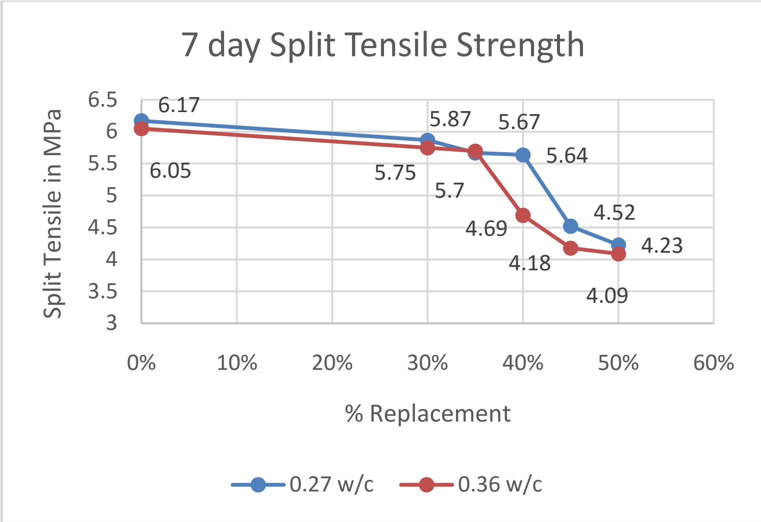

Figure.4.7: 7 days split tensile strength on concrete

From the above figure 4.7. Can be observe that the maximum split tensile strength achieved for NAC being 6.17 N/mm^2. and for 0.36 W/C, maximum tensile strength is at 0% replacement I.e., 6.05 N/mm^2. Among RAC the maximum 7 days split tensile strength developed for 30% replacement (0.27 W/C) it is 5.87 N/mm^2 with a strength reduction of 4.86%. among. RAC 50% replacement of NA by RA has lesser strength as compared to all replacement ratio. And the strength developed for 50% Replacement (0.27 W/C) is 4.23N/mm^2 and it is about 31.44% reduction in strength as compared to NAC and for 0.36 W/C with 50 % Replacement is 4.09 N/mm^2 and it is about 32.4% reduction in strength compared to NAC.

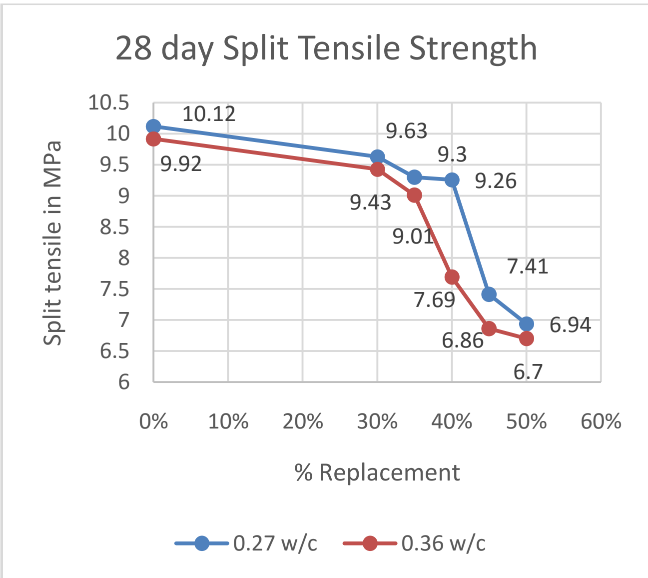

Figure.4.8: 28days split tensile strength of concrete

From the figure 4.8.Can be observe that the maximum split tensile strength achieved for NAC being 10.12 N/mm2. and for 0.36 W/C, maximum tensile strength is at 0% replacement I.e., 9.92 N/mm2. Among RAC the maximum 28 days split tensile strength developed for 30% replacement (0.27 W/C) it is 9.63 N/mm2 with a strength reduction of 4.84%. Among RAC 50% replacement of NA by RA has lesser strength as compared to all replacement ratio. And the strength developed for 50% Replacement (0.27 W/C) is 6.94N/mm2 and it is about 31.42% reduction in strength as compared to NAC and for 0.36 W/C with 50 % Replacement is 4.09 N/mm2 and it is about 32.46% reduction in strength compared to NAC.

4.2.3. FLEXURE TEST RESULTS:

The flexural strength was carried out by flexural testing machine as shown in figure 4.9.. Table 4.4 shows that average flexural strength recorded during the test.By observing table 4.4 the flexural strength indicates a decreasing trend when the percentage of RA is increased in concrete.

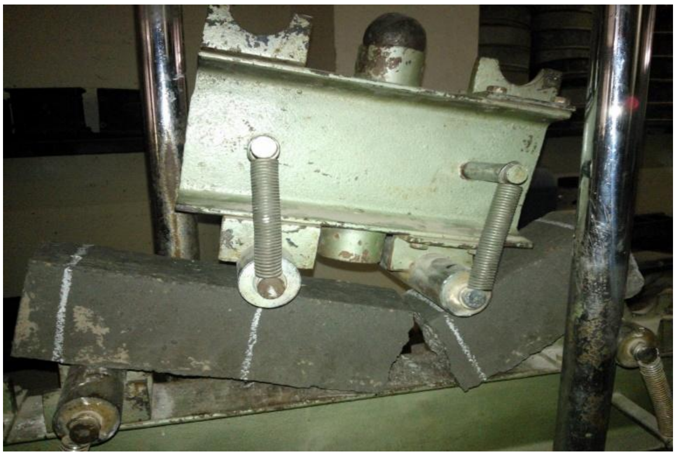

Figure.4.9: Specimen subjected to flexure test

Table .4.4: Flexure test results on concrete prisms

W/C	% replacement	7 day Flexure strength (N/mm^2)	28 day Flexure strength (N/mm^2)
0.27	0%	3.41	4.95
0.27	30%	3.3	4.82
0.27	35%	3.2	4.64
0.27	40%	3.01	4.43
0.27	45%	2.64	3.94
0.27	50%	2.59	3.76
0.36	0%	3.25	4.85
0.36	30%	3.23	4.72
0.36	35%	3.13	4.54
0.36	40%	2.76	4.12
0.36	45%	2.49	3.77
0.36	50%	2.29	3.69

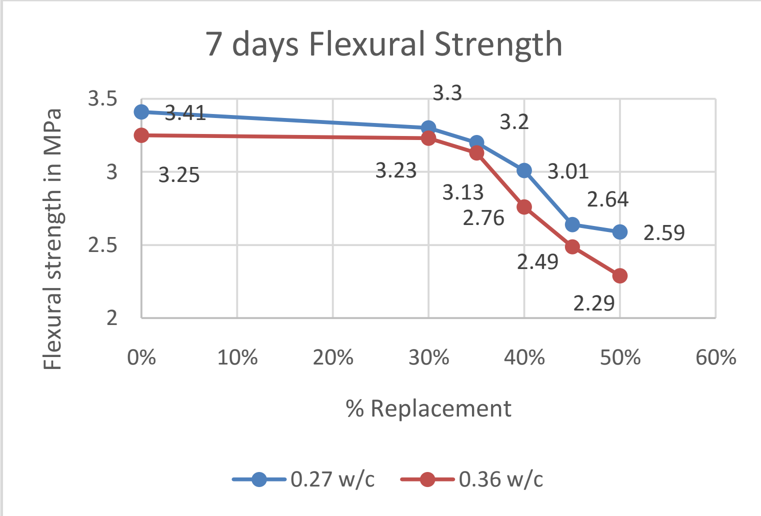

Figure.4.10: 7 days flexure strength of concrete

The above figure 4.10. Shows Flexure strength and from results we can observe that with increased in % replacement of RA the strength gained reduces. The 7 day flexural strength developed is for NAC for 0.27 W/C is 3.41 N/mm2 and for 0.36 W/C is 3.25 N/mm2. Among RAC the maximum flexural strength developed for 30% replacement of 0.27 W/C which is 3.3N/mm2 and it is about 3.22% reduction in strength as compared to NAC. And among RAC the least strength developed for 50% replacement of 0.36 W/C which is 2.29N/mm2 and it is 29.54% reduction in strength as compared to NAC.

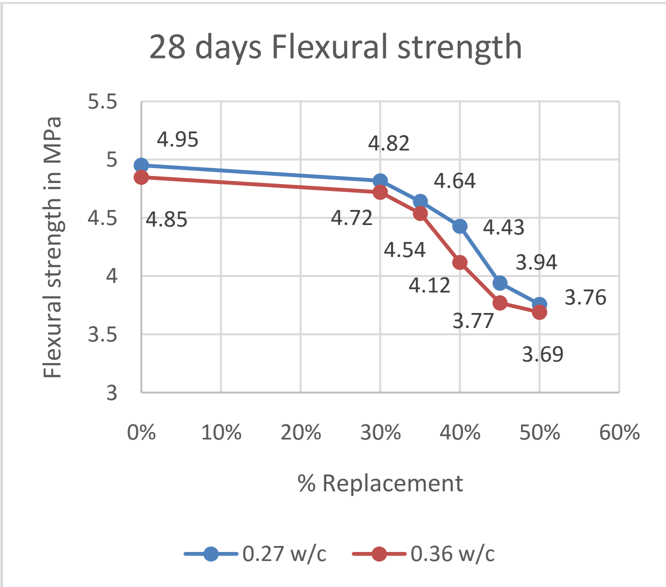

Figure.4.11: 28 days flexure strength of concrete

The above figure 4.11. Shows Flexure strength and from results we can observe that with increased in % replacement of RA the strength gained reduces. The 28 days flexural strength developed is for NAC for 0.27 W/C is 4.95 N/mm^2 and for 0.36 W/C is 4.85 N/mm^2. Among RAC the maximum flexural strength developed for 30% replacement of 0.27 W/C which is 4.82N/mm^2 and it is about 2.63% reduction in strength as compared to NAC. And among RAC the least strength developed for 50% replacement of 0.36 W/C which is 3.69N/mm^2 and it is 23.92% reduction in strength as compared to NAC.

4.3 Optimization by Taguchi Method

Taguchi's method is a statistical method developed by Taguchi. Initially Taguchi method was developed for improving the quality of goods manufactured. It involves identification of proper control factors to obtain the optimum results of the process (Mix proportion). Orthogonal Arrays (OA) are used to conduct a set of experiments. Results of these experiments are used to analyse the data and predict the quality of components produced.

Taguchi suggested a specially designed method I.e., the use of orthogonal array to study theentire parameter space with lesser number of experiments to be conducted. The value of loss function is further transformed into signal-to-noise (S/N) ratio. The S/N measures the level of performance and the effect of noise factors on performance. Here nominal the best type of S/N ratio has been taken. The S/N can be calculated as given in Equation

S/N = 10*log$_{10}$(μ^2/ σ^2)

Where, μ =mean value
σ = Standard deviation

In this research work 4 types of W/C ratio has been taken (0.27, 0.30, 0.33 and 0.36). The values of 0.30 w/c and 0.33 w/c ratio are taken from Laxmi Shravanthi (2016), Optimization of Recycled Aggregate Concrete using statistical approach. For each w/c ratio of different replacement ratio (30%, 35%, 40%, 45% and 50%) compressive strength values at 3, 7 and 28 days are obtained. Thus 3 factors are taken with 5 levels.

Levels	Factors		
	A	B	C
Level 1	0.27	50%	3
Level 2	0.3	30%	7
Level 3	0.33	35%	28
Level 4	0.36	40%	**7***
Level 5	**0.27***	45%	**28***

*Dummy level
Where, Factor A represents W/C,
Factor B represents % replacement
Factor C represents a day of Compressive strength

For the above values L25 Orthogonal array has been taken and values are incorporated and analyzed.

4.3.1 Effect of S/N ratio with W/C ratio

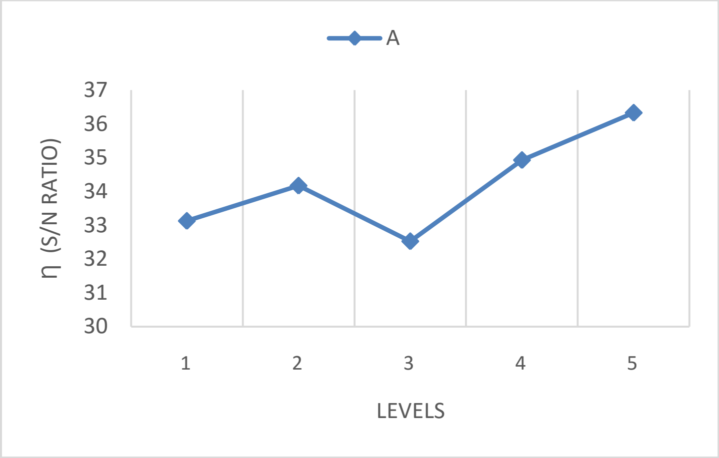

Fig.4.12 S/N Ratio against W/C ratio graph

By Taguchi method of analysis, fig. shows that W/C ratio has significant effect on compressive strength of concrete. Compressive strength increases with decrease in W/C ratio. In the above figure 4.12 for level 5, S/N ratio is highest I.e., for 0.27 W/C S/N ratio is highest. Thus 0.27W/C ratio is considered as optimum.

4.3.2 Effect of S/N ratio with % Replacement

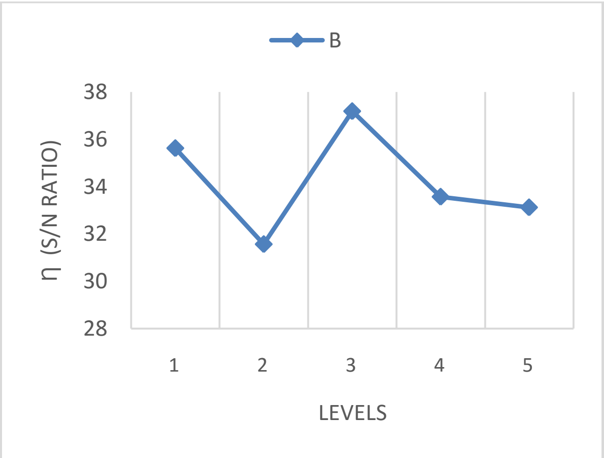

Fig.4.13 S/N Ratio against % Replacement graph

By Taguchi method of analysis, fig. shows that % Replacement has significant effect on compressive strength of concrete. Compressive strength decreases with increase in % Replacement. In the above figure. 4.13 for level 3, S/N ratio is highest I.e., for 35% Replacement, S/N ratio is highest. Thus 30% Replacement is considered as optimum.

4.3.3 Effect of S/N ratio with days

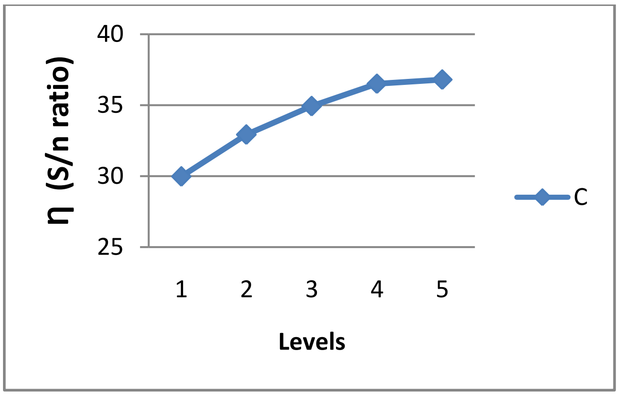

Fig.4.14 S/N Ratio against Days graph

By Taguchi method of analysis, fig. shows that day at which compressive test has been conducted has significant effect on compressive strength of concrete. Compressive strength increases with increase in number of days. In the above figure 4.14 for level 5, S/N ratio is highest I.e., for 28 days, S/N ratio is highest. Thus 28 days is considered as optimum.

4.3.4 Optimum Level

w/c = 0.27
% Replacement = 35%
Days = 28 days

V. CONCLUSION

The specific gravity and bulk density of recycled aggregates is lower than that of the natural aggregates and this can be attributed to the attached mortar present in the recycled aggregates.

The attached mortar in the aggregates make the aggregate lighter hence reducing the specific gravity and bulk density of it.

Optimum compressive strength obtained at 0.27 w/c ratio with 35% Replacement.

The maximum 28 days split tensile strength developed for 30% replacement (0.27 W/C) it is 9.63 N/mm2 with a strength reduction of 4.84%

The maximum flexural strength developed for 30% replacement of 0.27 W/C which is 4.82N/mm2 and it is about 2.63% reduction in strength as compared to NAC.

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