Predictive Models of Compressive Strength Concrete Produced from Recycled Concrete Aggregate

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Abstract- The investigation in this research is targeted at evaluating the most favourable proportion inclusion of RA as a partial replacement for NA to produce a grade-30 concrete using different water cement ratio of 0.40, 0.45 and 0.50. Experimental results indicate that 15%RA replacement gave a targeted compressive strength using different water cement ratios of 0.40-0.50. However, an acceptable compressive strength of 30Mpa and above was achieved for 30%RA replacement with w/c ratios of 0.4 and 0.45 after 28days curing. Mathematical tools known as least square model and the polynomial regression model were used to predict and monitor the compressive strength of concrete; whereas, developing models for different W/C ratio and %RCA for 7, 14 and 28days was considered useful in predicting and monitoring compressive strength of concrete as validation of developed models equation revealed range of coefficient of determination (R^2) of 0.80-0.97 by approach of ANOVA.

1. INTRODUCTION

All over the world, the high cost building materials has led to the huge demand for alternative sources of construction materials. The Recycle Concrete aggregate accounts for a large percentage of reusable solid waste generated from the construction and demolition sites in the building industry which today serves as a substitute to the conventional granite. Recycling concrete waste materials from demolished construction sites does not only foster sustainability but help minimise environmental waste in the industry [1-19].

Several studies have been carried out to understand the physical and mechanical properties of concrete made with different types of recycled aggregates (Rahal, 2007 and Meyer, 2009). They concluded that concrete deterioration occurs in the presence of free water; therefore the structure should be designed wherever possible to minimize exposure to moisture. In order to achieve concrete desirable strength, recycled concrete aggregate incorporation ratio with normal aggregate is determined [7-21].

Thorough investigation also revealed that Recycled Concrete Aggregates (RCAs) can be visualized as a two phased components made of Natural Concrete Aggregate (NCAs) and the adhering Mortar also known as AM.AM is characterized by micro cracks and pores that are penetrated by water therefore, making it more porous, compared to Natural Aggregate (NA). The porosity of RCAs depends on the composition of the original concrete. The porosity of RCAs significantly influenced the strength of RAC. It alters the initial water/cement ratio due to the pores infiltration [3-18].

2. MATERIALS AND METHOD

2.1 Mix Design

Table 1: Concrete Mix for water cement ratio of 0.4 and 0.45

S/No.	W/C	Ref No.	Mix Ratio	Cement	Sand	Coarse Aggregate		Nos. of cube
						NCA%	RCA%	
1	0.4	M1	1: 1.5:2	1	1	100	0	9
2	0.4	M2	1: 1.5:2	1	1	85	15	9
3	0.4	M3	1: 1.5:2	1	1	70	30	9
4	0.4	M4	1: 1.5:2	1	1	55	45	9
5	0.4	M5	1: 1.5:2	1	1	40	60	9
6	0.4	M6	1: 1.5:2	1	1	25	75	9
7	0.4	M7	1: 1.5:2	1	1	10	90	9
8	0.45	M8	1: 1.5:2	1	1	100	0	9
9	0.45	M9	1: 1.5:2	1	1	85	15	9
10	0.45	M10	1: 1.5:2	1	1	70	30	9
11	0.45	M11	1: 1.5:2	1	1	55	45	9
12	0.45	M12	1: 1.5:2	1	1	40	60	9
13	0.45	M13	1: 1.5:2	1	1	25	75	9
14	0.45	M14	1: 1.5:2	1	1	10	90	9

Table 1: Concrete Mix for Water Cement Ratio of 0.5

S/No.	W/C	Ref No.	Mix Ratio	Cement	Sand	Coarse Aggregate		Nos. of cube
						NCA%	RCA%	
15	0.5	M15	1: 1.5:2	1	1	100	0	9
16	0.5	M16	1: 1.5:2	1	1	85	15	9
17	0.5	M17	1: 1.5:2	1	1	70	30	9
18	0.5	M18	1: 1.5:2	1	1	55	45	9
19	0.5	M19	1: 1.5:2	1	1	40	60	9
20	0.5	M20	1: 1.5:2	1	1	25	75	9
21	0.5	M21	1: 1.5:2	1	1	10	90	9

2.2 Particle Size Distribution

The result of sieve analysis carried out in accordance with BS 812: Part 103:1995 for coarse aggregate (NCA and RCA) was found to have 5-20% fine particles (<4.75mm) of the total aggregate, 75% falling within size 4.75-20mm and about 10% of the rest falls within the maximum aggregate size of 20mm.

The obtained result from PSD for fineness modulus of sand yields values of 4.42. This value agrees with those obtained in the study of other researchers. (Abrams, 1971; Jayawardena&Dissanayake, 2006; Shahul&Seker, 2009).

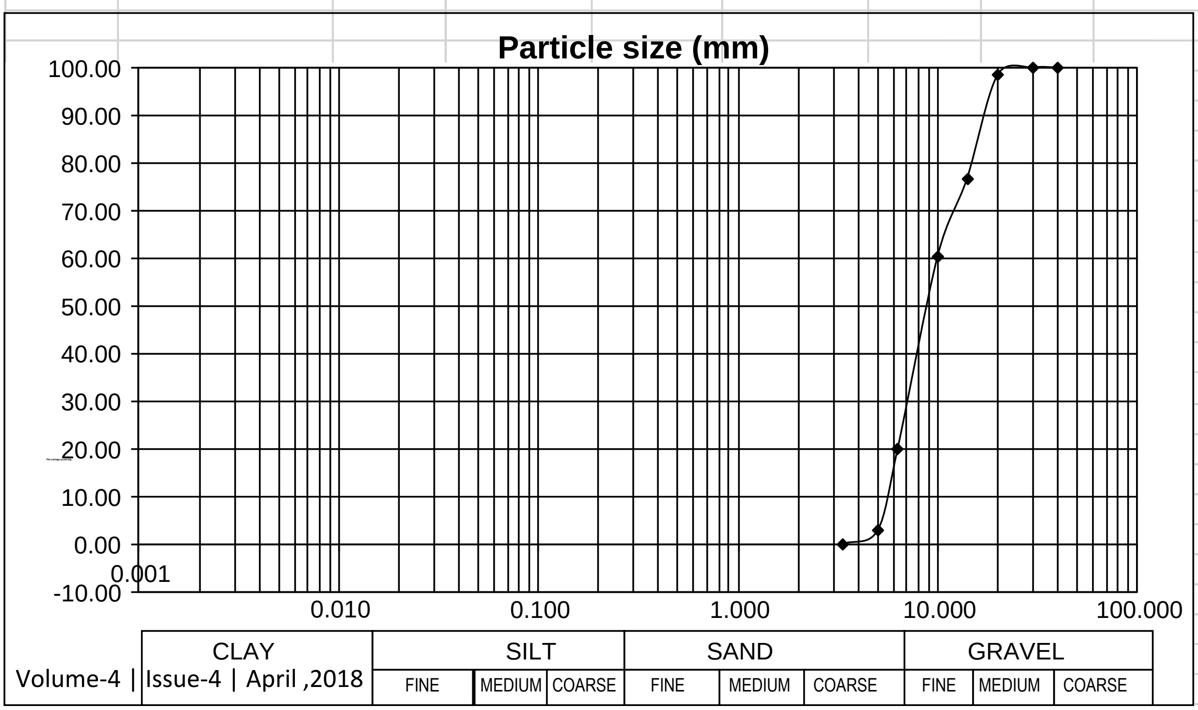
Figure 1: Particle Size Distribution for Sand

Particle size distribution- (Coarse aggregate- Granite)

Weight of sample taken for dry/wet grading	g	1400
Weight retained on No.75 micromillimetreB.S.sieve	g	0
Weight passing No.75 micromillimetreB.S.sieve	g	0

Sieve (mm)		Mass (g)	% retained	% passing
				100.00
40.00		0	0.0	100.00
30.00		0	0.0	100.00
20.00		20	1.5	98.50
14.00		293	22.0	76.50
10.00		214	16.1	60.44
6.30		538	40.4	20.05
5.00		229	17.2	2.85
3.35		38	2.9	0.00
Pan		0	0.0	0.00

Total Mass (g) = 1332



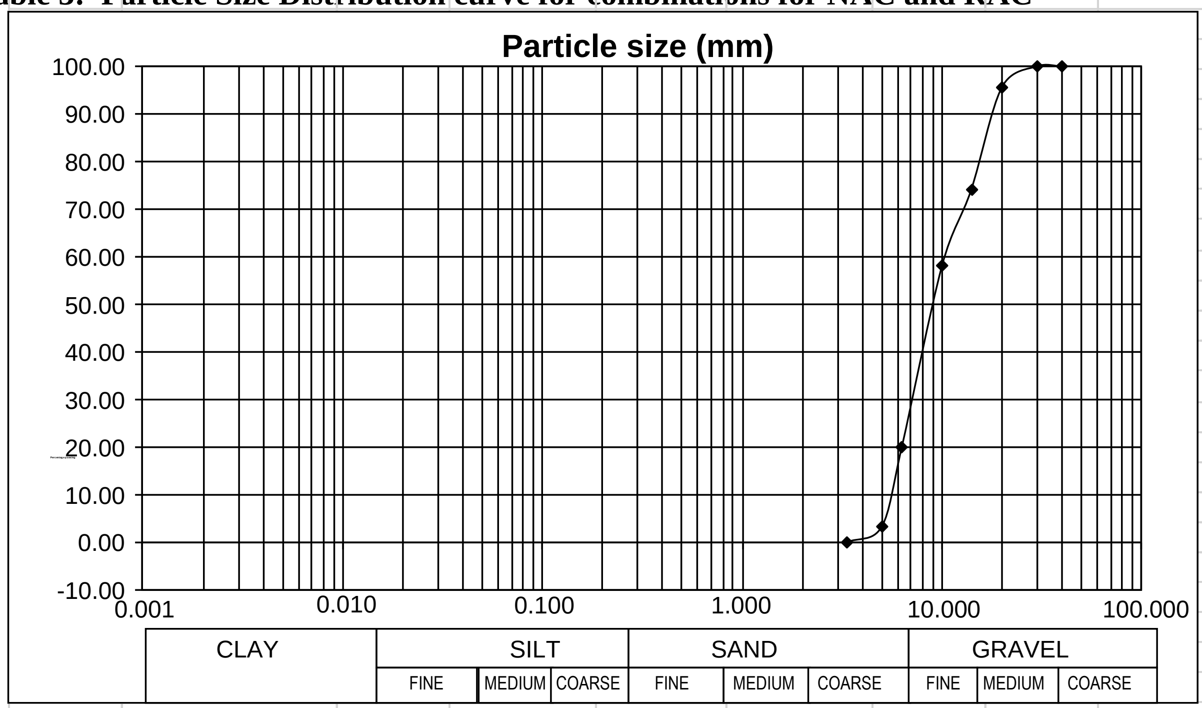
Particle size distribution- (Coarse aggregate- Recycle Aggregate)

Weight of sample taken for dry/wet grading	g	1400
Weight retained on No.75 micromillimetreB.S.sieve	g	0
Weight passing No.75 micromillimetreB.S.sieve	g	0

Sieve (mm)	Mass (g)	% retained	% passing
			100.00
40.00	0	0.0	100.00
30.00	0	0.0	100.00
20.00	60	4.4	95.62
14.00	298	21.7	73.89
10.00	218	15.9	57.99
6.30	520	37.9	20.06
5.00	230	16.8	3.28
3.35	45	3.3	0.00
Pan	0	0.0	0.00

Total Mass (g) = 1371

Table 3: Particle Size Distribution curve for combinations for NAC and RAC



D_{10} =	5.8	mm
D_{60} =	12	mm
C_u =	**2.07**	

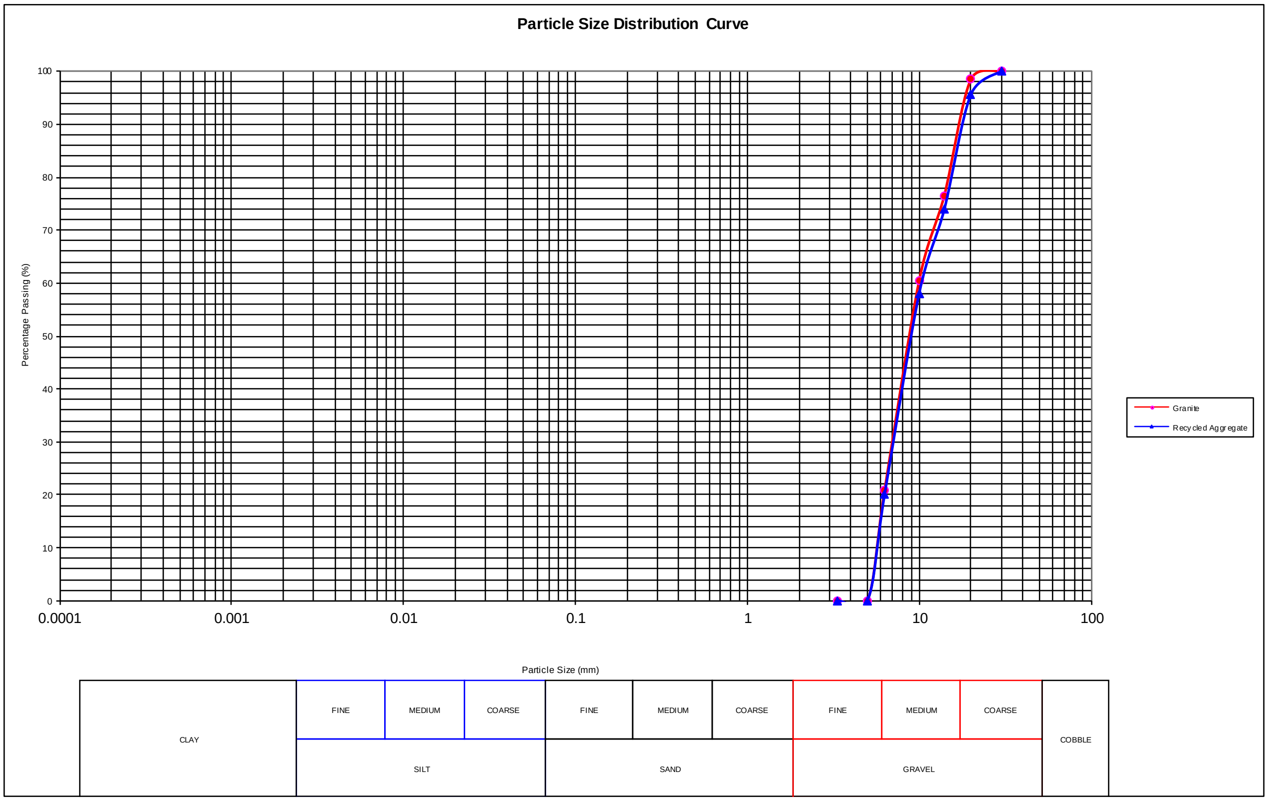


Figure 3:Particle Size Distribution for RCA vs NA

2.3 Density of concrete

Results in Figure 5 indicate corresponding increase in density as the age of soaking is prolonged; this was different for concrete with reduced %RA inclusion. From laboratory results below I Table 4 it can therefore be deduced that the pores in RCA caused the reduction in concrete weight.

Table 4: Density of Concrete with Age

Age (Days)	Concrete Density (kg/m^3)			
	NCA(0%RCA)	90%RCA	60%RCA	30%RCA
7	2700	2637	2589	2525
14	2726	2649	2590	2538
28	2785	2650	2647	2636

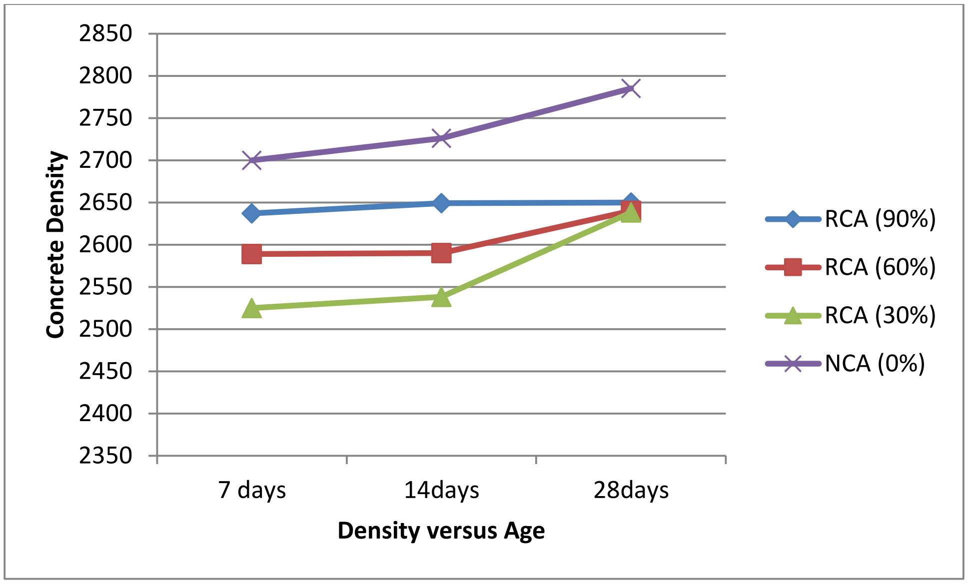


Figure 5: Density versus Age

3. RESULTS AND DISCUSSION

Table 5: Experimental Compressive Strength of Concrete and Model Compressive Strength for Different W/C Ratio and %RCA

Age	%RCA	Experimental Compressive Strength for W/C of 0.40, 0.45, 0.50			Predicted Compressive Strength for W/C of 0.40, 0.45, 0.50		
		0.40W/C	**0.45W/C**	**0.50W/C**	**0.40W/C**	**0.45W/C**	**0.50W/C**
28Days	15	33.50	31.34	30.52	35.19	31.24	32.11
	30	31.52	30.34	27.22	33.27	27.59	29.55
	45	28.01	25.09	24.00	31.35	23.80	26.79
	60	26.11	21.99	20.01	29.43	20.19	23.83
	75	23.74	18.86	15.11	27.51	16.49	20.67
	90	20.34	16.56	13.44	25.59	12.69	17.31
14Days	15	24.13	21.97	18.88	22.53	21.58	16.74
	30	20.33	18.17	16.38	18.52	17.05	12.55
	45	17.99	14.14	12.31	14.71	13.12	8.56
	60	14.00	10.91	11.34	11.10	9.79	4.77
	75	13.43	9.00	8.21	7.69	7.06	1.18
	90	10.53	8.64	7.11	5.45	4.93	-2.21

7Days	15	8.03	5.91	4.81	9.55	6.5	5.71
	30	7.97	5.64	4.34	9.72	6.5	5.95
	45	7.00	5.36	4.30	9.91	6.5	6.19
	60	6.61	4.87	3.9	10.01	6.5	6.43
	75	5.54	4.63	3.5	10.27	6.5	6.67
	90	4.51	3.54	2.02	10.44	6.5	6.91

3.2 Polynomial model in the prediction of compressive strength of %RCA concrete for varying w/c ratio

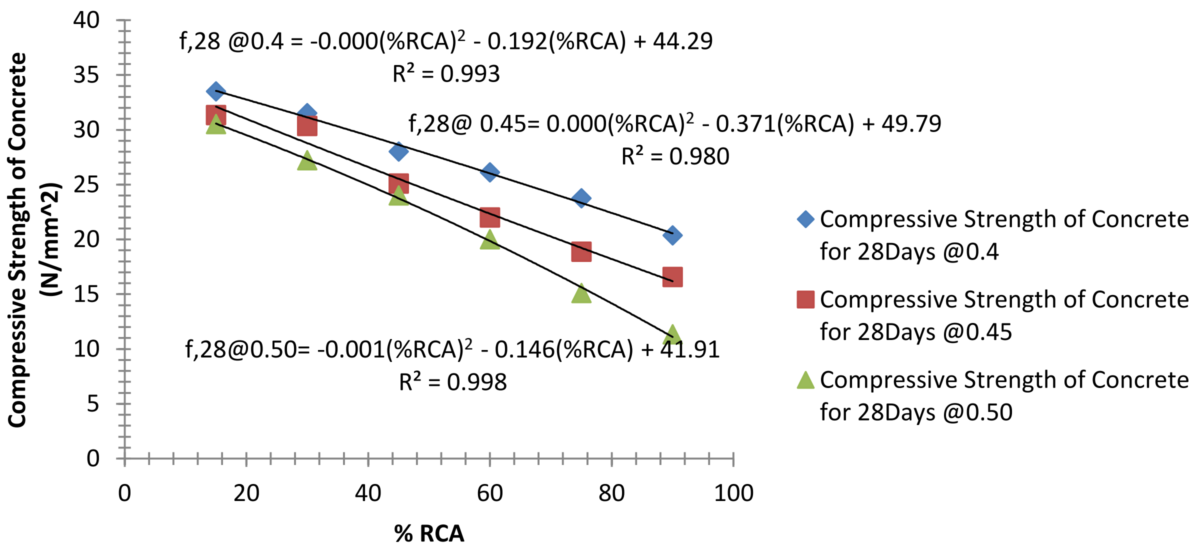


Figure 5: Plot of Compressive Strength of Concrete against Percentage of Recycled Concrete Aggregate

Figure 5 established the correlation between compressive strength of concrete and %RCA at various water cement ratio of 0.4, 0.45 and 0.50. The polynomial regression model were applied to examine the correlation between the compressive strength of concrete and %RCA and the following regression models was established for 28days at 0.4, 0.45 and 0.50 water cement ratio, $f_{28,0.4}$= -0.00(%RCA)^2 - 0.192(%RCA)+ 44.29 with R^2 = 0.993, $f_{28,0.45}$= 0.000(%RCA)^2 - 0.371(%RCA) + 49.79 with R^2 = 0.980 and $f_{28,05}$= -0.001(%RCA)^2 - 0.146(%RCA) + 41.91 with R^2 = 0.998. Figure 5 shows that as %RCA replacement is increased in the concrete mix the compressive strength of concrete were decreasing also with respected to increase in water cement ratio. Developed models due to different W/C ratio at 28days for curing and crushing concrete is useful in simulating the compressive strength of concrete produced using %RCA as partial replacement.

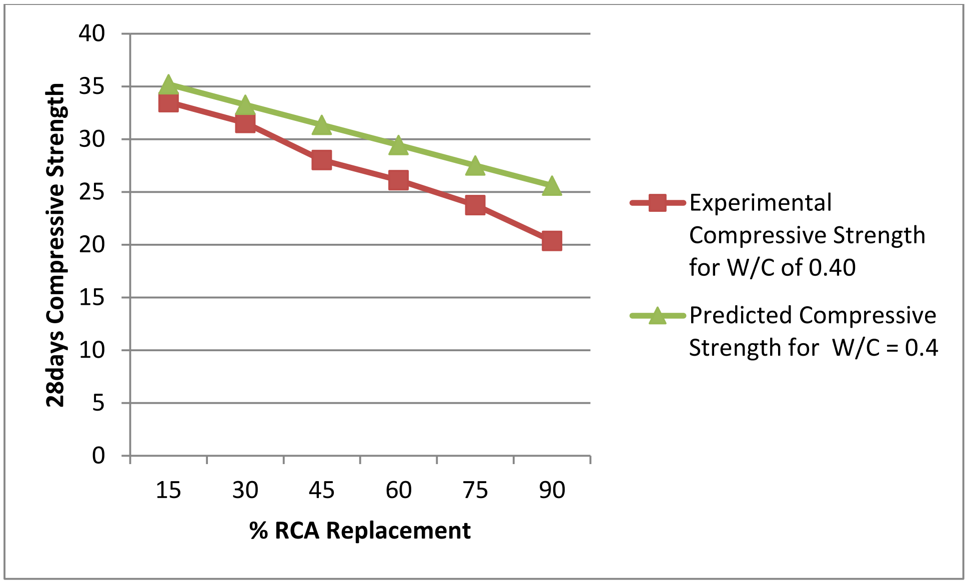


Figure 6: Comparison of Experimental and Model Compressive Strength for W/C Ratio= 0.4 and %15-90%RCA

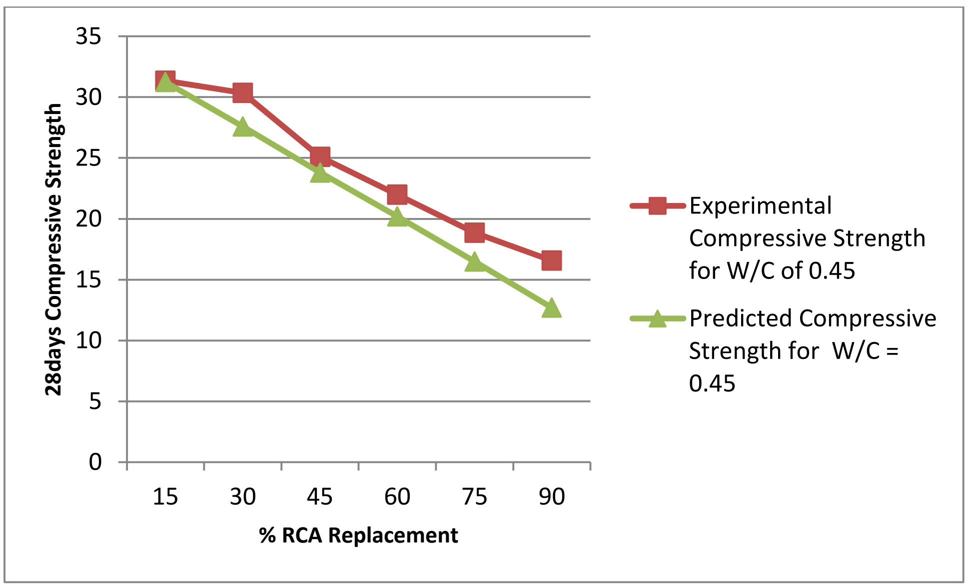


Figure 7: Comparison of Experimental and Model Compressive Strength for W/C Ratio= 0.45 and %15-90%RCA

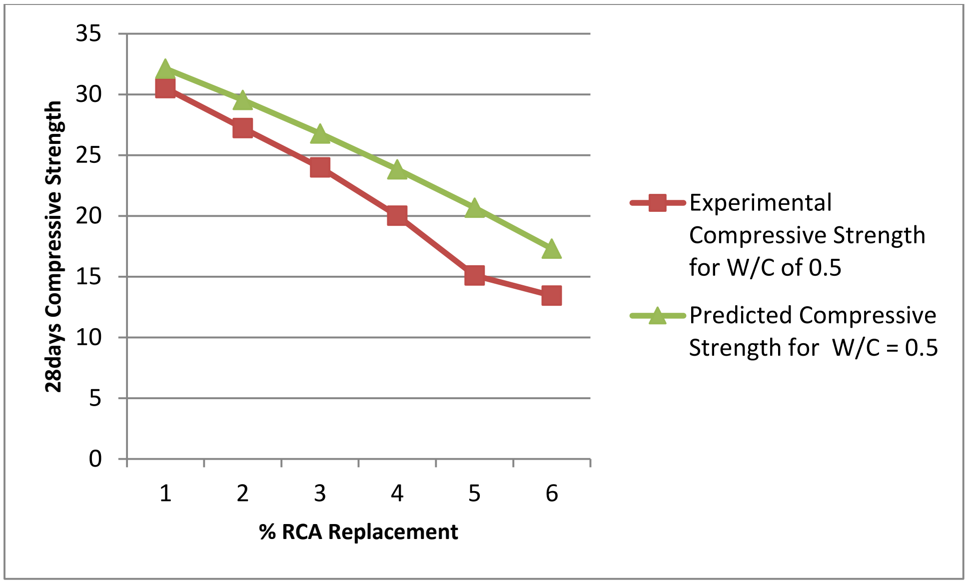


Figure 8: Comparison of Experimental and Model Compressive Strength for W/C Ratio= 0.5 and %15-90%RCA

Validation of Polynomial Regression Model for W/C ratio of 0.40, the experimental and model results of compressive Strengthsis validated using the concept of ANOVA.

The compressive strength of concrete using % RCA as partial replacement for a water cement ratio of 0.40 means explaining the variability of compressive strength of concrete and %RCA.

Table 6: ANOVA for W/C ratio 0.40

ANOVA	d.f	Sum of Squares	Mean sum of Squares	F-ratio
Regression or Explained	1	1734.22	1734.22	117.26
Residual or Unexplained	16	236.57	14.79	
Total	17	1970.79		

The calculated test statistical F_C =117.26. At 5% level of significant and (1,16) d.f., the critical value using F distribution is 4.49 which is lower than the calculated value. Therefore, at 5% level of significant we reject the null hypothesis and conclude that there is an evidence of polynomial relationship, meaning that the difference between experimental compressive strength is significant and R^2 = 0.87 were determined which indicated that developed polynomial regression model for 7,14 and 28 days can be use to simulate and monitor the compressive strength of concrete using %RCA as a replacement aggregate for 0.40 water cement ratio.

Water Cement Ratio of 0.45, modelled and experimental results of compressive strength of concrete established using %RCA as a replacement. The model obtained is fitted by evaluating R^2=0.94 by studying the relationship between the experimental and experimental compressive strength of concrete which is close to 1. Thus, the fitted models for 7, 14 and 28 days is considered to be good one. The analysis of variance for 0.45 W/C ratio model is tabulated below.

Table 6: ANOVA for W/C ratio 0.45

ANOVA	d.f	Sum of Squares	Mean sum of Squares	F-ratio
Regression or Explained	1	1182.97	1182.97	F_C=260.60
Residual or Unexplained	16	72.63	4.54	
Total	17	1255.60		

The computed statistic F_C = 260.60. At 5% level of significant and (1,16).d.f., the critical value using F-distribution is 4.49 which is lower than the calculated value. Therefore, at 5% level of significant we reject the null hypothesis and conclude there is an evidence of polynomial relationship.

Considering Water Cement Ratio of 0.5, experimental and modelled results of compressive strength of concrete produced by applying %RCA as a replacement were validated by fitting the model results of compressive strength of concrete. The coefficient of determination R^2 = 0.81 which a good indication that the models equation developed for 7,14 and 28 days for W/C ratio of 0.50 is useful in simulating and monitoring compressive strength of concrete when %RCA is used as replacement aggregate.

Table 8: ANOVA computation for W/C ratio 0.50

ANOVA	d.f	Sum of Squares	Mean sum of Squares	F-ratio
Regression or Explained	1	1765.45	1765.45	F_C=67.22
Residual or Unexplained	16	420.16	26.26	
Total	17	2185.61		

As tabulated in table: F_C = 67.22. At 5% level of significant and (1,16)d.f., the critical value using F-distribution is 4.49 which is smaller than the calculated value. Then, at 5% level of significant we reject the null hypothesis and conclude that there is an evidence of polynomial regression relationship.

4. CONCLUSION

1. Increased incorporation of RA to NAC as substitute results to increase in the overall porosity of the concrete compared to the conventional concrete. Various tests conducted indicate high porosity as a result of increasing percentage replacement of RA and w/c ratio.
2. Reduced w/c ratio and RA content in RCA results to better strength characteristics compared to the increased water to RA content. This is in agreement with Popovics and Ujhelyi, which states that increasing the w/c ratio, will lead to a decrease in concrete strength.
3. The substitution of RA especially at a high percentage replacement level has negative effects on mechanical properties by lowering the compressive strength.
4. The compressive strength test and other test performed during this research strongly hint that the optimum strength of concrete were achieved for 15% RCA replacement for water cement ratio range of 0.40-0.50 and an acceptable strength of concrete were achieved for 30% RCA replacement for W/C ratio of 0.40-0.45 at 28days curing age which is within the targeted strength of 30Mpa.
5. From result of the cost analysis, an alternative source of sound concrete with RAC that meets required targeted strength is cost effective compared to the conventional aggregate.
6. Developed models from different W/C ratio at 28days for curing and crushing concrete is useful in simulating the compressive strength of concrete produced using %RCA as partial replacement.
7. The developed polynomial regression models are useful in predicting and monitoring the compressive strength of concrete as validation of models by concept of ANOVA shows satisfactory results.

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