STRENGTH PREDICTION OF RECYCLED AGGREGATE CONCRETE USING ACCELRATED CURING METHOD

Nouman Iqbal[1,]*, Z.A. Siddiqi[2], Rashid Hameed[2], M. Rizwan Riaz[2]

[1]Civil Engineering Department, UET Rasul, Mandi Bahauddin, Pakistan

[2] Civil Engineering Department, UET Lahore, Lahore, Pakistan

*Corresponding author nouman.iqbal@ce.uol.edu.pk

ABSTRACT; *Compressive Strength of concrete is one of the most important and useful properties of concrete which is used by the engineer in designing RC structures. Generally, 3-days or 7-days normally cured concrete cylinders specimen are tested to determine the early gain in compressive strength and to predict the 28 day strength at site. However, 28-days compressive strength test is mandatory according to the building code requirements. Currently, research studies all over the world are being carried out on the applications of Recycled Aggregate Concrete (RAC) in real structures. The research work presented in this paper is an attempt to develop a simple mathematical equation based on simple linear regression analysis to estimate the 28-day compressive strength of RAC by employing results of early age (28.5 hr instead of 3 or 7 days) compressive strength tests. The proposed equation requires the value of 28.5 hr accelerated curing compressive strength to predict 28- days compressive strength of RAC. The results of 28-days compressive strength obtained using the proposed equation showed good agreement when compared with experimentally obtained 28-days compressive strength values.*

Keywords: *Recycled aggregate concrete (RAC), Accelerated Curing, Compressive strength, Linear regression analysis, Strength prediction*

1. INTRODUCTION

The compressive strength of concrete is used in the design of concrete structures and 28-days compressive strength of concrete is taken as design strength. Mix design of concrete is a process based on code and needs some prior experience. If due to some inaccuracy in mix design or mix preparation at site the designed strength is not achieved from the test results, in this situation, it is always required to repeat the entire process which is always costly and time consuming. Moreover, every time one has to wait for at least 28 days to estimate the design compressive strength. Due to all these reasons the need arises for a reliable method to estimate the 28-day compressive strength at an early age of concrete [1]. Now-a-days researchers are working to explore the performance of Recycled Aggregate Concrete (RAC) when used in structures. Keeping in mind the use/application of RAC in RC structures, prediction of compressive strength of RAC is an active area of research. Already some research work has been done in on normal aggregate concrete (NAC) [2]. Different methodologies using regression functions have been developed for forecasting the compressive strength of concrete [3;4]. Traditional modelling methods are being established based on empirical relation and experimental data. Some very accurate modelling systems utilizing artificial neural network (ANN) [5] and support vector mechanics (SVM) [6] have been developed for the accurate prediction of concrete compressive strength based on the early age compressive strength.

The main Objective of all the studies which have been carried out was to predict the compressive strength of concrete and to increase the efficiency of this prediction. In this research study, an effort is made to develop a simple linear relationship between 28.5 hr accelerated curing strength and normal curing 28-days strength of RAC.

2. MIX-DESIGN DATA

Portland cement concrete (PCC) made from three principal components i-e cement, aggregate, and water. The ordinary Portland cement, ASTM C 150 Type-I [7] was used. The brand name of cement used was “DG cement”, one of the well-known cement brands in Pakistan. In this study, crushed stone from Margala query was used as natural coarse aggregate. The cracked high strength Pre-Stressed concrete girders were used to produce the recycled coarse aggregate. The maximum size of natural coarse aggregate used was 20 mm (3/4 inch). Two types of the fine aggregate were used were Lawrencepur sand and Chenab sand. The Lawrencepur sand comes from Lawrencepur Quarry and it is extensively used in Punjab region due to its superior quality and strength. Lawrencepur sand was used in mix of 24.5 MPa (3500 psi), 28 MPa (4000 psi) and 35 MPa (5000 psi) to achieve required strength of concrete. The Chenab river sand comes from Chenab river bed and used in central Punjab regions. Chenab sand was used in mix of 14 MPa (2000 psi) and 17 MPa (2500 psi) to get the required strength of concrete. Mixing of Lawrencepur and Chenab sand was done in case of concrete with targeted compressive strength of 21 MPa (3000 psi). Properties of fine and coarse aggregates are given in table 1.1.

Table 1.1: Material Properties of coarse and fine aggregates

Material Properties	Fine Aggregate		Coarse Aggregate	
	Lawrencepur	Chenab	Margala	Recycled
SG_{SSD}	2.60	2.44	2.67	2.47
PA	2.9 %	2.2 %	0.95 %	4.1 %
γ_{bulk}	1840	1930	1590	1440
$n_{\%}$	25.6 %	18.0 %	39.4 %	39.4 %
F.M	2.54	2.05	7.29	7.13

Note : SG_{SSD} = Bulk specific gravity (Saturated surface dry)
PA = Percentage Absorption
γbulk = Compacted (Dry rodded density) unit weight
n% = Void content percentage in Compacted state
F.M = Fineness modulus of aggregate

Table 1.2: Concrete mix Design

f_c' MPa	Concrete Constituents ,kg/m^3 (Mix Ratio)				w/c
	Water	Cement	Fine Aggregate	Coarse Aggregate	
14.0	195	280 (1)	755 (2.7)	1040 (3.7)	0.70
17.0	195	315 (1)	725 (2.3)	1040 (3.3)	0.62
21.0	190	345 (1)	690 (2.0)	1040 (3.0)	0.55
24.0	190	380 (1)	645 (1.7)	1040 (2.7)	0.50
28.0	185	415 (1)	620 (1.5)	1040 (2.5)	0.45
35.0	185	480 (1)	570 (1.2)	1040 (2.1)	0.39

Note: f_c' = 28-days designed compressive strength
w/c = water to cement ratio

In this study, different concrete mixes were prepared with recycled as well as natural coarse aggregate. Six compressive strengths were chosen i.e 14 MPa (2000 psi), 17 MPa (2500 psi), 21 MPa (3000 psi), 24 MPa (3500 psi), 28 (4000 psi) and 35 MPa (5000 psi) and Five replacement level of recycled coarse aggregate replacements were studied i.e 0%, 25%, 50%, 75% and 100%, for every targeted strength. Hence, total of 30 batches were prepared. The mix design of each batch was based on the absolute volume method. The mix proportions were prepared according to ACI 211.1 [8]. Detail of each concrete mix is given in the table 1.2. The water used for mix was free from any kind of impurities like salinity & alkalinity. Drinkable tap water within the laboratory was used for casting all samples.

3. EXPERIMENTAL PROGRAMME

Four specimens were cast from each batch specified in Table 1.2 producing a total of 120 cylinders. For mixing of concrete all aggregates were used in SSD condition to maintain the same water to cement ratio (w/c) as per mix design. The normal curing of concrete cylinders was done following the instructions given in ASTM C192 [9]. Two out of four cylinders were cured normally. Once the concrete cylinders were cast, they were covered with a plastic sheet to stop evaporation before de-molding after 24 hours. After that, the cylinders were put in a water storage tank until they reach the specified age for the compression test.

The rapid curing of concrete was done by following the instructions given in ASTM C 684 [10]. After detail investigation and research Procedure B was chosen because in other procedures sophisticated equipment is required and chances of error are much more than Procedure B. Procedure B is simple and give better results as compared with other three procedures given in ASTM C 684. For the Procedure B, rapid curing tank was designed and manufactured locally. For the rapid curing of concrete cylinders specimens the concrete cylinders were placed in rapid curing tank after 23 h ± 15 min. According to ASTM C 684 guidelines for Procedure B the temperature of the water at the time of immersion and throughout the curing period was maintained at boiling point of water. After curing for 3.5 h ± 5 minutes, the concrete cylinders specimens were removed from the boiling water and allowed to cool at room temperature for at least 1 hour prior to testing.

For each concrete mix, two specimens were tested at 28.5 hr and two specimens were tested at 28 days.

4. DERIVATION OF THE MODEL

The main aim of this study was to make a strength development relationship for the earlier prediction of 28 days compressive strength of the RAC using early age compressive strength. Simple linear regression was used to develop a relationship between two variables by fitting a linear equation to observed data. The most common method which is used for fitting a regression line is "least-square method". This method calculates the best-fitting line for the experimental data by minimizing the sum of the squares of the vertical deviations from each data point to the line. Before attempting to fit a linear model to observed data, a modeller should first determine whether or not there is a relationship between the variables of concern.

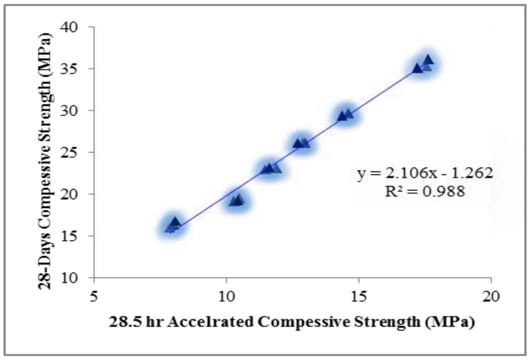

Figure 1.1 : Simple Linear Regression relationship for control mix 0 % Replacement (28-Days)

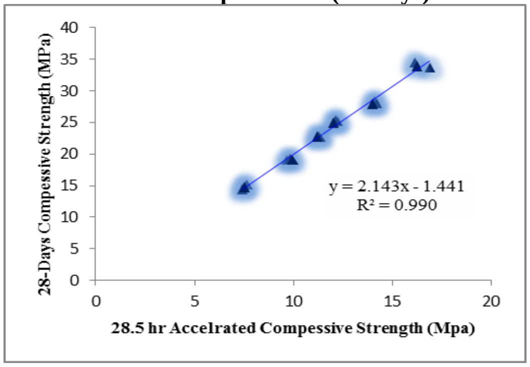

Figure 1.2 : Simple Linear Regression relationship for RAC 25 % Replacement (28-Days)

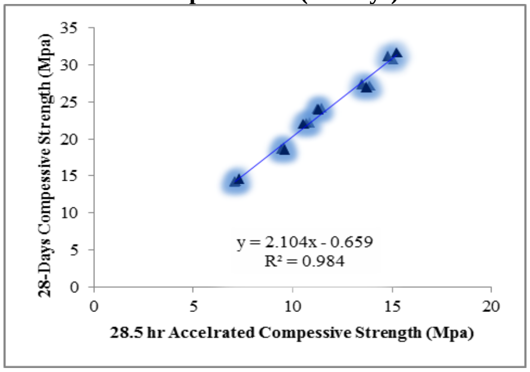

Figure 1.3 : Simple Linear Regression relationship for RAC 50 % Replacement (28-Days)

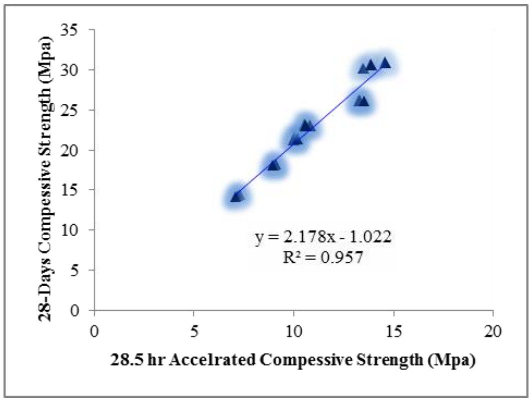

Figure 1.4 : Simple Linear Regression relationship for RAC 75 % Replacement (28-Days)

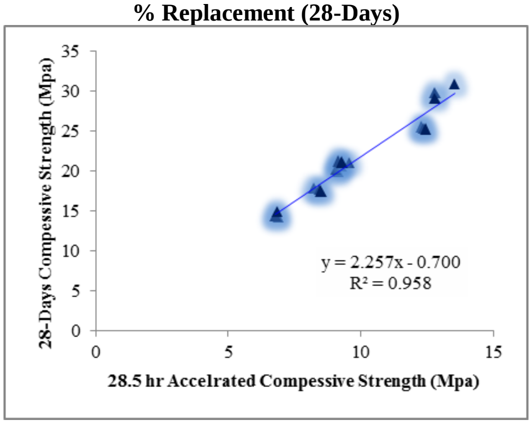

Figure 1.5: Simple Linear Regression relationship for RAC 100 % Replacement (28-Days)

A scatterplot is very helpful in defining the strength of the relationship between two variables. If there appears to be no association between the explanatory and dependent variables (i.e., the scatterplot does not indicate any increasing or decreasing trends), then fitting a linear regression model to the data probably will not provide a useful model. A valuable numerical measure of association between two variables is the coefficient of determination (R^2), whose value lies between "0" and "1". "0" value shows no association and "1" show 100% association between two variables. In a simple linear equation, one variable is considered to be an independent variable, and the other is considered to be a dependent variable.

For example, in this particular study 28.5 hr accelerated compressive strength is considered to be independent variable and 28-Days compressive strengths are dependent variables. A linear regression line has an equation of the form

$$Y = aX + b \qquad \textbf{Eq. 1.1}$$

Where X is the independent variable and Y is the dependent variable. The slope of the line is a, and b is the intercept (the value of y when x = 0).

Table 1.3: Linear Regression equations for different Replacement Level of RAC

Sr. no.	Percentage Replacement in RAC	Eq. for 28-Day Prediction	*R^2 for 28-Day Prediction
1	0 %	y = 2.106x - 1.262	0.988
2	25 %	y = 2.143x - 1.441	0.990
3	50 %	y = 2.104x - 0.659	0.984
4	75 %	y = 2.178x - 1.022	0.957
5	100 %	y = 2.257x - 0.700	0.958

**R*^{2} *is co-efficient of determination which explains how much the eq. is compatible for predicting a certain value (i-e in our case it is compressive strength). In eq.'s "x" represents 28.5 hr accelerated compressive strength.*

Table 1.3 summarizes the graphs given in Fig. 1.1to1.5. These graphs show trend-line which represents the eq. of predicting 28-Day compressive strength from 28.5hr accelerated compressive strength of concrete. Each graph is made from comparing 18 sets of data, 3 from each compressive strength, i-e 14MPa(2000psi), 17MPa(2500psi), 21MPa(3000psi), 24MPa(3500psi), 28MPa(4000psi) and 35MPa(5000psi). From these graphs, following conclusions are made:

i. For the prediction of 28-Day compressive strength the value of R^2 (co-efficient of determination) is greater than 0.95. This means, there is maximum of ± 5% difference in actual and predicted values from these equations.

ii. Co-efficient of determination gives indication of very strong relationship between 28.5 hr accelerated compressive strength and 28-Day normally cured compressive strength of concrete for the specified replacement level, irrespective of specified compressive strength.

iii. Co-efficient of determination is more than 0.98 in most of the equations especially for the prediction of 28-day compressive strength. However, as the replacement level is increased from 0% to 100% the R^2 (co-efficient of determination) is decreased. It means higher the replacement level lower will be the accuracy.

iv. PERFORMANCE AND VALIDATION

After the development equations it is complementary to check their validity. The performance of the proposed equations are evaluated by taking average 28.5 hr. accelerated compressive strength from all the 30 different mixes as a known value and by placing this value in the selected equation to determine the 28-Day compressive strength in table 1.5. The experimental results of 28-Day compressive strength are very close to the predicted values.

To graphically represent the results, the percentage reduction is found for 28-Day compressive strength and graphically represented in Fig. 1.6. This figure shows percentage difference in 28-Day compressive strength of RAC w.r.t. actual 28-Day compressive strength of RAC. The graph in Fig. 1.6(a) is screening percentage difference for different compressive strength of RAC which are of strength 14MPa(2000psi) to 35MPa(5000psi), irrespective of the percentage replacement of RAC and Fig. 1.6(b) is screening percentage difference for different percentage replacement of RAC which is 0 to100 % irrespective of the compressive strength of RAC. From these graphs following conclusion are made:

i. The Graph in Fig. 1.6(a) clearly depicts that most of the results lies within 5% percentage difference, which is clear indication of authenticity of the equation proposed to predict 28-days compressive strength using the early age (28.5 hr) compressive strength values.

ii. The Graph in Fig. 1.6(b) also shows that as percentage replacement of natural aggregates with recycled aggregates increases the percentage difference also increases but it does not show any well defined decreasing trend.

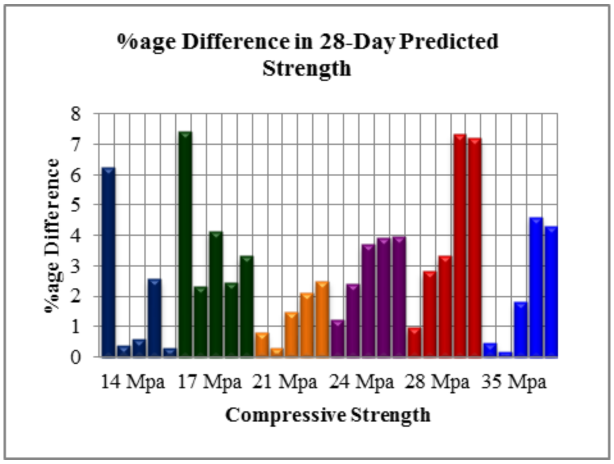

Figure 1.6 (a): %age difference in Predicted Compressive Strength (28-Days), (compressive strength as basic parameter)

Table 1.4: Percentage Difference in Predicted Compressive Strength of Concrete

Compressive Strength	Sample ID	28.5 hr Strength	28-Day Compressive Strength		
			Actual	Predicted	%age Diff.
14 Mpa	R0F14	7.97	16.56	15.52	6.26
	R25F14	7.53	14.64	14.70	0.38
	R50F14	7.16	14.49	14.41	0.58
	R75F14	7.18	14.25	14.62	2.57
	R100F14	6.83	14.67	14.72	0.31
17 Mpa	R0F17	10.41	19.23	20.66	7.44
	R25F17	9.83	19.18	19.62	2.32
	R50F17	9.54	18.64	19.41	4.15
	R75F17	9.03	18.2	18.65	2.45
	R100F17	8.39	17.65	18.24	3.32
21 Mpa	R0F21	11.66	23.11	23.29	0.80
	R25F21	11.27	22.78	22.71	0.30
	R50F21	10.68	22.14	21.81	1.48
	R75F21	10.08	21.38	20.93	2.09
	R100F21	9.14	20.44	19.93	2.50
24 Mpa	R0F24	12.85	26.12	25.80	1.22
	R25F24	12.13	25.16	24.55	2.41
	R50F24	11.33	24.07	23.18	3.70
	R75F24	10.65	23.08	22.17	3.93
	R100F24	9.33	21.2	20.36	3.97
28 Mpa	R0F28	14.52	29.6	29.32	0.96
	R25F28	14.1	27.99	28.78	2.81
	R50F28	13.69	27.24	28.14	3.32
	R75F28	13.36	26.16	28.08	7.32
	R100F28	12.36	25.37	27.20	7.20
35 Mpa	R0F35	17.46	35.67	35.51	0.45
	R25F35	16.43	33.83	33.77	0.18
	R50F35	15.02	31.51	30.94	1.80
	R75F35	13.98	30.85	29.43	4.61
	R100F35	13.04	30.03	28.73	4.32

Note: *Table 1.4 shows different Identification numbers (ID) given to each batch according to their compressive strength and recycled aggregate replacement e.g in "R100F14" "R" shows replacement percentage which is "100" and "F" shows designed 28 days compressive Strength ($fc^{/}$) in Mpa, which is "14".*

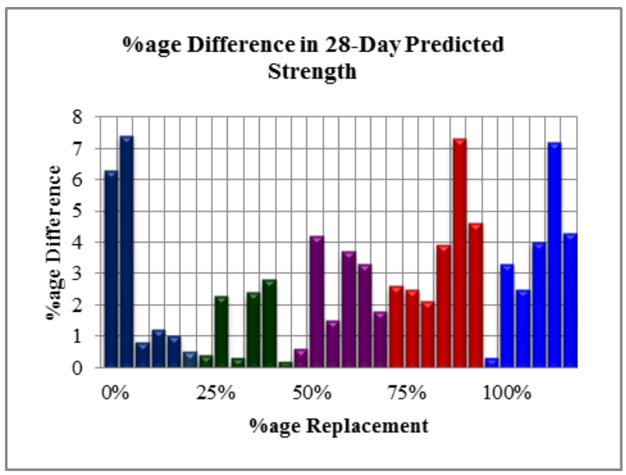

Figure 1.6 (b): %age difference in Predicted Compressive Strength (28-Days), (%age Replacement as basic parameter)

5. CONCLUSIONS

Prediction of RAC compressive strength was the focus of this study. Based on the obtained results the following conclusions were made.

1) It is known that the reduction in compressive strength of accelerated cured concrete cylinders increases with the increase in %age replacement of coarse aggregate with recycled aggregates, but by the use of high strength recycled aggregate this reduction level may be decreased.

2) R^2 (co-efficient of determination) for all the proposed equations gives indication of very strong relationship

between 28.5 hr accelerated compressive strength and 28-Day normally cured compressive strength of concrete for the specified replacement level, irrespective of specified compressive strength.

3) The results also show that that most of the predicted values lies within 5% percentage difference for 28-days compressive strength, which is clear indication of authenticity of the proposed equations.

4) It is also concluded from the results that as the compressive strength and percentage replacement of natural aggregates with recycled aggregates increases the percentage difference in predicted values also increases.

5)

6. RECOMMENDATIONS

Below are some of the recommendations which will help the researchers for further studies:

1) The same work may be carried out on the other types of concrete like self compacting concrete and fiber reinforced concrete made using recycled aggregates.

2) More investigations and laboratory tests should be done on the durability of recycled aggregate concrete and its creep and shrinkage characteristics.

3) Existing specification should be revised to permit and encourage the use of recycled aggregate in concrete. Using recycled aggregate in concrete mixes leads to conserve current resources of natural aggregates and also reduce solid waste that must be disposed of in landfills.

4) Specifications and standards were found to be key to the future use of recycled aggregates. Work is required to develop specifications and standards in order to create opportunities for the increased use of recycled aggregates.

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