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RELATIONSHIP BETWEEN CRUSHING VALUE OF RECYCLED AGGREGATES FROM DEMOLISHED WASTE AND COMPRESSIVE STRENGTH OF RECYCLED AGGREGATE CONCRETE

Bashir Ahmed Memon[1]*, Shahbazi Khan[2], Zubair Ali[3], Asadullah Abbasi[4], Mahboob Oad[5] and Kamran Memon[6]

[1]Professor, Civil Engineering Department, QUEST Nawabshah.
[2,3,4]Civil Engineering Graduate, Civil Engineering Department, QUEST Nawabshah.
[5]Assistant Professor, Civil Engineering Department, QUEST Nawabshah.
[6]Civil Engineering Student, QUEST Nawabshah.

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***Corresponding Author**
Bashir Ahmed Memon
Professor, Civil Engineering Department, QUEST Nawabshah.

ABSTRACT

This research article presents the numerical modeling by regression analysis between crushing value of recycled aggregates and compressive strength of recycled aggregate concrete. Recycled aggregates were produced from demolishing waste. Thirty samples were used for determination of the crushing value. For preparation of concrete cubes 50% replacement of conventional coarse aggregates was done with recycled aggregates in 1:2:4 mix. Water to binder ratio was used equal to 0.45. Thirty standard size cubes were prepared and cured in standard way. Compressive load recorded from the crushing of cubes was converted to compressive strength. Regression analysis using Microsoft EXCEL was performed on crushing value and compressive strength results. Obtained numerical model was verified with experimental data and found in good agreement to it.

KEYWORDS: Demolished waste, recycled aggregates, recycled aggregate concrete, crushing value, compressive strength.

1. INTRODUCTION

Quality of product in every walk of life is an important factor for success of the product. So is the case with concrete in construction industry. The parameter is to be ensured by testing performance under known and anticipated conditions. The testing not only involves the checking of the final product but also the checking of constituent materials. It is not only time consuming but also involves finance, skilled personals and dedicated equipment. An alternative is by achieving the purpose using mathematical modeling. A tool in which real work problem is reshaped in mathematical form which in turn is analyzed for required parameters. Also, it helps in establishing the relationship between various factor. It in turn help in determining the quality parameter based on the simple test results of the product or its constituent materials. Several techniques may be used for the purpose, among which, trend line analysis, regression analysis and artificial neural network are few examples. Every method has its own merits and demerits therefore, selection of the technique requires careful consideration for better results. Linear and multi variable regression is commonly used technique in the field of mathematical modeling to study the dependency of a variable on certain other parameters. The quality of concrete may also be estimated using these techniques. Good number of methos / framework for estimation of quality parameters of conventional concrete has been developed by research community for conventional concrete. But when it comes to recycled aggregate concrete still more work is required to reach certain level of confidence.

Recycled aggregate concrete is not only highly demanding in present but is also a prosperous product for future to conserve the conventional sources and to deal with the construction and demolishing waste. The waste is increasing day by day to a level that has become a serious problem worldwide. The waste exists since centuries but was not serious as dumping space was available everywhere. But now when, industry is forced to opt vertical expansion in place of horizontal development due to unavailability of space specially in developed region where concentration of the population is more and increasing with every passing day, space for dumping the waste is also scarce. The idea of recycling this waste in useable material started after second world war which left millions of tons of the waste as one of the negative results of the war. Rebuild of regions faced serious problem of dealing the waste first. Hence it was aimed to recycle the waste into useful material for new construction. Various components of the waste have been reprocessed and used in new construction including, bricks, glass, concrete etc. As leftover of demolished concrete is more compared to other ingredients thus reprocessing of it in aggregates for new concrete lead to the maximum utilization of the waste. Specially if the waste is recycled into coarse aggregates.

However, the aggregates obtained from recycling of the demolishing waste has few problems in comparison to conventional aggregates. These include life of the structure, its exposure to different natural and human generated situation, processing technique, old mortar attached with the aggregates, parent strength etc. All of these not only impact the properties of the aggregates but also the properties of concrete developed by using such aggregates. Therefore, quality checking of the aggregates and concrete is a must before taking any decision for such concrete for load carrying structural members.

It is evident from literature that good quantum of time by research community has been devoted to understand the properties and behavior of the aggregates. Such works has been reviewed by Patel and Singh[1] with respect to physical properties. Recent development on use of demolished waste as coarse aggregates has been reviewed by Memon.[2] Buller et. al.[3] reviewed the literature on reuse of the construction and demolishing waste in concrete. Continuing the effort, Bhatti et. al.[4] revied the development on flexural strength of green concrete. Basic properties of recycled coarse aggregates developed from demolished waste has been reviewed by Memon et. al.[5] The authors summarized various properties of the aggregates and highlighted the scatter in the same showing that more work is still required in the field.

Among several properties of the aggregates, strength of the aggregates in an important one, to contribute to the final strength of the concrete. For determination of strength of the aggregates crushing value test is performed. It is the resistance of the aggregates against gradually applied compressive load. It is measured as the percentage loss of the weight of the aggregates. Rehman et. al.[6] in their research program investigated the crushing value of the recycled aggregates of various sizes and their impact on the compressive strength. The test results showed 28.57% crushing value of recycled aggregates in comparison to 16.33% for conventional aggregates. Hence the crushing value of the recycled aggregates was 74.95% higher than that of conventional coarse aggregates. Merin et. al.[7] in their laboratory investigation program also studied crushing value and its impact on strength properties of concrete but also used surface treatment of the aggregates with pozzolan slurry and triple mixing method to improve the deficiency of the recycled aggregates. The test results showed 14.9% higher crushing value of the untreated recycled aggregates than conventional aggregates. But when surface treatment of the aggregates was opted the crushing value was recorded 19.8% higher. However, the surface treatment and triple mixing method showed positive effect on the compressive strength of the concrete as increase in compressive strength was recorded at 20%, 40%, 60% and 100% replacement of conventional coarse aggregates with proposed recycled aggregates. Similar to it, the surface treatment of the recycled aggregates also failed to improve the crushing resistance of the aggregates as observed by Salgadoa and Silvaa.[13] In another study crushing value of recycled aggregates was recorded in the range of 19% - 26% for recycled aggregates of different sizes from different sources.[8] Li et. al.[9] also used different combinations of the aggregates to study the crushing value and its effect on compressive strength. They also modeled the dependency of compressive strength on crushing value with R^2=0.9996. Kumawat et. al. [10] in their research program observed 19.18% higher crushing values of recycled aggregates. Unlike it, Bashir et. al.[11] observed 15.5% higher crushing value of the recycled aggregates. Another research outcome report 101.6% higher crushing value of the recycled aggregates.[12] Higher crushing value was also observed in.[14-21]

Regression analysis is a powerful mathematical tool to evaluate the dependency of a variable with change in other variables. The process may also be used to predict concrete properties, i.e., strength, strain, deflection etc. using properties of constituent materials or other variables. It has been used along with hard and fuzzy clustering techniques to predict the compressive strength of the concrete.[22] Compressive strength of concrete has also been modeled by regression analysis along with artificial neural network and neuro fuzzy techniques.[23,25] Considering different curing conditions as independent variables compressive strength of concrete has been modeled by Olonade et. al.[24] Concrete compressive strength was also modeled by Wilson et. al.[26] using mix proportion and properties of constituent materials as independent variables. In a case study of Nairobi metropolitan Maina et. al.[27] modeled concrete compressive strength using multilinear regression analysis. Regression analysis and its variants has also been used to model concrete strength with different variables, i.e., mix design parameters and admixture[28], concrete with coconut shell[29], gradient booster technique[30], and polynomial regression with gradient booster for compressive strength of recycled aggregate concrete.[31]

The discussion of available state of art shows clearly that good quantum of work has been done using regression analysis for conventional concrete. Few studies also attempted to model compressive strength of recycled aggregates using mix proportion and advance techniques of regression analysis but available state of art is almost silent on modeling the compressive strength of recycled aggregate concrete prepared with recycled aggregates from demolishing waste and crushing value of the recycled aggregates. Therefore, this research work proposes the experimental evaluation of crushing value of recycled aggregates from demolishing waste and compressive strength of recycled aggregate concrete. Based on the experimental results numerical modeling of compressive strength and crushing value of recycled aggregates will be done using regression analysis. The developed numerical model will be validated with experimental observations of the parameters.

2. MATERIALS AND METHODS

2.1 Recycled aggregates

The demolished waste (Figure 1) for processing into recycled aggregates was collected from the demolishing of a public sector reinforced concrete building from Nawabshah, Sindh, Pakistan. It was then manually hammered in the laboratory to maximum of 1 inch size. The process was ensured by sieving the product through 1 inch sieve and retained material was discorded. The recycled coarse aggregates were then sorted for unwanted substances. Washing of the aggregates was done with clean water followed by drying in the laboratory. Figure 2 shows the pictorial view of the aggregates. To ensure well graded aggregates in concrete, the obtained material was sieved in standard fashion. The fineness modulus of the aggregates was recorded equal to 5.4.

Figure 1: Demolished waste.

Figure 2: Recycled aggregates.

2.2 Conventional ingredients of concrete

The conventional ingredients of concrete used in this research work were ordinary Portland cement (Lucky star), fine aggregates (hill sand), coarse aggregates (crush), and drinking water. The specific gravity, fineness, initial setting time, final setting time, consistency, and loss on ignition of cement were determined and were observed equal to 3.16, 98%, 68 min, 334 min, 31%, and 1.56% respectively. Both fine and coarse aggregates were obtained from the approved sources of the materials. The specific gravity, and water absorption of fine aggregates were determined and recorded equal to 2.67 and 0.98%. Water absorption and specific gravity of both conventional and recycled aggregates were determined and recorded equal to 1.43% and 2.52 for conventional aggregates and 2.14% and 2.27 for recycled aggregates. Sieve analysis of conventional coarse aggregates was done in line with recycled aggregates to ensure well graded conventional aggregates in concrete. The fineness modulus was recorded equal to 5.44. The water used for washing, mixing and curing was obtained from the water supply line having pH value equal to 6.8.

2.3 Crushing value test

Aggregate crushing value test of both conventional and recycled aggregates was done in accordance with BS 812-Part 110[32] following the procedure and specification set by the code. Obtained results are given in Table 1. Crushing value apparatus used in testing is shown in Figure 4.

Figure 3: Concrete ingredients.

Figure 4: Crushing value test.

Table 1: Aggregate crushing value.

Crushing value (%)					
Sample	Conventional aggregates	Recycled aggregates	Sample	Conventional aggregates	Recycled aggregates
1	4.10	3.65	16	3.65	5.20
2	4.15	4.47	17	4.95	4.95
3	4.20	5.00	18	4.83	4.83
4	3.85	5.34	19	3.60	4.76
5	3.80	5.78	20	3.65	4.65
6	3.78	5.21	21	3.55	4.66
7	3.70	4.78	22	3.50	4.76
8	3.80	4.56	23	3.70	4.40

9	3.60	4.69	24	3.50	4.45
10	3.90	4.86	25	3.60	4.87
11	3.90	4.72	26	3.50	4.85
12	4.00	4.65	27	3.40	4.95
13	3.87	4.91	28	3.40	5.10
14	3.65	5.10	29	3.20	4.85
15	3.60	5.10	30	3.50	5.20

2.3 Compressive strength

To determine the compressive strength of recycled aggregate concrete, thirty standard size cubes were prepared using 1:2:4 mix with 0.45 water-binder ratio. The mix ratio is select due to fact that it is most commonly used mix ratio in the field. Conventional aggregates were replaced in 50% dosage with recycled aggregates from demolished waste. The concrete ingredients in dry state were thoroughly mixed in mixer followed by adding the water in required quantity. The mixer was operated till the uniform paste is obtained. The inner surface oiled cube molds were filled in three layers. The molds were compacted using table vibrator till cement slurry appeared on the top of the mold. Few samples are shown in Figure 5. After a day in molds the specimens were taken out of the molds and allowed to air dry. Then the specimens were allowed curing for 28-days by fully immersing in the water.

After the elapse of curing age, the specimens in turn were crushed in universal testing machine under gradually increasing load. The crushing load was recorded and used to compute the compressive strength using standard formula. A specimen during testing is shown in Figure 6. The obtained results of compressive strength are given in Table 2.

Figure 5: Cube specimens.

Figure 6: Specimen testing.

Table 2: Compressive strength.

Sample #	Compressive strength (MPa)	Sample #	Compressive strength (MPa)
1	18.16	16	16.50
2	18.73	17	16.90
3	17.96	18	16.60
4	17.80	19	16.70

5	18.40	20	16.41
6	18.30	21	16.53
7	17.83	22	16.68
8	18.93	23	16.10
9	17.82	24	18.14
10	17.68	25	17.23
11	17.12	26	18.73
12	16.35	27	17.23
13	16.61	28	16.33
14	17.85	29	16.76
15	17.75	30	16.95

2.4 Regression analysis

It is a statistical process which provide relation between two or more variables. It consists of two sets of data i.e., target variables and predictor variables. Using data set the method develops mathematical expression which computes the target variables from predictor variables. In this research work the target variable is compressive strength and the predictor variables are crushing values of conventional and recycled aggregates. Using the test results of both type of variables regression analysis was performed. For the purpose Microsoft EXCEL[34] was used. The software is capable of performing the regression analysis. The outcome of the process is given in equation below

$$CS = 17.4225 + 0.4243CV_{RCA}$$

In the above expression CS is compressive strength, and CV_{RCA} is the crushing value of recycled aggregates.

3. RESULTS AND DISCUSSION

From the rests results of water absorption and specific gravity it may be observed that recycled aggregates observed 49.65% higher water absorption and 9.83% lower specific gravity. The reason for this deviation is the old mortar attached with recycled aggregates among other factors. The properties of cement presented earlier complies well with the set ASTM standards for the ordinary Portland cement. Analogous to it the fine aggregates also confirm with relevant ASTM specifications for water absorption and specific gravity. The fineness modulus obtained from sieve analysis verifies it as coarse sand (hill sand). The percentage passing of fine and coarse aggregates at sieves specified by relevant ASTM standards is shown in Figure 7 and Figure 8 along with lower and upper limits set by ASTM standards. It may be observed that the passing percentages of different size aggregates is well with the allowable range. Thus, confirms well graded aggregates in concrete.

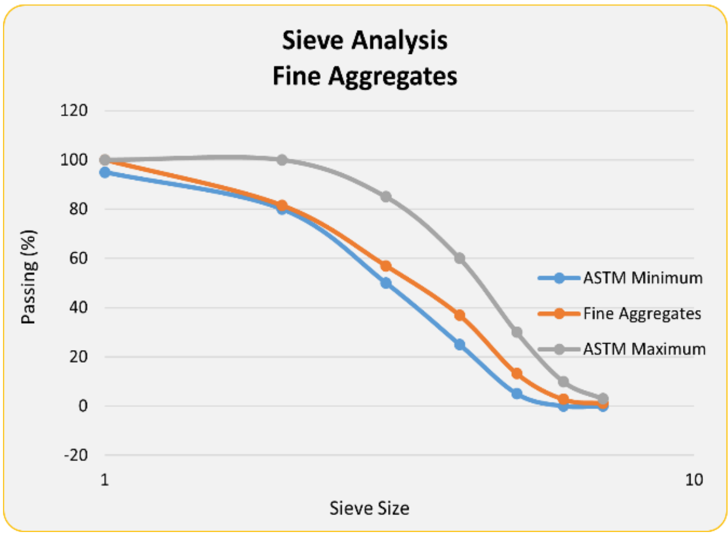

Figure 7: Sieve analysis of fine aggregates.

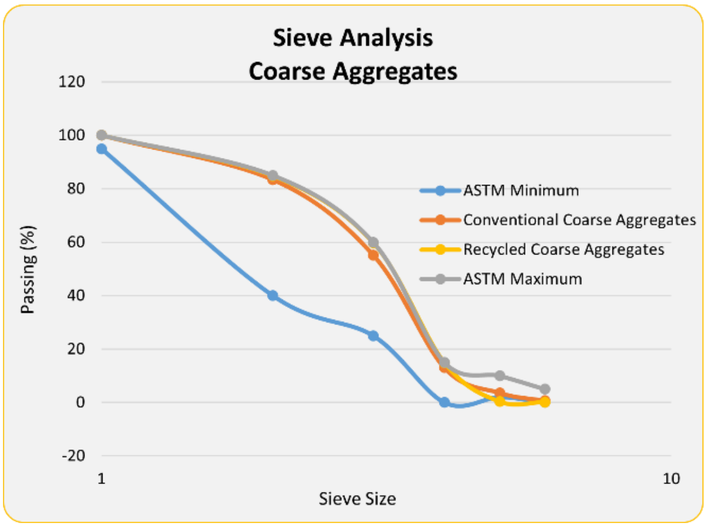

Figure 8: Sieve analysis of coarse aggregates.

The crushing value results presented earlier are averaged and plotted in Figure 9 for comparison. It may be observed that the recycled aggregates remained lower by 31% in resistance to crushing load. The average compressive strength of the specimens was recorded equal to 17.37 MPa. The average compressive strength of conventional concrete is used equal to 22.53 MPa as reported by Oad and Memon.[33] The average compressive recorded for recycled aggregate concrete in this work is compared in Figure 10. It may be observed that the average compressive strength of recycled aggregate concrete is 23% lower than that of the conventional concrete. The percentile deviation of the compressive strength of individual specimens with respect to average compressive strength of conventional concrete is plotted in Figure 11 for further visualization.

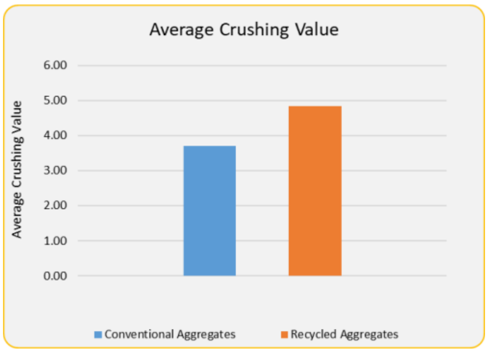

Figure 9: Average crushing values.

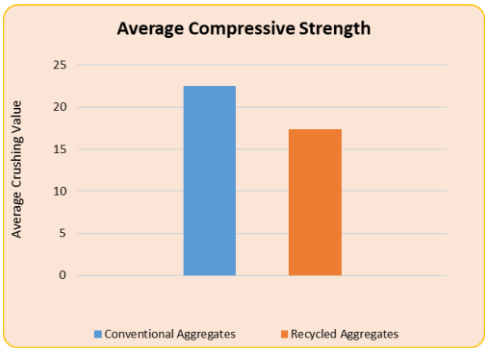

Figure 10: Average compressive strength

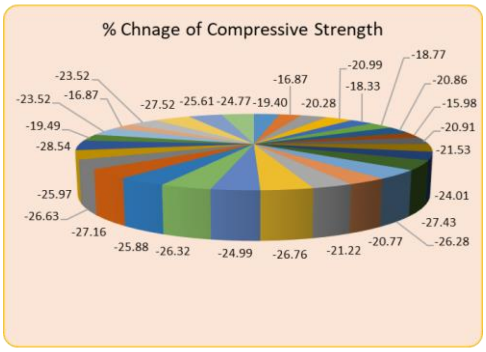

Figure 11: % deviation of CS.

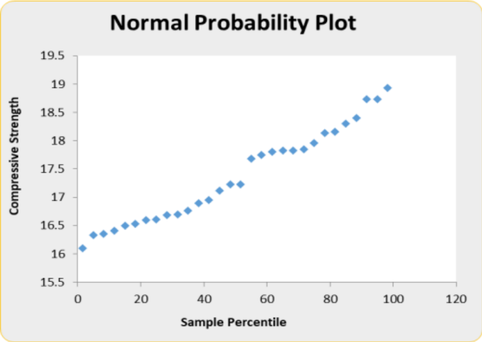

Figure 12: Average compressive strength.

The regression analysis performed for the purpose and obtained numerical equations was presented earlier. The ANOVA statistic of the analysis using crushing value of recycled aggregates is given in Table 3. It may be observed that the p-value of intercept is well below 0.05, whereas the same for crushing value of recycled aggregates is less than 1. The f-significance and R^2 values are recorded equal to 0.9795 and 0. The value presents significance of the analysis and goodness of the fit. The obtained values are in good agreement with standard observations. Figure 12 shows the normal probability plot generated during regression analysis. It shows the smooth participation of all data points in the analysis procedure.

To check the efficiency of the developed equation, crushing value of two samples of recycled aggregates was determined. Also, using the same aggregates two cubes of standard size were prepared, cured and tested. The experimental and predicted values are tabulated in Table 4. It may be observed that the predicted values are maximum of 7.3% less than the experimental observations. This shows the validity of the numerical analysis in prediction of compressive strength from aggregate crushing value. It will not only save the time but the capital involved in testing of the compressive strength of concrete.

Table 3: ANOVA summary using recycled aggregates.

	Coefficients	Standard Error	t Stat	P-value
Intercept	17.42246	2.060804	8.454204	3.41E-09
ACV (RA)	-0.01097	0.424312	-0.02585	0.979561

Table 4: Verification of numerical equation.

Sample	Crushing value	Compressive Strength	Predicted Compressive Strength	
1	4.8	18.65	17.370	6.8
2	4.93	18.74	17.368	7.3

4. CONCLUSION

Numerical modeling provides an alternative to the experimental analysis. In this regard regression analysis between compressive strength of recycled aggregate concrete and crushing value of recycled aggregates from demolished concrete is presented in this research article. In preparation of concrete cubes 100% recycled aggregates were used. Numerical equation developed through regression analysis was check with two sample prepared for the purpose and obtained results were found in good agreement with predicted values with maximum of 7.3% deviation. Hence the numerical equation developed paves the way to estimate the compressive strength from the crushing value of the recycled aggregates.

5. Conflict of interest

The authors declare no conflict of any interest at any stage of this research work.

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