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REGRESSION ANALYSIS OF IMPACT VALUE AND COMPRESSIVE STRENGTH OF RECYCLED AGGREGATE CONCRETE

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ABSTRACT

This research article presents the regression analysis between impact value of recycled aggregates and compressive strength of recycled aggregate concrete. Regression analysis is powerful statistical procedure to model the dependency of a variable on one or more independent variables and provide the alternative of the experimental evaluation of dependent variable. For the purpose thirty samples of each of recycled aggregates from demolished concrete and conventional coarse aggregates were tested for impact value. Also, thirty cubes of recycled aggregate concrete (50% recycled aggregates, 1:2:4 mix with 0.45 water cement ratio) were tested for compressive strength. Both sets of results were used in regression analysis to develop numerical equation. The developed expression was found in good agreement with experimental observation.

KEYWORDS: Demolished waste, Recycled aggregates, Recycled aggregate concrete, Impact value, Compressive strength, Regression analysis.

1. INTRODUCTION

Change always remained vital in every walk of life, so is the case with construction industry. From scattered dwellings at far distances to accumulated dwellings in sky scrappers, construction industry underwent drastic changes in materials, architecture, methods, and technology fronts. Sky scrappers are now common around the globe. The structures are not only the proof of technology and methods but also need to accommodate fast growing population particularly in busy centers of the world where space problem has forced the industry to opt vertical expansion in place of horizontal development. The phenomenon not only consumes the natural sources of materials but also generate huge quantum of the waste as a result of demolishing of old, life completed and short height structures. The waste so generated is increasing at faster pace posing a serious problem of waste management as dumping spaces are becomes scarce with time. A potential way of dealing the waste is to make its use in new concrete. A part of it is used in floor and plinth fills, also several components of the waste has been used in concrete. As the coarse aggregates occupies maximum of concrete volume therefore the use of the demolishing concrete waste as coarse aggregates will help in minimizing the waste management to much extent. The idea started after second world war which left millions of buildings destroyed – waste to the extent of serious problem in rebuilding of the areas. Since than good time and effort has been dedicated by research community around the globe to study the waste from processing, its properties to fresh and hardened properties of concrete using it. However, several issues associated with old concrete show scatter in properties of aggregates and thus the properties of concrete using it.

Strength of concrete is the key parameter which ensures durability and serviceability of it during service life and must be ensure. Among several factors which affect the strength of concrete, properties of ingredients, batch, placing, and curing are a few. Therefore, to ensure design strength of concrete care must be exercised at all levels. Also, the properties of ingredients should be evaluated and ensured. Basic properties of ingredients particularly coarse aggregates affect the final strength of the product. Water absorption, specific gravity, moisture content, porosity, impact value, crushing value, abrasion resistance are few examples. The effect of the properties on strength of conventional concrete is well understood with time. But when it comes to the recycled aggregate concrete using recycled aggregates from demolished waste although good number of publications are available addressing the issue but scatter in the results is also evident. Specially the impact of the impact resistance of recycled aggregates on compressive strength of recycled aggregate concrete.

Test procedures for compressive strength are not only time consuming but also require dedicated equipment. Also, samples prepared from running batch at site, will give results after some time (due to curing time). In case of any error, remedial measure also becomes difficult. An alternative to it is the mathematical modelling of the same based on simple test results like impact value of the aggregates. To this end several mathematical methods are available to rescue. Trend line analysis, regression analysis, artificial neural network, fuzzy logic are few examples.

Regression analysis is simple and efficient statistical tool to model effect of variation in independent variables i.e., impact value of recycled aggregates, on dependent variable (compressive strength). Therefore, this research work aims at developing relationship between impact value of recycled aggregates and compressive strength of recycled aggregate concrete using regression analysis. Both parameters will be investigated experimentally to use in the mathematical model. The outcome will provide a way to calculate compressive strength of recycled aggregate concrete using impact value of the recycled aggregates. Thus, before using the aggregates in concrete the approximate estimate of the compressive strength of concrete using the aggregates will be available. The approach will not only help in utilizing the demolishing waste in concrete thus minizine the waste management but also will provide numerical way of estimating the compressive strength of the concrete.

2. Literature review

The review of the available literature relevant to topic of research provide insight of past work in the field, highlight the problems associated, and extracts the gaps for future work. In the following, literature relevant to proposed topic is reviewed.

The use of recycled aggregates from demolished concrete as coarse aggregates in new concrete is not new. From the point of view of conservation of natural deposits of aggregates, environmental issues, human health, indigenous material and waste management issues, the waste is processed as additive to concrete particularly as coarse aggregates since long. Literature reports good number of publications on the topic. Additionally, several scholars have also reviewed the past works of other researchers. In this regard Patel and Singh[1] and Memon et. al.[2] reviewed the physical properties of the aggregates researched by other researchers and provided a summary of the same. The authors also highlighted the scatter of the results and the hurdles associated with the use of the aggregates. Memon[3] also reviewed the recent developments on the use of the demolished waste as coarse aggregates in 2016.

The author reviewed from processing of the aggregates to its effect on hardened properties of concrete. Based on the study it was suggested that the proper implementation of concerned rules and regulations and incentives to the concerned quarters will improve the use of the material with certain level of confidence. In absence of which, a reluctance in adoption of the material is observed with relevant personals.

Rehman et. al.[4] in their research study evaluated mechanical properties of coarse aggregates from demolished waste including impact value. The authors used 10-14 mm aggregates. The recorded impact value of both conventional and recycled aggregates was same, showing that impact resistance of the recycled aggregates is similar to that of conventional aggregates. The study also evaluated the size effect of the aggregates on compressive strength of 7-, 14-, and 28-day cured samples. Ahmada et. al.[5] studied the relationship of strength and durability indices of recycled aggregates from demolished waste. The outcome of the study for different samples of coarse aggregates showed impact value in the range of 9.5% – 39.5%. Based on the experimental observations, authors developed numerical expression for estimating crushing value from impact value of the aggregates. The recycled aggregates prepared from demolished waste from Ogun state were used by Omopariola and Jimoh[6] to study the physical properties. From the experimental finding authors concluded that although the grading requirement is not met by the recycled aggregates yet their physical and mechanical properties are in good agreement with those set by different codes. Therefore, the authors suggest careful processing of the waste into aggregates so that they even meet the grading requirements. Joshi and Gupta[7] in their research work evaluated basic properties of recycled aggregates and developed relationship for crushing and impact values based on water absorption and specific gravity separately. The developed equations were verified with experimental observations for dependent variables and found good agreement between two sets of the results. Mbaezue et. al.[8] used different rocks from Abuja Nigeria to check their impact value and its influence on hardened properties of concrete. The experimental observations revealed impact value in the range of 22% – 32% with good hardened properties of concrete for coarse aggregates having better impact resistance.

Das et. al.[9] in their research program developed numerical equations for impact value and crushing value based on light compaction test. Twenty samples of the aggregates were tested experimentally for light impact factor, impact value and crushing value. The results were used to developed the numerical equations. The verification of the predicted values from numerical equations proved that the light compaction factor test along with numerical equations can be the suitable alternative of the impact and crushing value tests. Al-Waked et. al.[10] in their research work attempted to improve the impact value of the coarse aggregates by surface treatment. For the purpose authors used accelerated carbonation, cyclic lime water and soaking in cement and silica fume slurry. Based on the results authors found cement and silica fume slurry surface treatment of the aggregate good among other for improvement of the impact resistance of the aggregates. Merin et. al.[11] also used surface treatment technique along with triple mixing method to attempt improvement in the impact value of the aggregates. The authors used pozzolan slurry (fly ash, alcofine and cement) to treat the aggregate and found the method efficient and feasible for the purpose. Fernando et. al.[12] in a separate work also used surface treatment of the aggregates to improve the impact resistance of recycled aggregates. The authors used fly ash, silica fume and rice husk ash. The surface treated aggregates showed better performance against impact.

Mathematical modeling of concrete parameters particularly strength has been done by several scholars using multilinear regression model,[13][14][15][16][17] polynomial regression with stepwise method,[18] hard clustering and fuzzy clustering techniques,[19] regression model with artificial neural network.[20] But when it comes to recycled aggregate concrete particularly effect of impact resistance on compressive strength the literature is almost silent, therefore the aim of this research work is to perform regression analysis of compressive strength of recycled aggregate concrete based on the impact value of conventional and recycled aggregates.

3. MATERIALS AND METHODS

This section describes the materials used for proposed research work, tests conducted and results obtained. Further discussion and analysis of results will be done in next section.

3.1 Ingredients of concrete

Ordinary Portland cement (Pak Land), hill sand, and crush were used as the ingredient of conventional concrete. The basic properties of all three ingredients were evaluated and are listed in Table 1, Table 2 and Table 3. Water used for mixing, curing, etc. was collected from city water supply line with pH value equal to 6.7. It may be observed that the results confirm the standard requirement of the materials. The pictorial view of the materials is shown in Figure 1.

Table 1: Properties of cement.

Property	Value	Unit
Specific Gravity	3.15	
Fineness	97	%
Consistency	32	%
Setting Time (I)	71	min
Setting Time (F)	325	min
LOI	1.14	%

Table 2: Properties of fine aggregates.

Property	Value
Fineness Modulus	3.09
Specific Gravity	2.68
Water Absorption (%)	0.93

Table 3: Properties of coarse aggregates.

Property	NCA	RCA
Water absorption (%)	1.42	2.31
Specific gravity	2.64	2.24

The fine aggregates were sieved in accordance with ASTM C33/C33M [21] to ensure its grading in accordance with the code. The obtained results are given in Table 4. It may be observed that the percentage passing of the material on various sieves in within the allowable limits of the code.

Table 4: Sieve analysis of fine aggregates.

Sieve Size	Retained (g)	Retained (%)	Cumulative Retained (g)	Cumulative Retained (%)	Passing (%)	ASTM Range
#4	0	0	0	0	100.00	95 - 100
#8	172	17.2	17.2	17.2	82.80	80 - 100
#16	261	26.1	43.3	43.3	56.70	50 - 85
#30	215	21.5	64.8	64.8	35.20	25 - 60
#50	221	22.1	86.9	86.9	13.10	5 - 30
#100	97	9.7	96.6	96.6	3.40	0 - 10
#200	26	2.6	99.2	99.2	0.80	0 - 3
Pan	8	--	--	--	--	--

Figure 1: Concrete ingredients. Figure 2: Demolished Waste and Recycled aggregates.

Similar to fine aggregates, coarse aggregates were also sieved as per the specifications defined in ASTM C33/C33M.[21] The percentage passing of the material on various sieves is listed in Table 5.

Table 5: Sieve analysis of coarse aggregates.

Sieve	NCA	RCA	ASTM Range
1”	100.00	100.00	95 – 100
3/4”	63.60	64.80	40 – 85
1/2”	29.20	26.76	25 – 60
3/8”	7.04	9.32	0 – 15
#4	2.12	3.44	2 – 10
#8	0.76	1.36	0 – 5

3.2 Demolished Waste and Recycled aggregates

Demolished waste for this research work was collected from demolishing of a reinforced concrete slab of private unit dwelling located in Nawabshah city. The material was hammered to maximum of 25 mm size in the laboratory. Obtained material with respect to size was sieved through 25 mm sieve followed by sorting for unwanted substances. The water absorption and specific gravity of the aggregates were evaluated and are listed in Table 3. In line with conventional coarse aggregates, it was also sieved and the percentage passing of the material on various sieves is listed in Table 5. It may be observed that both conventional and recycled aggregates meet the allowable range requirement of the code. Both conventional and recycled aggregates were washed and dried before using for impact value test and preparation of concrete cubes.

3.3 Impact value test

Thirty samples of each conventional and recycled aggregates were used to evaluate the aggregate impact value following the recommendations of BS 812-Part 112.[22] Obtained results are given in Table 6. The apparatus used for the impact testing is shown in Figure 3.

Figure 3: Impact value test.

Figure 4: Cube testing.

3.4 Compressive strength

For determination of compressive strength, thirty cubes of 6"x6"x6" size were prepared using 1:2:4 mix with 0.45 water-cement ratio. The mix was selected as it is commonly used in the field. Conventional and recycled aggregates were used in equal proportion following the recommendations of Oad and Memon.[23] The ingredients in required quantities were mixed in concrete mixer till formation of uniform paste. In mean time the inner surface of the cube molds was oiled for easy demolding. The molds were filled in standard fashion with compaction by table vibrator. On the second day of pouring concrete in molds, the specimens were taken out of the molds and allowed to air dry for 24-hours. Then the specimens were fully immersing in potable water for curing for 28-days.

After the completion of curing time, the cubes were allowed to air dry followed by testing in turn in universal testing machine under gradually increasing load (0.5 kN/sec). The crushing load was recorded and converted to compressive strength by dividing it with the cross-sectional area of the cube. A specimen during testing is shown in Figure 4. The compressive strength results are listed in Table 7.

Table 6: Aggregate impact value.

Sample	Recycled aggregates	Sample	Recycled aggregates
1	13.9	16	14.5
2	14.2	17	14.6

3	14.3	18	15.1
4	14.5	19	13.8
5	14.5	20	13.8
6	13.8	21	13.9
7	14.1	22	14.2
8	13.6	23	14.3
9	14.3	24	14.6
10	14.4	25	14.7
11	14.6	26	13.9
12	13.8	27	13.9
13	13.9	28	13.7
14	13.7	29	13.8
15	14.1	30	14.4

Table 7: Compressive strength.

Sample #	Compressive strength (MPa)	Sample #	Compressive strength (MPa)
1	18.55	16	18.87
2	18.63	17	17.14
3	17.73	18	17.65
4	16.28	19	17.36
5	17.95	20	18.88
6	17.32	21	18.63
7	18.69	22	17.65
8	18.16	23	18.10
9	18.98	24	18.75
10	18.34	25	18.64
11	17.74	26	18.96
12	17.81	27	16.58
13	17.93	28	18.44
14	17.41	29	18.56
15	17.86	30	18.91

3.5 Regression analysis

Regression analysis is a mathematical procedure for establishing relationship between dependent variable (in this case compressive strength) and one or more independent variables (in this case impact value of recycled aggregates). It is a powerful tool offering linear, multilinear, polynomial, etc., techniques for the purpose along and in combination with other mathematical method i.e., artificial neural network, fuzzy logic etc. The experimental results are used as data for the regression analysis. The task is performed using Microsoft EXCEL,[24] a member of Microsoft Office having inbuilt regression analysis options. The numerical expression produced by the analysis is given in equation below

$$CS = 18.9075 - 0.0582AIV_{RCA}$$

In the above expression CS is compressive strength, and AIV_{RCA} is the impact values of recycled aggregates.

4. RESULTS AND DISCUSSION

The basic properties of recycled aggregates produced from demolishing waste are observed deviated from the same of the conventional aggregates. Higher water absorption and lower specific gravity is mainly due to the old mortar attached with the old concrete aggregates, age of the structure, and exposure conditions of the structure during the service life. This deviation makes the aggregates inferior than the conventional aggregates, however it is evident that the material has good potential to be used in new concrete with careful considerations i.e., adjustment of water cement ratio to avoid shortage of mixing water in concrete due to higher absorption demand of the aggregates. Use of optimized dosage of the aggregates minimizes the effect of loss of specific gravity of the recycled aggregates.

The impact value of the aggregates presented earlier is compared with the aggregate impact value of conventional aggregates reported in reference.[25] The comparison is plotted in Figure 5 for visualization and comparison. Similarly, Figure 6 shows the comparison of the compressive strength of recycled aggregate concrete with the same reported in[23] for conventional concrete. The average of the impact value was recorded equal to 14.16. the value is 11.7% less than the impact value of conventional aggregates reported in.[25] Analogous to it average compressive strength of thirty samples used in this work was recorded equal to 18.08 MPa. It was further observed that the average compressive strength was about 20% less compared to the compressive strength of conventional concrete reported in.[23] The loss of strength is due to the total replacement of conventional aggregates yet the residual strength is 80% which may carefully be used even in structural members. The regression analysis equation produced was presented earlier. It was further observed that significant f value was equal to 0.87. The p value of intercept was less than 0.05 however the same for the independent variable remained higher than 0.05. During the process of regression analysis developed plots for residual, line fit and normal probability are shown in Figures 7 to 9. It may be observed that the residual with respect to mean or datum have observed scatter. The same is also evident from the line fit plot. This requires more in-depth analysis with more samples and varying percentage of the recycled aggregates in compressive strength evaluation. However ever the normal probability plot shows the smooth trend thus the validity of the regression analysis. The equation developed by regression analysis was checked back and found that it predicts the compressive strength values with -4.77% to 10.97% error. Although, the deviation is there in the predicted results yet it gives good idea of compressive strength based on aggregate impact value with out compressive strength test. To validate the equation further, impact value of a sample of recycled aggregates was determined equal to 14.4. The same was used to prepare, cure and test the cube specimen for compressive strength. The recorded value of the compressive strength was equal to 18.72 MPa. The impact value was used to predict the compressive strength developed by regression analysis. The predicted value was 18.07 MPa with error equal to 3.5% than the experimental results.

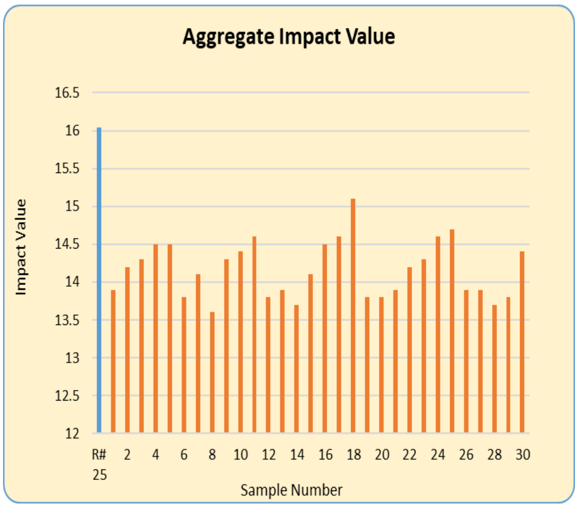

Figure 5: Impact value.

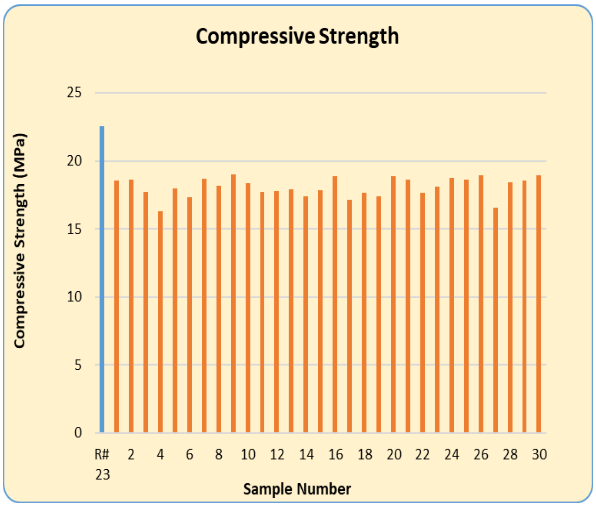

Figure 6: Compressive strength.

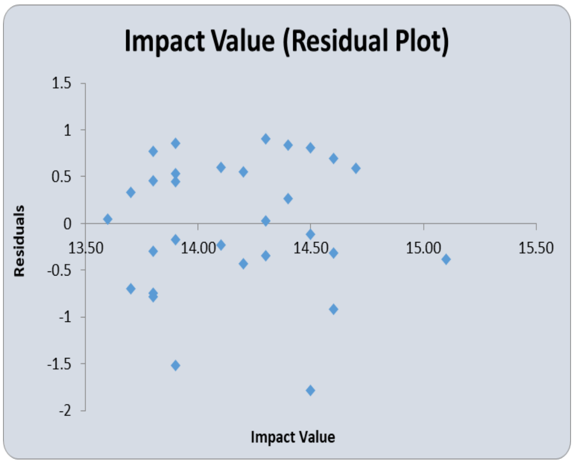

Figure 7: Residual plot.

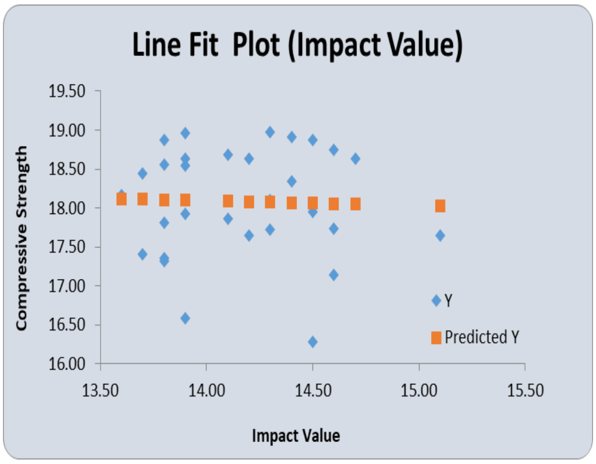

Figure 8: Line fit plot.

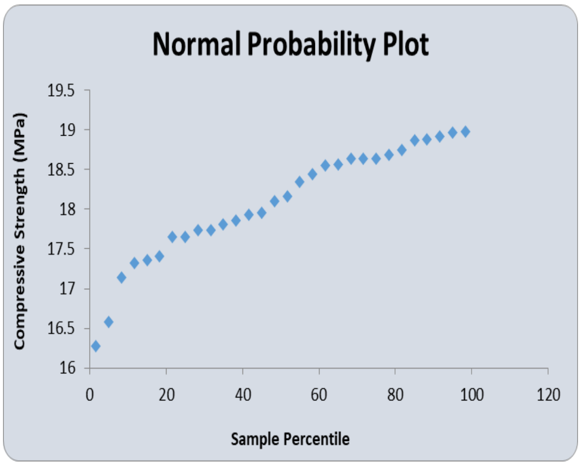

Figure 9: Normal probability plot.

5. CONCLUSION

Regression analysis provides alternative approach of testing procedures. It estimates dependent variables from one or more independent variables. This research article presented the regression analysis for compressive strength of recycled aggregate concrete using 100% recycled aggregates from the aggregate impact value of the recycled aggregates. For the purpose inbuilt features of Microsoft EXCEL are used. The equation was checked with the laboratory data and found -4.77% to10.97% error. The same was also verified with a separate sample prepared in the lab. The predicted value of compressive strength deviated 3.5% from the experimentally evaluated compressive strength. This shows the validity of the developed equation. Hence it is concluded that the mathematical modeling by regression analysis provides reasonably good estimate of the compressive strength from aggregate impact value with testing the samples for compressive strength.

6. No Conflict

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

7. REFERENCES

1. Patel D K, and Singh V K, “A Review on Physical Properties of Recycled Concrete Aggregate”. International Journal of Advance Research in Science and Engineering, Special Issue No, 2018; 7: 1.
2. Memon B A, Oad M, Buller A H, and Bhutto A H, “Basic Properties of Recycled Coarse Aggregates from Demolishing Waste: A Review”. World Journal of Engineering Research and Technology, 2022; 8: 3.

3. Memon B A, "Recent Development on Use of Demolished Concrete as Coarse Aggregates". International Journal of Emerging Technology and Innovative Engineering, 2016; 2: 1.
4. Rahman I A, Hamdam H, and Zaidi A M A, "Assessment of Recycled Aggregate Concrete". Modern Applied Sciences, 2009; 3: 10.
5. Ahmada M, Ansaria M K, Sharmaa L K, Singh R, Singh T N, "Correlation between Strength and Durability Indices of Rocks- Soft Computing Approach". Procedia Engineering, 2017; 191.
6. Omopariola S S and Jimoh A A, "A Comparative Study of the Physical and Mechanical Properties of Coarse Aggregates Produced in Ogun State", Nigerian Journal of Technology (NIJOTECH), 2018; 37: 1.
7. Joshi P and Gupta R K, "Interrelation of Physical and Mechanical Properties of Basalt". SRG International Journal of Civil Engineering, 2019; 6: 10.
8. Mbaezue N D, Ndububa E E, Kolawole O S, and Aminu A E, "Comparative Study of the Quality of Various Road Aggregate Types in Abuja, Nigeria". Global Scientific Journals, 2020; 8: 6.
9. Das J K, Deb S, and Bharali B, "Prediction of Aggregate Impact Values and Aggregate Crushing Values using Light Compaction Test", Journal of Applied Engineering Sciences, 2021; 11, 24(2).
10. Al-Waked Q, Bai J P, Kinuthia J, Davies P, "Enhancing the Aggregate Impact Value and Water Absorption of Demolition Waste Coarse Aggregates with Various Treatment Methods". Case Studies in Construction Materials, 2022; 17.
11. Merin M, Girija K, and Sreedevi A R, "Strengthening of Recycled Coarse Aggregate using Different Surface Treatment Techniques". Proceedings of 12th Structural Engineering Convention – An International Event (SEC 2022) - ASPS Conference Proceedings, 2022; 1.
12. Fernando A, Selvaranjan K, Srikanth G and Gamage J C P H, "Development of High Strength Recycled Aggregate Concrete Composite Effects of Fly Ash, Silica Fume and Rice Husk Ash as Pozzolans". Materials and Structures, 55: 185.
13. Maina K, Gwaya, A O, and Koteng D O, "Concrete Strength Prediction using Multi-Linear Regression Model: A Case Study of Nairobi Metropolitan". International Journal of Soft Computing and Engineering, 2019; 8: 5.
14. Khademi F, Jamal S M, Deshpande N, and Londhe S, "Predicting Strength of Recycled Aggregate Concrete Using Artificial Neural Network, Adaptive Neuro-Fuzzy Inference

System and Multiple Linear Regression", International Journal of Sustainable Built Environment, 2016; 5.

15. Unamba U K, Nwajagu E S, Abutu J and Agbo-Anike O J, "Predictive Model of the Compressive Strength of Concrete Containing Coconut Shell Ash as Partial Replacement of Cement Using Multiple Regression Analysis". International Journal of Innovative Science and Research Technology, 2021; 6: 8.
16. Assegie T A, Salau A O, and Badrudeen T U, "Estimation of Concrete Compression using Regression Models". Bulletin of Electrical Engineering and Informatics, 2022; 11: 5.
17. Wilson J, Jones E, Dickson M, "Prediction of Concrete Compressive Strength using Mathematical Regression Model", Concrete NZ Conference – Concrete for Life, 2019.
18. Imran H, Al-Abdaly N M, Shamsa M H, Shatnawi A, Ibrahim M, and Ostrowski K A, "Development of Prediction Model to Predict the Compressive Strength of Eco-Friendly Concrete Using Multivariate Polynomial Regression Combined with Stepwise Method", Materials, 2022; 15: 373.
19. Nagwani N K and Deo S V, "Estimating the Concrete Compressive Strength Using Hard Clustering and Fuzzy Clustering Based Regression Techniques". Hindawi Publishing Corporation - Scientific World Journal, 2014 (Article ID 381549).
20. Charhate S, Subhedar M, and Adsul N, "Prediction of Concrete Properties using Multiple Linear Regression and Artificial Neural Network", Journal of Soft Computing in Civil Engineering, 2018; 2: 3.
21. ASTM C33/C33M, "Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates", American Society for Testing and Materials (ASTM), Philadelphia, PA. USA.
22. BS 812- Part 112, "Testing Aggregates – Methods for Determination of Aggregate Impact Value (AIV)". British Standards Institution, London.
23. Oad M and Memon B A (2014), "Compressive Strength of Concrete Cylinders using Coarse Aggregates from Old Concrete". 1st National Conference on Civil Engineering (NCCE 2013-14) - (Modern Trends and Advancements), 2014; 28–29.
24. MS EXCEL, "Microsoft Excel", Microsoft Corporation, USA.
25. Surya M, Kanta-Rao V V L, Lakshamy P, "Recycled Aggregate Concrete for Transportation Infrastructure", Procedia Social and Behavioral Sciences, 2013; 104.