A Multiple Regression Approach for Compressive Strength Modelling of Recovered Coarse Aggregate (RCA) Impregnated Concrete Matrix

Dr.G.K.Arunvivek[1], Dr.D.Rameshkumar[2] Dr.D.Ambika[3]

1. Assistant Professor Department of Civil Engineering, Karpagam College of Engineering, Coimbatore, India. E-mail: arun.vivekgk@gmail.com.
2. Associate Professor, Department of Civil Engineering, Mangalam College of Engineering, Ettumanor,Kottayam, Kerala. India. rameshcivil2002@gmail.com
3. Assistant Professor Department of Civil Engineering, Kongu Engineering College Perundurai, Erode, India. ambikaceg@gmail.com

Abstract

The application of Multi-Linear Regression Analysis (MLRA) for strength prediction of concrete offers a technical guide for the designers. Strength characteristics of concrete are influenced by several parameters. In this study, an attempt has been made to predict the 28 days compressive strength of recovered coarse aggregate (RCA) incorporated concrete. An empirical model capable of predicting the compressive strength of recovered coarse aggregate (RCA) incorporated concrete is proposed. The empirical model consists of a rational polynomial equation having six independent variables. Mix proportioning elements were considered as the variables in the model. The developed empirical model is validated for conventional concrete and also for recovered coarse aggregate incorporated concrete. 28 trials were conducted with different mix proportions and the data obtained from the experimentation was utilized to develop the model. The developed model exhibits a reliable prediction of compressive concrete strength at 28 days with excellent efficiency. The predicted strength was in complete agreement with experimentally obtained values.

Keywords: Concrete matrix, Multiple regression, Recovered Coarse aggregate (RCA), Strength modelling.

1. Introduction

Multi-Linear Regression Analysis (MLRA) is an effective method that predicts the relationship between independent and dependent variables using statistical approaches. In all civil engineering applications, concrete rules the roost ever since it was evolved as the most dependable and strong building material compound. However from the point of view of mathematical modelling with statistical regression and correlation corroborations related to the attainment of strength by concrete matrix has the determinacies namely optimal proportions of cement, fine aggregate, coarse aggregate and water mantles [1-5]. Since, the natural building materials are mostly derived from geological formation like the rocks and soils along with potable quality of water will become non-renewable. Hence the order of the day is to sustain the strength of concrete by partial substitution or total replacement of individual mantles of the concrete matrix [6-9]. However any substitution will be construed as an introduction of a foreign body into the traditional system of concrete that is supposed to gain more than 90% of its strength over a nominal curing spell of 28 days. The material substitution will naturally destabilize the equilibrium and synergy between the conventional concrete ingredients and newly substituted alternate and equivalent mantle materials [10-13]. This situation warrants a strength endorsement analysis in concrete improvised with possible substitution materials at optimal proportional combinations. Any improvisation tried on concrete should be reliably analysed for strength predictions as a combine response of the wholesome concrete matrix with respect to the fragmented impulses at different proportions of concrete mantles [13-17].

2. Formulation of Mathematical model

By and large a multiple regression analysis taking the compressive strength of an improvised concrete as the dependent variable and influencing parameters such as optimal combinational proportion of substituted material, water absorption of aggregate, density of concrete, weight of cement, weight of aggregates and weight of water as independent variables. At a dependable correlation level, the regression equation depicts the impulse-response behaviour of concrete at different variable levels of ingredient substitution. The present investigation focuses on the response of the improvised concrete in terms of its predictable compressive strength in relation to the optimal combinations of Recovered Coarse Aggregate (RCA) from unutilized fresh concrete residue only, retaining the other ingredients of concrete undisturbed.

Multi- linear regressions determine the relationship between independent variables and a dependent variable by fitting a linear equation to the observed data. Every value of the independent variable is associated with a value of the dependent variable as represented in equation (1)

$$Y = a_o + a_1(\boldsymbol{\rho}) + a_2(A_{RC}) + a_3(W) + a_4(C) + a_5(W_{ab}) + a_6(A_n \quad \text{--(1)}$$

If the multiple dependencies are curvilinear (non-linear) the logarithmic transformation can be applied to this type of regression as represented in equation (2).

$$\log(Y) = \log(a_o) + a_1\log(\boldsymbol{\rho}) + a_2\log(A_{RC}) + a_3\log(W) + a_4\log(C) + a_5\log(W_{ab}) + a_6 \log(A_n) \quad \text{--(2)}$$

Where,

Y= 28 days compressive strength in MPa

$\boldsymbol{\rho}$ = Density of concrete (Kg/m^3)

C = Weight of cement (Kg/m^3)

A_{RC} = Weight of Recovered coarse aggregate (Kg/m^3)

A_n = Weight of normal aggregate (Kg/m^3)

W = Weight of water (Kg/m^3)

W_{ab}= Water absorption % of recovered coarse aggregate

a_0= Proportionality constant influencing strength prediction

This equation when transformed back to a form that predicts the dependent variable (Y) by taking the anti- logarithm yields equation (2) as stated below

$$Y = a_0.\boldsymbol{\rho}^{a_1}.(A_{RC})^{a_2}.W^{a_3}.C^{a_4}.(W_{ab})^{a_5}.(A_n)^{a_6} \quad \text{--(3)}$$

The regression analysis was performed based on the data set of Table 2 and values of regression coefficients a_0 to a_6 obtained are as shown in Table 1.

Table 1 Regression co-efficients of the model

Description of parameters	Coefficients	Values
Proportionality Constant	a_0	6.137
Density (ρ)	a_1	0.4010
Recovered coarse aggregates (A_{RC})	a_2	0.1522
Water (W)	a_3	0.1491
Cement (C)	a_4	0.4591
Water absorption % (W_{abs})	a_5	-0.1851
Normal aggregate (A_n)	a_6	-0.8335

Based on extensive experimentation the exponents of this multiple regression equation were found partly positive and negative depending on their interactive reactions with the individual mantles of the integrated concrete matrix. Accordingly the predictable strength was found to be inversely proportional to the original coarse and fine aggregate proportions. Based on the multiple regression analysis supported by a correlation level of R^2 = 0.904 (90.4% of the data confirming to the experimental dependability range) the regression model obtained is furnished as

$$Y = 6.137 \frac{\rho^{0.4010} {A_{RC}}^{0.1522} W^{0.1491} C^{0.45912}}{{W_{abs}}^{0.18512'} {A_n}^{0.8335'}} \qquad \text{--(4)}$$

Wherein, the value of K = 6.137 represents the factor of proportionality related to the case of partial substitution only with recovered coarse aggregates. For other optimal proportions with differential concrete ingredients with alternate materials the value of K will be changing and the impulse-response of the concrete strength will depend up on the changes in the exponents of the independent variables considered (It may be noted that the sum of the exponent values of all dependent variables in the numerator and the denominator will nearly approach 1).

3. Validation of mathematical model

The higher 28 days compressive strength of improvised concrete was found to be 37.72 MPa for the optimal proportions of cement (C) = 422 Kg/m^3, Water (W) = 189.33 Kg/m^3, other aggregates = 945.57 Kg/m^3, recovered coarse aggregate (RCA) = 589.6 Kg/m^3, with concrete density (ρ) of = 2647.17 Kg/m^3. Through the developed empirical equation the predicted strength for the above combination was found to be 37.1 MPa. Thus the percentage error observed in obtaining compressive strength was reckoned as 1.62%. Similarly, 27 different proportional combinations of substitute materials were tried and concrete samples were cast and the 28 days compressive strength of cast concrete samples was test verified.

Table 2 proportion of concrete ingredient and water absorption values of RCA

Sl.No	ρ	W_{abs}	RCA	Other aggregates	W	C	Actual compressive strength	Predicted compressive strength	% error
1	2539.17	3.38	589.6	945.57	199	442	35.41	35.77	-1.013
2	2528.41	3.42	589.6	945.57	199	442	35.45	35.634	-0.516
3	2591.94	2.61	589.6	945.57	189.13	422	33.96	36.76	-7.620
4	2541.79	4.19	579.82	939.55	204.92	418	34.35	33.76	1.740
5	2647.17	2.6	589.6	945.57	189.13	422	37.72	37.10	1.672
6	2519.45	2.7	583.67	942.11	199	422	38.11	36.45	4.559
7	2581.88	2.62	583.67	942.11	199	422	38.23	37.01	3.288

8	2535.21	5.51	569.35	932.24	221.72	418	30.3	32.56	-6.943
9	2539.43	5.58	569.35	932.24	221.72	418	31.25	32.51	-3.865
10	2641.86	5.54	569.35	932.24	221.72	418	33.52	33.07	1.361
11	2659.72	3.1	581.35	940.14	202.11	422	37.47	36.43	2.844
12	2519.98	7.59	432.85	949.44	236.28	373	26.7	27.71	-3.630
13	2504.18	7.62	432.85	949.44	236.28	373	28.13	27.62	1.862
14	2559.58	7.58	510.49	943.75	181.5	380.23	27.77	27.88	-0.378
15	2467.11	7.6	510.49	943.75	181.5	380.23	26.46	27.45	-3.619
16	2530.08	7.59	589.6	936.25	189.13	418	30.12	30.00	0.415
25	2540.19	4.22	579.82	939.55	204.92	418	33.45	33.71	-0.769
26	2530.11	4.14	580.23	939.97	203.93	418	32.23	33.74	-4.480
27	2554.93	4.09	580.23	939.97	203.93	418	32	33.95	-5.745
28	2639.88	2.61	589.6	945.57	189.13	422	34.23	37.03	-7.567

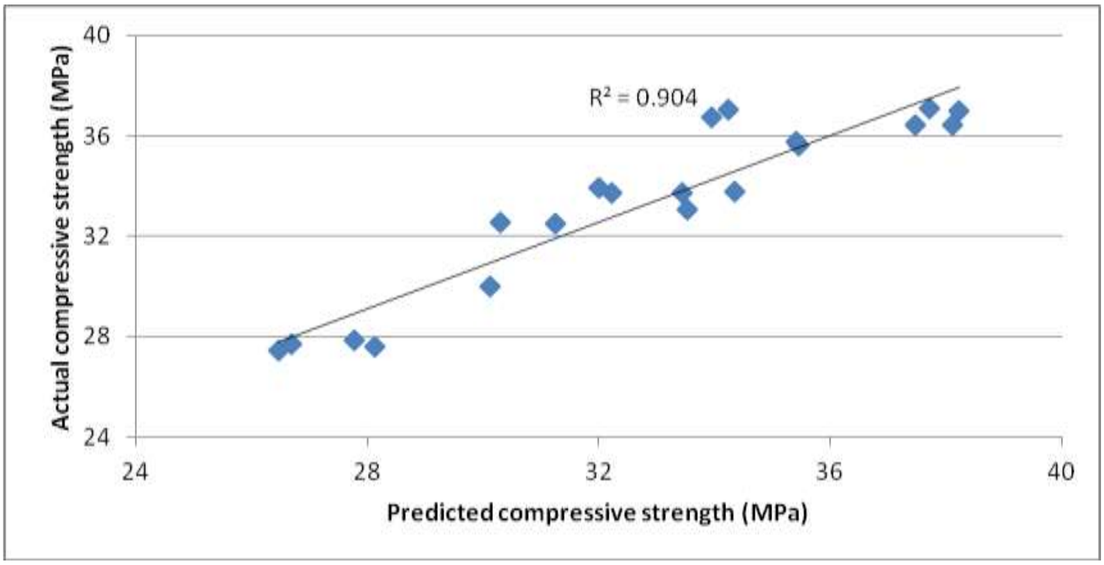

Figure 1 Predicted Vs Observed compressive strength values at 28 days

The actual strength attained from the experimentation was compared with the predicted values obtained from the empirical equation. The percentage error is also in the permissible limit of less than 10% with correlation dependence of 90.4% of the data scatter.

4. Conclusion

Based on the strength prediction analysis performed using the developed multiple regression model it could be concluded that:

- The percentage error calculated between the obtained values and the predicted values through the mathematical model was found in the range between 0.378 to 7.62% (plus or minus from the actual values).
- Since the impulse-response model is backed by a highly correlated multiple regression function, the interpolations as well as extrapolations of the predictable strength values will be highly dependable with an error percentage less than 10% which shows the reliability of the model.
- The proposed model could be used to estimate the compressive strength of concrete containing recovered coarse aggregate because of its high dependability.

5. References

1. Kheder, G.F. (2003). Al-Gabban A.M. & Suhad M.A.Mathematical model for the prediction of cement compressive strength at the ages of 7&28 days within 24 hour materials and structures.36, 693-701.
2. Jee Namyong, Yoon Sangchun, Cho Hongbum, (2004). Prediction of Compressive Strength of In-Situ Concrete Based on Mixture Proportion, Journal of Asian Architecture and Building Engineering, 16, 141-147.
3. Chou, C. Tsai, C.F. (2012). Concrete compressive strength analysis using a combined classification and regression technique, Automation in Construction, 24, 52-60.
4. Hwang, K. Noguchi, T. Tomosawa, F. (2004). Prediction model of compressive strength development of fly-ash concrete. Cement Concrete Res., 34, 2269-2276.
5. Bhanja, S. Sengupta, B. (2002.) Investigations on the compressive strength of silica fume concrete using statistical methods. Cement and Concrete Research, 32, 1391–1394.
6. Zelic, J. Rusic, D. Krstulovic, R. (2004). A mathematical model for prediction of compressive strength in cement–silica fume blends. Cement and Concrete Research, 34,2319–2328.
7. Nwaogazie, I.L. (2006). Probability and Statistics for Science and Engineering Practice, University of Port Harcourt Press, Port Harcourt, 274 – 280.
8. Osadebe, N.N. (2003). Generalised Mathematical Modelling of Compressive Strength of Normal Concrete as a Multivariant function of the properties of its constituent components, Lecture, University of Nigeria, Nsukka, 1 – 11.
9. Clifton, J.R. (1993).Predicting the Service Life of Concrete, ACI Materials Journal, 90, 611-617.
10. Liang, M.T. Hong, C.L. Liang, C.H. (1999).Service Life Prediction of Existing Reinforced Concrete Structures, Journal of the Chinese Institute of Civil and Hydraulic Engineering, 11, 3, 485-489.

11. Loo, Chin, Y.H. Tam, M.S. Ong, C.T. (1994). A Carbonation Prediction Model for Accelerated carbonation Testing of Concrete, Magazine of Concrete Research, 46, 191-200.
12. Zain, M.F.M. and Abd, S.M. 2009.Multiple regression model for compressive strength prediction of high performance concrete. J. of Applied Sciences, 9(1), 155-160.
13. Okafor, F.O. and Sule, S. 2008. Models for prediction of structural properties of palmnut fibre-reinforced cement mortar composites Nig. Journal of Technology, 27, 13-20.
14. Namyong, J., Sangchun, Y. and Hong Bum, C., 2004. Prediction of compressive strength of concrete based on mixture proportions. Asian Architect Build. Engineering. 3, 9-16.
15. Bayrak, H., and Akgül, F., 2013. Effect of coefficients of regression model on performance prediction curves.International journal of engineering and applied sciences, 5, 32-39.
16. Hwang, K., Noguchi, T. and Tomosawa, F., 2004.Prediction model of compressive strength development of high volume fly-ash concrete. Cement Concrete Research, 34, 2269-2276.
17. Kheder, G.F., Al-Gabban, A.M. and Suhad, M.A., 2003. Mathematical model for the prediction of cement compressive strength at the ages of 7 and 28 days within 24 hours. Materials and Structure. 36,693-701,