Research Article *G. Murali et al, Carib.j.SciTech, 2014,Vol.2, 257-262*

Prediction of Compressive Strength of Fiber Reinforced Concrete Containing Silica Fume Using MLR Model

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Keywords:

Fiber, Compressive strength, silica fume, regression analysis

ISSN 0799-3757

http://caribjscitech.com/

ABSTRACT

In this paper an attempt has been made to evaluate the compressive strength of fiber reinforced concrete (FRC) from the multiple linear regression (MLR) model. For this, the experimental results of earlier researchers were analysed using SPSS software package and the MLR model was developed. Further the developed MLR model was validated with the experimental results of another researcher's data. The results shows that the proposed model was in good agreement with the experimental results and the maximum difference of 15% were observed between the actual and the predicted value.

Introduction

Concrete is brittle in nature and its degree of brittleness increases with its increasing strength. This may be due to the low tensile strength, limited ductility, little resistance of cracking and lack of bonding in the transition zone of the cement matrix which minimizes its utilization under static and, in particular dynamic loading [1–3]. In spite of its brittle nature the demand for high strength concrete continues to grow as it finds a major application in bridges, high rise buildings, airport runways, etc. A pozzolanic admixture named silica fume is used in concrete to enhance its strength though it increases the brittleness to a greater extent [4–5]. By incorporating steel fibers into the concrete its mechanical properties such as the compressive, tensile and flexural toughness, durability and resistance to impact load can be greatly improved [6-8]. Katkhuda et al [9] investigated the effect of silica fume on mechanical properties of high strength light weight concrete. 0%, 5%, 10%, 15%, 20% and 25% of cement was replaced by silica fume for water binder ratio varying from 0.26-0.42. It was observed that the mechanical properties increased with the increase in silica fume content. Based on the results, a relationship between the mechanical properties of concrete containing silica fume was developed using statistical methods. Pawade Prashant.Y et al [10] carried out an investigation on the influence of silica fume in enhancement of mechanical properties of steel fiber reinforced concrete. Silica fume of 0%, 4%, 8% and 12% was added to the concrete mix along with the addition of crimped steel fiber of two diameters 0.5mm and 1.0mm with constant aspect ratio of 60, at various proportions viz., 0%, 0.5%, 1.0% and 1.5% by volume of concrete. The test results showed that replacement of 4%, 8%, 12% and 16% cement by silica fume increased the compressive strengths by 7.46%, 11.17%, 11.91%and 9.83%. Also it was found that the maximum increase in compressive strength of 15.38% and 18.69% (for 0.5mm and 1.0 mm diameter) was achieved at the optimum combined effect of 8% silica fume and 1.5% steel fiber. Numerous investigations have been carried out by various researchers to evaluate the effect of silica fume and fibers on the compressive strength of concrete. Even though there are more literatures on the experimental works carried out to study the effect on compressive strength due to addition of silica fume and fiber, there exist only a limited number of mathematical models. Hence in this study a focus is given upon the development of mathematical model for which the data of the earlier researchers has been taken into account and it was analyzed using SPSS software to obtain the coefficients of the equation. Further the developed MLR model was validated using another set of data obtained from similar research work conducted by other researcher.

Analysis and Modeling of Concrete Strength

Compressive strength of FRC is considered as a function of the following 8 input parameters;

1. Cement, kg (X_1)
2. Fine aggregate, kg (X_2)
3. Coarse aggregate, kg (X_3)
4. Water cement ratio, (X_4)
5. Silica fume, kg (X_5)
6. Volume fraction of fiber (X_6)
7. Aspect ratio of fiber (X_7)
8. Tensile strength of fiber, MPa (X_8)

Regression analysis was carried out to establish a relationship between the dependent and independent variables, and hence to determine the coefficients of the linear equations.

MLR model

The coefficients of the linear equation involving more than one independent variable are estimated using multiple linear regression analysis. In MLR analysis, it is assumed that the variable y is related to variables x_1, x_2, x_3,. x_n, for which an individual value of y is defined as:

$$y = c_0 + \sum c_i x_i \qquad (i = 1 \text{ to } n) \tag{1}$$

The mathematical model for predicting compressive strength is expressed by a linear equation (2) by rewriting the Equation (1) in the expanded form as:

$$y_1 = c_0 + c_1x_1 + c_2x_2 + c_3x_3 + c_4x_4 + c_5x_5 + c_6x_6 + c_7x_7 + c_8x_8 \tag{2}$$

Where y is the estimated compressive strength or dependent variable, n is the number of parameters; c_o and c_i (c_1 to c_8) are the regression coefficients, (i =1 to 8), and x_1, x_2, x_3......x_8 are the independent variables.
In the case of MLR modeling, a new set of data in addition to the data set which has been used in developing the model will be required in order to test the validity of the developed model.

Results and Discussions

The experimental data obtained from the earlier researchers are presented in Table 1 and Table 2. The MLR model (equation for compressive strength) was developed by analyzing the data set containing 8 parameters using SPSS software package as given in equation (3) and the corresponding correlation coefficient R^2 was observed 0.986.

$$y_1 = -251.614 + (0.182 * x_1) + (0.155 * x_2) + (0.108 * x_3) + (-25.807 * x_4) + (0.380 * x_5) + (4.844 * x_6) + (0.05149 * x_7) + (0.00121 * x_8) \quad (3)$$

It can be seen that the predicted values given in Table 1 and Table 2 are obtained using equation (3). The predicted values obtained with the proposed model are in good agreement with the experimental value as the maximum difference between the experimental and predicted value was found to be 6.9 %.

Figure 1 shows the correlation of predicted value by MLR model with the experimental values. The validity of the proposed model was examined with the data set of an earlier researcher Prashant et al and it is given in Table 3. It is observed that MLR model predicts the values quite accurately and not too far away from the experimental results and this proves the validity of the model.

Table 1 Input data obtained from earlier researchers for analysis and the predicted values obtained

Author	Mix Id	Y_1	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	P.V	P.D
		Fck	Cement	F.A	C.A	W/C	Silica fume	V_f	Aspect ratio	Tensile strength of fiber		
P. Ramadoss and K. Nagamani [11]	FC1-0	46.85	416	691	1088	0.4	22	0	0	0	46.26	-1.3
	FC1-0.5	48.94	416	687	1079	0.4	22	0.5	80	910	50.11	2.4
	FC1-1.0	52	416	682	1071	0.4	22	1	80	910	50.89	-2.1
	FC1-1.5	52.68	416	678	1062	0.4	22	1.5	80	910	51.73	-1.8
	FC1*-0	52.56	394.2	691	1088	0.4	43.8	0	0	0	50.59	-3.8
	FC1*-0.5	54.77	394.2	687	1079	0.4	43.8	0.5	80	910	54.43	-0.6
	FC1*-1.0	56.01	394.2	682	1071	0.4	43.8	1	80	910	55.22	-1.4
	FC1*-1.5	57.4	394.2	678	1062	0.4	43.8	1.5	80	910	56.05	-2.4
	FC2-0	52.69	461.7	664	1088	0.35	24.3	0	0	0	52.55	-0.3
	FC2-0.5	55.64	461.7	660	1079	0.35	24.3	0.5	80	910	56.40	1.4
	FC2-1.0	57.85	461.7	655	1071	0.35	24.3	1	80	910	57.18	-1.2
	FC2-1.5	58.23	461.7	651	1062	0.35	24.3	1.5	80	910	58.01	-0.4
	FC2*-0	55.85	437.4	664	1088	0.35	48.6	0	0	0	57.37	2.7
	FC2*-0.5	59.65	437.4	660	1079	0.35	48.6	0.5	80	910	61.21	2.6
	FC2*-1.0	61.05	437.4	655	1071	0.35	48.6	1	80	910	62.00	1.6
	FC2*-1.5	61.44	437.4	651	1062	0.35	48.6	1.5	80	910	62.83	2.3
	FC3-0	60.1	522.5	624	1088	0.3	27.5	0	0	0	59.90	-0.3
	FC3-0.5	62.81	522.5	620	1079	0.3	27.5	0.5	80	910	63.75	1.5
	FC3-1.0	64.01	522.5	615	1071	0.3	27.5	1	80	910	64.54	0.8
	FC3-1.5	64.56	522.5	611	1062	0.3	27.5	1.5	80	910	65.37	1.3
	FC3*-0	63.86	495	624	1088	0.3	55	0	0	0	65.36	2.3
	FC3*-0.5	67.12	495	620	1079	0.3	55	0.5	80	910	69.21	3.1

	FC3*-1.0	68.91	495	615	1071	0.3	55	1	80	910	69.99	1.6
	FC3*-1.5	69.67	495	611	1062	0.3	55	1.5	80	910	70.82	1.7
	FC4-0	71.64	608	562	1088	0.25	32	0	0	0	68.84	-3.9
	FC4-0.5	74.15	608	558	1079	0.25	32	0.5	80	910	72.69	-2.0
	FC4-1.0	75.65	608	553	1071	0.25	32	1	80	910	73.47	-2.9
	FC4-1.5	76.09	608	549	1062	0.25	32	1.5	80	910	74.30	-2.3
	FC4*-0	74.87	576	562	1088	0.25	64	0	0	0	75.18	0.4
	FC4*-0.5	77.42	576	558	1079	0.25	64	0.5	80	910	79.03	2.1
	FC4*-1.0	79.96	576	553	1071	0.25	64	1	80	910	79.82	-0.2
	FC4*-1.5	80.41	576	549	1062	0.25	64	1.5	80	910	80.65	0.3

A.V: Actual value, P.V: Predicted value

Table 2 Input data obtained from earlier researchers for analysis and the predicted values obtained

Author	Mix Id	Y_1	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	P.V	P.D
		Fck	Cement	F.A	C.A	W/C	Silica fume	V_f	Aspect ratio	Tensile strength of fiber		
Mahmoud Nili, V. Afroughsabet [12]	1	41.3	385	920	884	0.46	0	0	0	0	44.17	6.9
	2	46.35	385	914	877	0.46	0	0.5	80	1050	47.75	3.0
	3	47.25	385	907	871	0.46	0	1	80	1050	48.44	2.5
	4	49.88	354.2	915	878	0.46	30.8	0	0	0	48.85	-2.1
	5	53.79	354.2	908	873	0.46	30.8	0.5	80	1050	52.50	-2.4
	6	55.3	354.2	901	866	0.46	30.8	1	80	1050	53.08	-4.0
	7	55.58	450	912	877	0.36	0	0	0	0	56.56	1.8
	8	58.44	450	906	868	0.36	0	0.5	80	1050	59.93	2.5
	9	60.21	450	899	864	0.36	0	1	80	1050	60.83	1.0
	10	63.34	414	906	870	0.36	36	0	0	0	62.02	-2.1
	11	66.87	414	899	864	0.36	36	0.5	80	1050	65.55	-2.0
	12	69.97	414	893	858	0.36	36	1	80	1050	66.40	-5.1
Wei-Ting Lin et al., [13]	A	56.85	558	908	700	0.35	0	0	0	0	56.72	-0.2
	A1	57.66	558	901	694	0.35	0	0.5	40	1100	58.14	0.8
	A2	60.18	558	894	687	0.35	0	1	40	1100	58.72	-2.4
	A3	59.43	558	881	674	0.35	0	2	40	1100	60.15	1.2
	Aa	61.99	530.1	908	700	0.35	27.9	0	0	0	62.26	0.4
	Aa1	62.71	530.1	901	694	0.35	27.9	0.5	40	1100	63.67	1.5
	Aa2	63.03	530.1	894	687	0.35	27.9	1	40	1100	64.26	1.9
	Aa3	63.62	530.1	881	674	0.35	27.9	2	40	1100	65.69	3.2
	Ab	67.24	502.2	908	700	0.35	55.8	0	0	0	67.79	0.8
	Ab1	68.21	502.2	901	694	0.35	55.8	0.5	40	1100	69.21	1.5
	Ab2	72.32	502.2	894	687	0.35	55.8	1	40	1100	69.79	-3.5
	Ab3	72.77	502.2	881	674	0.35	55.8	2	40	1100	71.22	-2.1
	B	36.9	395	908	780	0.35	0	0	0	0	35.75	-3.1
	B1	38.37	395	901	773	0.35	0	0.5	40	1100	37.06	-3.4
	B2	38.96	395	894	767	0.35	0	1	40	1100	37.75	-3.1
	B3	38.55	395	881	753	0.35	0	2	40	1100	39.07	1.3
	Ba	39.83	375.2	908	780	0.35	19.8	0	0	0	39.67	-0.4

	Ba1	41.09	375.2	901	773	0.35	19.8	0.5	40	1100	40.98	-0.3
	Ba2	41.97	375.2	894	767	0.35	19.8	1	40	1100	41.68	-0.7
	Ba3	42.13	375.2	881	753	0.35	19.8	2	40	1100	43.00	2.1
	Bb	42.48	355.5	908	780	0.35	39.5	0	0	0	43.58	2.6
	Bb1	44.89	355.5	901	773	0.35	39.5	0.5	40	1100	44.89	0.0
	Bb2	45.32	355.5	894	767	0.35	39.5	1	40	1100	45.58	0.6
	Bb3	45.76	355.5	881	753	0.35	39.5	2	40	1100	46.90	2.5

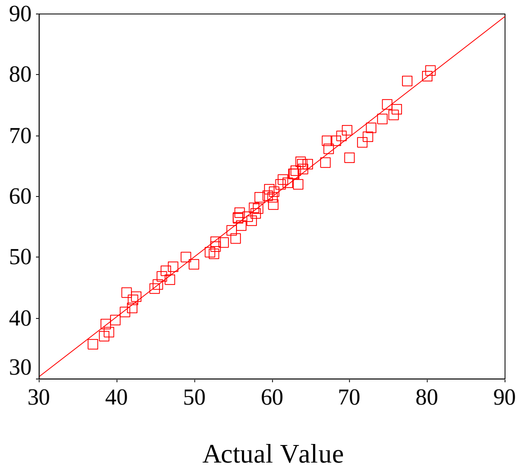

Figure 1 Actual and Predicted Compressive Strength

Table 3 validation of MLR model with Prashant et al [14] results

S.No	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	Actual Value	P.V	P.D
	Cement	F.A	C.A	W/C	Silica fume	V_f	Aspect ratio	Tensile strength of fiber			
1	400	648	1152	0.42	32	0	60	1250	44.88	48.94	9.05
2	400	648	1152	0.42	32	0.5	60	1250	45.82	51.36	12.10
3	400	648	1152	0.42	32	1	60	1250	46.32	53.78	16.11
4	400	648	1152	0.42	32	1.5	60	1250	46.58	56.21	20.67

Conclusions

Based on the investigation, following observations can be drawn.

- It was observed that the prediction of compressive strength of fiber reinforced concrete containing silica fume using MLR model is reliable, as the values were quite accurate.
- Performance of MLR model was found to be satisfactory and this model can be easily adopted since the equation is explicit in nature containing multiple variables influencing the compressive strength of FRC.
- The applicability of the MLR model which was developed using the data of earlier researchers has been validated with the test data of another researcher and a good correlation was found.
- The correlation coefficient R^2 value indicates that the MLR model is significant and the predicted results were found to be not far away from the experimental results.

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