Prediction of mechanical properties of high strength steel fiber reinforced concrete with multiple regression technique

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Abstract. High strength steel fiber reinforced concrete which has cube compressive strength greater than 60 N/mm² was prepared with OPC 53 grade cement confirming IS 269. Sand passing through IS sieve 4.75mm and retaining on IS sieve 150 micron was used in the investigation. Steel fiber with aspect ratio 80 reinforced randomly and at one third position from top of the concrete surface. The percentage of steel fiber varies from 0.5%, 1.0% and 1.5% by volume of concrete specimen. The percentage of silica fume varies from 5%, 10% and 15% by weight of cement used in concrete. Mechanical properties of concrete such as compressive strength, flexural strength were investigated for both the position of steel fiber in concrete. A multiple regression model was employed to predict the mechanical properties of HSSFRC. The regression analysis was performed based on the relationships between the independent variables and the dependent variables. Scatter plot was used to determine the relationship between predictor and criterion variables. The relationship between dependant and independent variable is explained by the magnitude (or the strength) and the direction of the relationship. The magnitude of relationship was calculated using “CORRELATION” formula, which gives the strength of the relationship. The actual shape of the curve determines the direction of the relationship.

1. Introduction

For most of the concrete construction work to save time and money, prediction of concrete strength in advance is required. Multiple regression technique can be effectively utilized to predict concrete strength in early days. M.F.M. Zain et al. [1] suggested the different formulae to predict split tensile strength obtained from compressive. Split tensile strength also related with water binder ratio, concrete age and compressive strength. Mahmoud Sayed-Ahmed [2] studied different matrix mixtures to find effect of matrix mixture on compressive strength. Prepared the statistical tool to forecast the compressive strength of various matrix mixtures at permanentage or at various ages. Julien Michels et.al.[3]shows ductile failure of steel fiber reinforced concrete as compared with steel concrete without fiber. A O Baarimah and S M Syed Mohsin [5] performed four point bending test on steel fiber reinforced slabs to investigate structural behavior with respect to slab thickness and percentage of steel fiber. The percentage of steel fiber is 0%, 1% and 2% in concrete.

Abdel latif Selmi [6] demonstrated major development in the behavior of concrete due to addition of steel fiber as reinforcing material. Kiambigi, Maina, Gwaya[8] developed empirical correlations that have been used to determine concrete strength estimation.
2. Materials
Coarse aggregate of aggregate greater than 4.75 mm is considered as coarse aggregate. For present study coarse aggregates passing through 16.5 mm and retained on 10 mm were used. Locally available fine aggregate which is free from organic impurities was used for present work. Sand passing through IS sieve 4.75mm and retaining on IS sieve 150 micron was used in the investigation. Ordinary Portland Cement 53 grade conforming IS 269 were used in the study. Dramix steel fibre used for steel fibre reinforced concrete having aspect ratio 80. It is circular in cross section hooked end type.

3. Preparation of mix
For the present investigation total 9 concrete mixes were prepared by varying percentage of steel fiber and silica fume. For the 9 concrete mixes other than controlled concrete steel fibers were reinforced randomly and at one third position from top of the pavement surface. ACI method was used for mix design to prepare concrete having cube compressive strength greater than 60N/mm2.

4. Result and discussion
4.1. Compressive strength test:
Cube specimens of size 150mm X150mm X 150 mm were casted and compressive strength test was taken on compressive testing machine. The compressive testing machine has capacity of 3000 KN. The results of compressive strength test were summarized in table 7 as mean value of three tests.

| % of SF | 0.5 | 1.0 | 1.5 | Position |
|--------|-----|-----|-----|----------|
| Comp. Strength (N/mm²) | 72.52 | 73.12 | 73.67 | 74.43 | 75.55 | 76.10 | 74.18 | 75.33 | 76.46 | Random |
| Comp. Strength (N/mm²) | 69.77 | 62.22 | 73.33 | 72.22 | 73.11 | 73.70 | 72.88 | 74.20 | 74.66 | One third |

ST: Steel fiber SF silica fume

4.2 Flexural strength test:
The specimens of size 150mmX150mmX700mm were tested on universal testing machine of capacity 1000KN. The deflection of beam at centre of span was directly measured by using digitized UTM of speed at no load is 0 to 150 mm per minute. The flexural strength of fiber reinforced concrete was found to be increasing as the percentage of fiber increases in both the position of steel fiber.

| % of SF | 0.5 | 1.0 | 1.5 | Position |
|--------|-----|-----|-----|----------|
| Flexural Strength (N/mm²) | 6.93 | 6.07 | 6.72 | 6.13 | 6.15 | 7.28 | 8.53 | 8.62 | 8.92 | Random |
| Flexural Strength (N/mm²) | 5.87 | 5.48 | 6.06 | 6.15 | 6.63 | 7.03 | 7.66 | 7.57 | 8.75 | One third |
4.3. Multiple Regression Technique to predict compressive strength with randomly reinforced steel fiber

The strength of correlation between the predictor variables (% of steel fiber and % of silica fume) and criterion variable (compressive strength) was calculated as shown below in figure 1 and figure 2 the scatter plots.

The strength of correlation of percentage steel fiber and percentage silica fume with compressive strength is 0.71 and 0.54 respectively. It shows a strong correlation between the two types of variables. The low value of Significance-F parameter (0.008) in ANOVA table shows that the regression result is not out of randomness. An adjusted R-square value of 0.73 in the regression statistics table shows that 73% of the change in the compressive strength is explained by the two predictor variables percentage steel fiber percentage silica fume. The p-values of both the independent variables, which are 0.01 and 0.03 respectively, are less than 0.05 (i.e. 5% significance level).

Table 3. Regression statics for Compressive strength test results with silica fume and randomly reinforced steel fiber

|                      |         |         |         |         |
|----------------------|---------|---------|---------|---------|
| Multiple R           | 0.89    |         |         |         |
| R square             | 0.80    |         |         |         |
| Adjusted R square    | 0.73    |         |         |         |
| Standard error       | 0.71    |         |         |         |

Table 4. Significance F for Compressive strength test results with silica fume and randomly reinforced steel fiber

|                      | Df  | SS     | MS    | F       | Significance F |
|----------------------|-----|--------|-------|---------|----------------|
| Regression           | 2   | 11.7276| 5.8638| 11.711118| 0.008480       |
| Residual             | 6   | 3.004222| 0.5007037|         |                |
| Total                | 8   | 14.7318222|       |         |                |
Table 5. P-value for Compressive strength test results with silica fume and randomly reinforced steel fiber

| Coefficients     | Standard Error | t- stat | P- value |
|------------------|----------------|---------|----------|
| Intercepts       | 70.68          | 0.85    | 83.11    | 0.00     |
| % of steel       | 2.22           | 0.58    | 3.84     | 0.01     |
| % of silica      | 0.17           | 0.06    | 2.94     | 0.03     |

The regression equation based on the regression model is as follows:

Compressive strength = 70.68 + (2.22 x % steel fiber) + (0.17 x % silica fume) + e. (1)

Finally, the graph below shows both the actual output and the output calculated from the fitted regression line. Both the curves show similar trends. Thus, the model demonstrated by the equation above explains the relationship between compressive strength and the two-independent variable i.e. % of steel fiber and % of silica-fume.

Figure 3. Fitted line equation curve for compressive strength test results with silica fume and randomly reinforced steel fiber.

4.4 Multiple Regression Technique to predict compressive strength with one third reinforced steel fiber

Scatterplot is drawn between the independent and dependent variables as shown below. The logarithmic relationship was determined between % of fiber and average compressive strength.

Figure 4. Strength of correlation between Log 10 percent of one third reinforced steel fiber and compressive strength

Figure 5. Strength of correlation between percent of silica fume and compressive strength when steel fiber reinforced at one third depth
The two scatter-plots demonstrate that compressive strength improves with logarithmic increase in % of fiber and linear increase in % of silica-fume. The strength of correlation of Log10 percentage steel fiber and percentage silica fume with compressive strength is 0.64 and 0.25 respectively. It shows a strong correlation between the first independent variable however a weak correlation with the second independent variable with average compressive strength. An adjusted R-square value of 31% in the regression statistics table shows that only 31% of the deviation in the compressive strength is explained by the two independent variables % of fiber and % of silica fume. The p-value of log of % fiber is close to 0.05 while the p-value of % silica-fume is higher than 0.05 (i.e. 5% significance level). Also, the t-stat value for log of % fiber is more than 2.

**Table 6.** Regression statics for compressive strength test results with silica fume and one third reinforced steel fiber

|                         |       |
|-------------------------|-------|
| Multiple R              | 0.69  |
| R square                | 0.48  |
| Adjusted R square       | 0.31  |
| Standard error          | 3.71  |

**Table 7.** Significance F for Compressive strength test results with silica fume and one third reinforced steelfiber

|                  | df   | SS      | MS       | F          | Significance |
|------------------|------|---------|----------|------------|--------------|
| Regression       | 2    | 56.972000 | 28.486000 | 2.762352   | 0.141112     |
| Residual         | 6    | 61.87335 | 10.31222 |            |              |
| Total            | 8    | 118.845355 |         |            |              |

**Table 8.** P- value for compressive strength test results with silica fume and one third reinforced steelfiber

|                  | Coefficients | Standard Error | t- stat | P- value |
|------------------|--------------|----------------|---------|----------|
| Intercept        | 93.75090     | 11.44945       | 8.1882  | 0.000178 |
| Log 10 % of fiber| 11.8710      | 5.43368        | 2.1847  | 0.071594 |
| % of silica fume | 0.22733      | 0.262198       | 0.8670  | 0.419245 |

The regression equation based on the regression model is as follows:

Compressive-strength = 93.75 + [11.87 x log (fiber)] + (0.227 x % of silica-fume) + e(2)

Finally, the graph below shows both the actual output and the output calculated from the fitted regression line. Both the curves show similar trends. Thus, the model demonstrated by the equation above explains the relationship between compressive strength and the two-independent variable log 10 of % of steel fiber and % of silica-fume.
4.5 Multiple Regression Technique to predict flexural strength when steel fiber randomly reinforced
Scatterplot is drawn between the independent and dependent variables as shown below and strength of correlation between the independent and dependent variables was calculated.

The strength of correlation of percentage steel fiber and percentage silica fume with flexural strength is 0.93 and 0.24 respectively. It shows a strong correlation between the % of steel fiber variable and flexural strength and a medium strong correlation between % silica-fume and flexural strength. The low value of Significance-F parameter in ANOVA table shows that the regression result is not out of randomness. An adjusted R-square value of 89% in the regression statistics table shows that 89% of the variation in the average flexural strength is explained by the sixth order of two independent variables % of fiber and % of silica-fume. This is a good indicator of fitness of model. The p-values of the first independent variable is less than 0.05 (i.e. 5% significance level) and the second one is close to it.
Table 9. Regression statistics for flexural strength test results with silica fume and randomly reinforced steel fiber.

|                      |       |
|----------------------|-------|
| Multiple R           | 0.96  |
| R square             | 0.92  |
| Adjusted R square    | 0.89  |
| Standard error       | 0.37  |

Table 10. Significance F for flexural strength test results with silica fume and randomly reinforced steel fiber

|                      |       |       |     |     |
|----------------------|-------|-------|-----|-----|
| df                   |       |       |     |     |
| SS                   |       |       |     |     |
| MS                   |       |       |     |     |
| F                    |       |       |     |     |
| Significance F        |       |       |     |     |
| Regression            | 2     | 9.70523 | 4.852617 | 34.70890 | 0.00050     |
| Residual              | 6     | 0.83885 | 0.13980   |           |             |
| Total                 | 8     | 10.544088 |           |           |             |

Table 11. P-value for flexural strength test results with silica fume and randomly reinforced steel fiber

|                      | Coefficients | Standard Error | t- stat | P- value |
|----------------------|--------------|----------------|---------|----------|
| Intercept            | 6.2447       | 0.19           | 33.10   | 0.00     |
| % of fiber-sixth     | 0.19541      | 0.02           | 8.07    | 0.0002   |
| % of silica fume-sixth | 0.00000005  | 0.00           | 2.08    | 0.0828   |

The regression equation based on the regression model is as follows:

\[
\text{Flexural-strength} = 6.244 + (0.195 \times \% \text{ of fiber}^6) + (5 \times 10^{-8} \times \% \text{ of silica-fume}^6) + e
\] (3)

Finally, the graph below shows both the actual output and the output calculated from the fitted regression line. Both the curves show similar trends. The model demonstrated by the equation above explains the relationship between average flexural strength and the two-independent variables i.e. % of fiber and % of silica-fume.

Figure 9. Fitted line equation curve for flexural strength test results with silica fume and randomly reinforced steel fiber.
4.6 Multiple Regression Technique to predict flexural strength when steel fiber reinforced at one third.

Scatterplot is drawn between the independent and dependent variables as shown below.

**Figure 10.** Strength of correlation between percent of one third reinforced steel fiber-squared and flexural strength

**Figure 11.** Strength of correlation between percent of silica fume-squared and flexural strength when steel fiber reinforced at one third depth

The strength of correlation of percentage steel fiber when reinforced at one third depth and percentage silica fume with flexural strength is 0.92 and 0.32 respectively. The low value of Significance-F parameter in ANOVA table shows that the regression result is not out of randomness. An adjusted R-square value of 0.92 or 92% in the regression statistics table shows that 92% of the variation in the flexural strength is explained by the second order of two independent variables % of fiber and % of silica-fume. This is a good indicator of fitness of model, and hence, it can still be surmised that the two variables explain the variation in the model. The p-values of both the independent variables are less than 0.05 (i.e. 5% significance level).

**Table 12.** Regression statics for flexural strength test results with silica fume and one third reinforced steel fiber.

|                |        |
|----------------|--------|
| Multiple R     | 0.97   |
| R square       | 0.94   |
| Adjusted R square | 0.92 |
| Standard error | 0.30   |

**Table 13.** Significance F for flexural strength test results with silica fume and one third reinforced steel fiber

|          | df    | SS     | MS     | F       | Significance F |
|----------|-------|--------|--------|---------|----------------|
| Regression | 2     | 8.261290 | 4.13064 | 46.5067 | 0.00022        |
| Residual  | 6     | 0.53290 | 0.08881 |         |                |
| Total     | 8     | 8.7942  |        |         |                |
Table 14. P- Value for flexural strength test results with silica fume and one third reinforced steel fiber

| Coefficients   | Standard Error | t- stat | P-value |
|----------------|----------------|---------|---------|
| Intercept      | 5.0748         | 0.2221  | 22.8455 | 0.00    |
| % of fiber-sixth | 1.0967     | 0.1204  | 9.1076  | 0.0001  |
| % of silica fume-sixth | 0.0038 | 0.0012  | 3.1726  | 0.0193  |

The regression equation based on the regression model is as follows:

\[
\text{Flexural-strength} = 5.075 + (1.0967 \times \% \text{ fiber}^2) + (0.0038 \times \% \text{ silica-fume}^2) + e(4)
\]

The graph below shows both the actual output and the output calculated from the fitted regression line. Both the curves show similar trends.

Figure 12. Fitted line equation curve for flexural strength test results with silica fume and one third reinforced steel fiber

5. Conclusions

- Coefficient of correlation values for compressive strength and flexural strength test is 0.80, 0.48, 0.92 and 0.94 it shows regression model best suited for experimental analysis.
- The experimental results were compared with the outcomes obtained from regression technique and found to be tolerable.
- Therefore regression technique can be applied for computation of strength properties of steel fiber reinforced concrete.

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