Research Article

Prediction of Mechanical Strength of Fiber Admixed Concrete Using Multiple Regression Analysis and Artificial Neural Network

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The present study is to compare the multiple regression analysis (MRA) model and artificial neural network (ANN) model designed to predict the mechanical strength of fiber-reinforced concrete on 28 days. The model uses the data from early literatures; the data consist of tensile strength of fiber, percentage of fiber, water/cement ratio, cross-sectional area of test specimen, Young's modulus of fiber, and mechanical strength of control specimen, and these were used as the input parameters; the respective strength attained was used as the target parameter. The models are created and are used to predict compressive, split tensile, and flexural strength of fiber admixed concrete. These models are evaluated through the statistical test such as coefficient of determination (R^2) and root mean squared error (RMSE). The results show that these parameters produce a valid model through both MRA and ANN, and this model gives more precise prediction for the fiber admixed concrete.

1. Introduction

Concrete is considered to be the fundamental and an important material in construction industry. Maintaining and testing the quality and behavior of concrete is the challenge faced by the industries in recent times. Also, the modeling of materials through regression tools and AI tools is recently increasing due to its accurate prediction and evaluation. The concrete as generally known for its good compressive behavior is made to behave well under tension and flexure through addition of fiber additives. The general tensile and flexural strength enhancements are made through addition of fibers made up of various materials with different physical and chemical properties. The addition of fibers made up of various materials changes the behavior of cement-based composites and enhances the toughness, tension resistance, and flexural resistance [1–9]. These fibers act at various levels in altering the mechanical behavior of concrete and thus defy the rules framed for its tensile and flexural

performance, making it hard to predict. The major factors that act in enhancing the tensile and flexural strength are fiber distribution and its physical parameters. In recent years, analyzing the concrete properties through prediction modeling is gaining importance due to its accuracy and effectiveness in real-time application. These concrete models were presumed to predict the strength development through certain factors which are used as input parameters. This prediction facilitates in making decision on concrete mix and material selection [10–15]. But there is a challenge when creating a model of concrete for predicting tensile strength and flexural strength, as an effective prediction model is not created through parameters which were used for predicting the compressive strength [16–18]. The challenge on accuracy in prediction increases in fiber admixed concrete while predicting tensile strength and flexural strength; this is due to the fiber properties and its distribution.

In this study, the predictive model was created through multiple regression analysis (MRA) and artificial neural

network (ANN). The fiber properties were used as parameters along with basic concrete and fiber parameters with single target system, and the model is tested through statistical tools for its performance.

2. Prediction Modeling and Testing

The model created here is for fiber-reinforced concrete; the data set was collected for steel fiber, polypropylene fiber, hybrid fiber, glass fiber, and basalt fiber from early studies. The actual compressive strength, split tensile strength, and flexural strength are taken as the target values based on the following parameters which are used as input parameters:

(1) Tensile strength of fiber (F)

(2) Percentage of fiber (P)

(3) Water/cement ratio (R)

(4) Cross-sectional area of test specimen (A)

(5) Young's modulus of fiber (Y)

(6) Mechanical strength of control specimen (S)

Based on the input parameter and target values, the output was generated through ANN and MRA, and these output values were compared with target (actual) values. The types of fibers and its respective literature source are presented in Table 1. The active compressive strength data set has 5 columns and 252 rows (5×252) of input data and 1 column and 252 rows (1×252) of target data. The active split tensile strength data set has 5 columns and 119 rows (5×119) of input data and 1 column and 119 rows (1×119) of target data. The active flexural strength data set has 5 columns and 150 rows (5×150) of input data and 1 column and 150 rows (1×150) of target data. The target data for compressive strength, split tensile strength, and flexural strength were used in both the MRA and ANN model as separate target in this study. This single target system was used due to the usage of cross-sectional area of test specimens as one of the parameters, and it was known that the shape of the specimens varies with different mechanical strengths.

2.1. Prediction Model and Its Statistical Test.
Two prediction models, artificial neural network (ANN) and multiple regression analysis (MRA), are used in this study to predict the compressive strength, split tensile strength, and flexural strength of fiber-reinforced concrete (FRC).

2.2. Artificial Neural Network (ANN).
The ANN prediction model is programmed through MATLAB with two hidden layers, 15 neurons in each hidden layer and one output layer with dependent variable as compressive strength, split tensile strength, and flexural strength. Among all the data, approximately 70%, 15%, and 15% has been considered for training, testing, and validation, respectively. The Levenberg–Marquardt (LM) algorithm is used for training due to its robustness and speed. Layered feed-forward networks have been used in this algorithm, in which the neurons are arranged in layers. Here, signals are sent forward, and errors are propagated backwards.

2.3. Multiple Regression Analysis (MRA).
In this study, the linear-type multiple regression analysis modeling is carried out using MS excel. The coefficients of regression are calculated by considering 95% confidence level; hence, the error tolerance level is limited to maximum of 5%. For a given input variable, the calculated probability value (p value) is considered to be significant, if and only if its value is less than 0.05. Through the regression analysis, the following coefficients presented in Table 2 were found and substituted in linear multiple regression equation (equation (1)):

$$\text{output} = I + C_1 F + C_2 P + C_3 R + C_4 A + C_5 Y + C_6 S. \quad (1)$$

2.4. Statistical Test.
The performance of the ANN and MRA prediction for the mechanical behavior was tested through the statistical methods. The tests involved are coefficient of determination (R^2) and root mean squared error (RMSE). The coefficient of determination is presented in equation (2). This can be obtained from the comparative chart of predicted compressive strength vs. experimental compressive strength. The accuracy of the predictions of a network was quantified by the root of the mean squared error difference (RMSE), between the experimented and the predicted values, and the procedure of finding RMSE is presented in equation (3):

$$R^2 = 1 - \frac{\text{sum of squares of residuals}}{\text{sum of sqaures of predicted values}}, \quad (2)$$

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (ACST - PCST)^2}. \quad (3)$$

3. Results and Discussion

The effectiveness and the acceptance of prediction models are based upon the ability of the model to predict the output. In this study, the models were designed to predict the mechanical behavior (mechanical strength) of FRC based on input parameters, and two methods of predictions, ANN and MRA, are used. The prediction models are validated through coefficient of determination (R^2) and root mean squared error (RMSE) and are consolidated in Table 3.

The MRA and ANN prediction of the compressive strength value is plotted with respect to the actual compressive strength and presented in Figures 1 and 2, respectively. The MRA prediction has the coefficient of determination R^2 as 0.93 which is almost an acceptable value, whereas the ANN has an R^2 value of 1 which indicates that the ANN model is accurate. The RMSE of the MRA model is 7.23 MPa, and the ANN model is 0.14 MPa which demonstrates that error in the MRA model is large and cannot be relied upon for predicting the compressive strength.

The MRA and ANN prediction model plot for split tensile strength with respect to its actual value is presented in Figures 3 and 4, respectively. The R^2 value for the MRA model is 0.87 and ANN model is 0.94. The RMSE for the

TABLE 1: Range of parameters in data base for prediction model.

Type of fiber	Tensile strength of fiber in MPa	Percentage addition of fiber	Water/ binder ratio	Area of specimen tested for compression in mm²	Data range for prediction model		Compression strength in MPa	Split tensile strength in MPa	Flexural strength in MPa	Elastic modulus of fiber in MPa
					Area of specimen tested for tension in mm²	Area of specimen tested for flexure in mm²				
Steel fiber [19–27]	1000–2800	0.025–2.000	0.15–0.5	1600–22500	22500–62832	25200–90000	38.2–146.3	3.23–8.95	3.5–20.2	22830–60.477.26846
Polypropylene fiber [18, 24, 28–34]	320–1200	0.0001–2.000	0.30–0.64	1600–22500	22500–141372	40000–79500	12.7–97.5	1.98–7.98	3–12.02	17818.53–49371.04
Hybrid fiber [35, 36]	450–1200	0.200–2.000	0.38–0.50	7850–17671	—	25200–40000	27.01–73.22	—	4.31–11.3	18460–42784.34
Glass fiber [15, 37–48]	1500–3750	0.100–0.300	0.2–0.71	380–141371	648–141371.67	10000–50000	14–75.82	1.07–7.1	3.39–10.1	3680–43537.34
Basalt fiber [23, 49–52]	3400–4600	0.015–12.450	0.4–0.5	7850–14137	22500–62831.85	24000–92720	29.13–85.78	2.37–4.59	3.9–10.8	26986–44415

TABLE 2: Multiple regression analysis coefficients.

MRA coefficients	Coefficients for compressive strength	Coefficients for split tensile strength	Coefficients for flexural strength
I	−2.083944795	2.864487059	7.214539466
C_1	0.000669227	5.24726×10^{-05}	-4.23499×10^{-05}
C_2	1.097340646	0.81644571	0.513456489
C_3	−31.43416778	−6.912788644	−13.36882713
C_4	-5.56151×10^{-05}	8.71841×10^{-06}	1.9284×10^{-05}
C_5	0.001154844	4.70901×10^{-05}	2.60556×10^{-05}
C_6	0.569536979	0.475257898	0.551752286

TABLE 3: Statistical test conducted on prediction models.

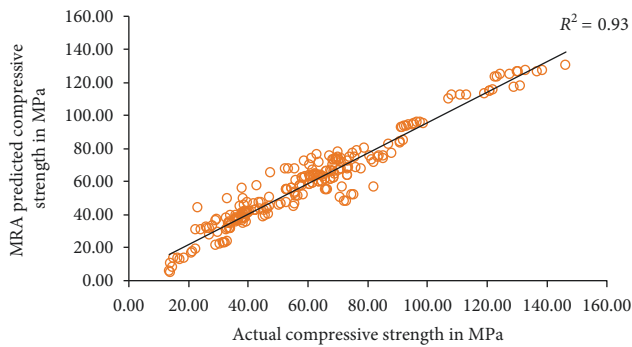| Predicted parameters	MRA		ANN	
	R^2	RMSE	R^2	RMSE
Compression strength	0.93	7.23	1.00	0.14
Split tensile strength	0.87	0.70	0.94	0.42
Flexural strength	0.92	0.99	0.94	0.79

FIGURE 1: Actual vs. MRA predicted value for compressive strength.

FIGURE 2: Actual vs. ANN predicted value for compressive strength.

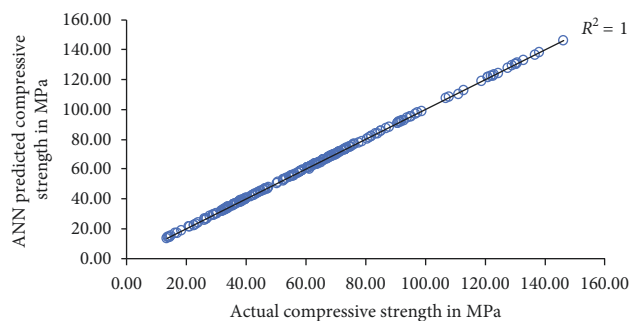FIGURE 3: Actual vs. MRA predicted value for split tensile strength.

FIGURE 4: Actual vs. ANN predicted value for split tensile strength.

MRA model is 0.70 MPa and ANN is 0.42 MPA. The statistical validation of the split tensile strength model shows that both the MRA model and ANN model are in acceptable limit; even though ANN shows more accuracy than MRA, the mathematical model is also predicting the split tensile strength in par with the ANN model. From Figure 3, it is observed that the MRA model predicts to a high accuracy u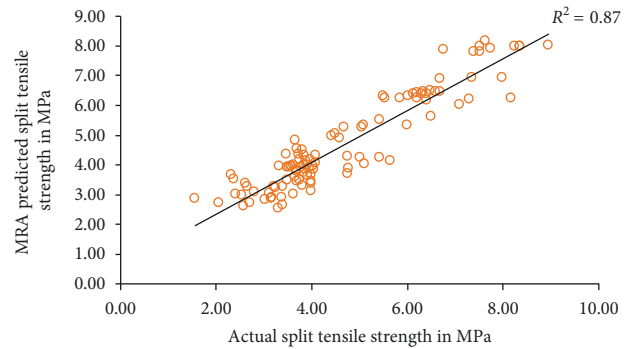ntil actual split tensile strength is 4 MPa, after which the scatter plots were deviating from the actual trend line. From Figure 4, it is observed that the ANN prediction is accurate until the actual strength is 7.5 MPa, after which the scattered plot almost does not fit the trend line.

The MRA and ANN prediction model plot for flexural strength with respect to its actual value is presented in Figures 5 and 6, respectively. The R^2 value for MRA and ANN was 0.92 and 0.94, respectively, which has similar validation value. The RMSE value of the MRA model is 0.99 MPa and ANN model is 0.79 MPa. Both the MRA and ANN were having similar model behavior in terms of statistical validation and graphical representation through Figures 5 and 6. The prediction is accurate in both MRA and ANN models until the actual flexural strength is 9 MPa after which the scattered plot is observed for both models. But there were fitted plots for the MRA model at higher actual flexural strength which lies between 13 MPa and 14 MPa. This higher-order flexural strength fitness towards the trend line was not observed in the ANN model. The observation indicates that flexural strength prediction using MRA and ANN model has effectiveness, and more accurate prediction is rendered in both models. Through the three strength aspects, it was observed that the MRA gains its accurateness in predicting split tensile and flexural strength. The ANN predicts compressive strength to the maximum possible accuracy, and the prediction of split tensile strength and
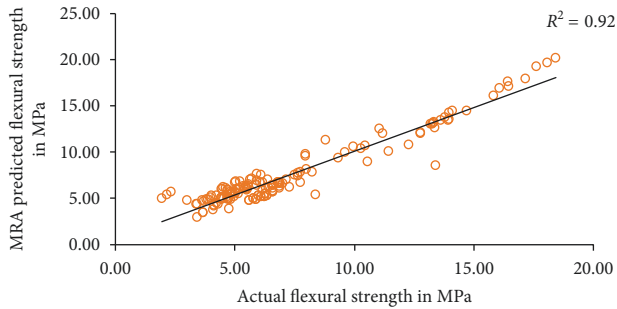
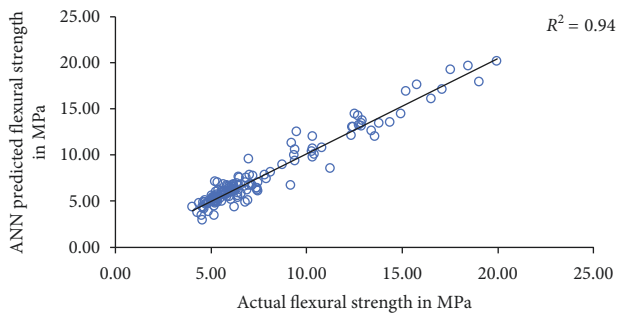FIGURE 5: Actual vs. MRA predicted value for flexural strength.

FIGURE 6: Actual vs. ANN predicted value for flexural strength.

flexural strength was also of higher accuracy. Though the fibers have various factors on influencing the strength development in concrete, the prediction models MRA and ANN are accurate by its output values. The ANN even though has its advantage of higher accuracy over MRA model; the performance of the MRA model is also efficient. The contribution of fiber properties in the prediction model proved to be effective and also gives more preciseness to the model. Earlier models that uses other parameters such as quantity of cement, admixtures, coarse aggregate, fine aggregate, and water were not able to perform well in prediction of tensile and flexural properties [53]; this limitation was overcome by the current model, where both the MRA and ANN model performs well with the given factors. Thus, both current models can predict the complete mechanical behavior of fiber admixed concrete with high precision.

4. Conclusion

This study investigated the feasibility of modeling a predictive analysis through earlier study data, converting the unstructured factors to possible structured parameters and using those in creating the MRA model and ANN model. Also, the effectiveness of these models is tested using statistical tools such as R^2 and RMSE. The compressive strength model shows that ANN has efficient prediction model with R^2 value in unity. The MRA model has R^2 value of 0.93, but the error difference is 7.23 MPa which is very high for a predictive model. The MRA model of split tensile strength and flexural strength shows high efficiency; even though the R^2 values are lesser than the compressive model, the performance of models is relatively strong. The ANN model for

split tensile and flexural strength has similar statistical valuation. The MRA model shows more robustness while predicting the flexural strength, than the split tensile strength. Also, it is noted that the MRA model performs well in split tensile and flexural strength prediction and is validated through the R^2 and RMSE values. The MRA performs well similar to that of ANN and achieves half its effectiveness, except in compressive strength prediction. The study concludes that the fiber properties contribute high to the prediction model, thus increasing the models' performance.

Data Availability

The data supporting this work are available from previously reported studies and datasets, which have been cited. The processed data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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