Artificial neural network applications in fiber reinforced concrete

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Abstract. The presence of fiber in the concrete increases the mechanical properties of the concrete considerably. This paper presents the application of Artificial neural network to predict the compressive and impact strength of the concrete with varying percentage of glass fiber along with different combination of chemical admixtures in concrete such as super plasticiser, air entraining agent, accelerators, retarder and water proofing agent. In experimental part of research, the specimens were tested to failure in order to measure the compressive strength and impact strength by drop weight method. The compressive strength and impact strength of the Glass Fiber Reinforced Concrete (GFRC) with different combination of admixtures get increased to 12% and 90% respectively as compared with control specimen. The predicted strength was compared with the experimentally obtained compressive and impact strength of glass fiber reinforced concrete. The strength predicted by ANN is very close to the experimental results with minimal error.

1. Introduction

Fiber reinforced concrete is formed by adding fibers like E-glass, carbon and aramid into the concrete by the weight of cement. It improves the strength and durability and also reduces the drying shrinkage and cracking. The compressive strength of the concrete was predicted using neural network approach (Guang et.al, 2000). The compressive strength and impact strength of the glass fiber reinforced concrete for varying percentage of fiber content and different combination of admixtures was studied and effect of the fiber and admixture discussed (Sangeetha, 2011). The compressive strength of the self compacting concrete was predicted by Least Square Support Vector Machine (LSSVM) and Relevance Vector Machine (RVM) and found that RVM model predicted better than LSSVM (Bhairevi Ganesh Aiyer et.al, 2014). Root Mean Square Error (RMSE) and Mean Square Error (MSE) indicate better accuracy of the ANN model and also R² ranges between 0 to 1 represents better accuracy of the model for prediction (Chai T & Draxler R R , 2014). Many researchers (5-10) presented the prediction of the compressive strength of concrete, shear strength of the reinforced concrete beams etc using proper ANN model. An artificial Neural Network approach was used to find the compressive stress of the confined and unconfined columns against the experimental and analytical results (Sangeetha et.al, 2019).

In this study the experimental work was carried out to find the effect of glass fiber and admixtures in concrete. The percentages of glass fiber varied are 0%, 0.1%, 0.2% and 0.3%. The
Compressive strength and impact strength of the specimens were also studied by adding different types of chemical admixtures like Superplasticiser (S), Air Entraining Agent (AEA), Accelerator (A), Retarder (R) and Water proofing compound (W) in combination. The cubes of standard size 150 x 150 x 150 mm and slab of size 250 x 250 x 30 mm were casted in order to know the compressive strength and impact strength of the GFRC respectively. All the specimens were made with M25 grade of concrete and are tested after 28 days of curing. The compressive strength of the specimens was done using Compression testing machine of capacity 200 Ton. The impact strength of the specimens was done by drop weight method. Figure 1 show the GFRC cube and slab specimens after failure.

![GFRC cube and slab specimens after failure](image)

**Figure. 1. Photos of Glass Fiber reinforced concrete specimens after test**

2. **Analytic study using ANN**

A neural network is the simple mathematical model using the functions of neuron to predict or stimulate the engineering problems. An ANN contains of many simple elements called neurons which are grouped together in layers. A neurons has many input and a single output. All the neurons are joined to each other by a link, which are in turn associated with the weights having knowledge about the input signals. The input layer receives information from outside environment and passes it on to the hidden layer where the information is processed by summing it up and applied to the transfer function to form the output function. The computational propagation algorithm takes place in a feed forward manner from input layer to output layer and the obtained output is compared with known experimental results, and propagates back to the network to adjust the weight and biases until the errors are sufficiently small. In this present work, the ANN toolbox of the program MATLAB was used to perform the necessary computations. A back-propagation training algorithm was utilized in a feed-forward network trained using the Levenberg–Marquardt algorithm. In general, ANN contains three different steps of training, validation, and test. Out of 32 data patterns, 70% have been used for training, 15% for cross validation, and 15% for network test. Various transfer functions consisting of Linear Sigmoid Axon, Bias Axon, Tanh Axon, Linear Axon, Sigmoid Axon, Linear Tanh Axon, and various training algorithms consisting of Momentum, Levenberg Marquat, Delta Bar Delta, Quick prop, and Step were considered to determine the best structure in the ANN.

In recent years ANN have been applied to many civil engineering problems such as modeling of material behavior and characteristic of concrete specimen etc. In this study, the input layer are comprises the dimensions of the specimen, admixtures used in the concrete mix and fiber content in the mix, the solution of the problem compressive strength and impact strength are evaluated with the output layer. The schematic plot of the ANN model is shown in Figure 2.
The correlation coefficient obtained for training, testing validating and overall data for each compressive and impact strength are shown in Table 1. A review of the experimental results and predicted value of GFRC – Compressive and Impact strength and the prediction errors for ANN are shown in Table 2 & 3.

**Table 1.** Correlation coefficient ($R$) of artificial neural network

| ANN model       | Correlation coefficient ($R$) | Training | Testing | Validating | Overall data |
|-----------------|--------------------------------|----------|---------|------------|--------------|
| Compressive strength | 0.99704                        | 1.00000  | 1.00000 | 0.98540    |              |
| Impact strength  | 0.96634                        | 1.00000  | 1.00000 | 0.94396    |              |

**Table 2.** Comparison of experimental value of GFRC - Compressive strength and predicted data using ANN

| Sl.No | Specimen detail | Fiber content (%) | Experimental Compressive strength (N/mm²) | ANN Compressive strength (N/mm²) | Error       |
|-------|-----------------|-------------------|------------------------------------------|---------------------------------|-------------|
| 1     | Control specimen| 0                 | 21.44                                    | 21.42134102                     | -0.018658982|
| 2     | Control specimen| 0.1               | 26.66                                    | 25.75022615                     | -0.909773846|
| 3     | Control specimen| 0.2               | 28.44                                    | 28.36529562                     | -0.074704379|
| 4     | Control specimen| 0.3               | 30.04                                    | 29.62867447                     | -0.411325535|
| 5     | S+AEA+A         | 0                 | 29.78                                    | 30.05144034                     | 0.271440337 |
| 6     | S+AEA+A         | 0.1               | 31.11                                    | 31.15185506                     | 0.041855064 |
| 7     | S+AEA+A         | 0.2               | 31.33                                    | 32.10702945                     | 0.777029448 |
| 8     | S+AEA+A         | 0.3               | 31.55                                    | 32.73060747                     | 1.180607472 |
| 9     | S+AEA+R         | 0                 | 27.77                                    | 27.83142558                     | 0.061425577 |
| 10    | S+AEA+R         | 0.1               | 29.33                                    | 29.19251298                     | -0.137487018|
| 11    | S+AEA+R         | 0.2               | 29.77                                    | 29.45464527                     | -0.31534735 |
| 12    | S+AEA+R         | 0.3               | 30.00                                    | 29.5751281                      | -0.424871896|
Table 3. Comparison of experimental value of GFRC - Impact strength and predicted data using ANN

| Sl.No | Specimen detail | Fiber content (%) | Experimental Impact Strength (N/mm²) | ANN Impact strength (N/mm²) | Error |
|-------|-----------------|-------------------|-------------------------------------|-----------------------------|-------|
| 1     | Control specimen| 0                 | 26.06                               | 28.70757678                | 2.647576779 |
| 2     | S+AEA+A         | 0.1               | 42.09                               | 35.81816667                | -6.27183333 |
| 3     | S+AEA+A         | 0.2               | 58.64                               | 60.65974706                | 2.01974706 |
| 4     | S+AEA+A         | 0.3               | 71.67                               | 81.99452605                | 10.32452605 |
| 5     | S+AEA+A         | 0                 | 43.38                               | 41.99732706                | -1.38267294 |
| 6     | S+AEA+A         | 0.1               | 60.78                               | 53.37831695                | -7.401683049 |
| 7     | S+AEA+A         | 0.2               | 78.18                               | 70.13467401                | -8.04532599 |
| 8     | S+AEA+A         | 0.3               | 86.86                               | 89.51160884                | 2.651608842 |
| 9     | S+AEA+R         | 0                 | 39.03                               | 48.08792588                | 9.057925878 |
| 10    | S+AEA+R         | 0.1               | 47.77                               | 59.66901206                | 11.89901206 |
| 11    | S+AEA+R         | 0.2               | 78.18                               | 79.0679863                 | 0.887986302 |
| 12    | S+AEA+R         | 0.3               | 95.55                               | 95.69641864                | 0.146418638 |
| 13    | S+AEA+W         | 0                 | 39.03                               | 52.0023806                 | 12.9723806 |
| 14    | S+AEA+W         | 0.1               | 82.52                               | 67.60375888                | -14.91624112 |
| 15    | S+AEA+W         | 0.2               | 86.67                               | 87.37022864                | 0.700228637 |
| 16    | S+AEA+W         | 0.3               | 104.24                              | 100.0643121                | -4.175687922 |

3. Result and Discussion

The results of the experimentally determined compressive strength and impact strength of the GFRC and ANN model for predicting the same are discussed in this section. Figure 3 shows the mean square error for compressive and impact strength specimen with network starting from higher value and getting decreases for the lower values. The model being learned is also shown in figure 3. All the GFRC specimens are grouped into three sets which is been represented as three different coloured lines as shown in figure 3 in order to get the targets. The training state of the ANN model was shown in figure 4.
Figure 3. Performance of the GFRC specimens

Figure 4. Training state for the compressive and impact strength of the specimens

The linear fit line is shown in Figure 5 for the training and testing ANN model for both compressive strength and impact strength of GFRC. The performance in predicting the strength of GFRC of the testing and training data were satisfactory with $R^2 = 0.98$ and $R^2 = 0.94$ using ANN model for the compressive and impact strength respectively. From the coefficient of regression, it is observed that the prediction of the compressive strength of the GFRC using ANN model is more accurate than the impact strength prediction model. Figure 6 shows the error stimulated by ANN model for GFRC specimens.
The performance of the ANN model for GFRC specimens was examined with the data set of the existing model and results were measured by $R^2$ and MSE show better prediction which was shown in figure 7 and it is also found that error is minimal.
From the figure 8 it is observed that the coefficient of regression for proposed ANN model lie in the range of $R^2 = 0.97$ and $R^2 = 0.89$ for the prediction of the compressive and impact strength of the GFRC specimens respectively and found to be satisfactory prediction and are within acceptable limit.

**Figure 7.** Comparison between the mean square error and coefficient of determination for compressive and impact strength of the GFRC specimens

**Figure 8.** Scattered plot between the experimental and predicted strength
4. Conclusions

The effect of glass fiber in the concrete to determine the compressive and impact strength of the specimens were studied experimentally and the same results were used to predict the strength using artificial neural network model. From the experimental and ANN model the following conclusion were arrived.

- The percentage increase in the Glass fiber content in the concrete specimens from 0% to 0.3% improves the compressive strength and impact strength of the specimens by 40% and 175% respectively.
- Compared to the control specimens with the glass fiber, the compressive and impact strength increases by 12 % and 90 % respectively after adding chemical admixtures into the mix proportion of the concrete.
- The coefficient of regression for proposed ANN model lie in the range of $R^2 = 0.97$ and $R^2 = 0.89$ for the prediction of the compressive and impact strength of the GFRC specimens respectively and found to be satisfactory prediction.
- The performance of the ANN model was examined with the data set of the existing model and results were measured by $R^2$ and MSE show better prediction and lower error compared to the previous literature.
- The prediction of compressive strength and impact strength of the glass fiber reinforced concrete using ANN model is accurate and within the acceptable limit.

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