PREDICTION OF COMPRESSIVE STRENGTH OF LIGHT WEIGHT FIBER REINFORCED CONCRETE USING ARTIFICIAL NEURAL NETWORKS

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Abstract - Fiber reinforced concrete (FRC) is a type of concrete that contains discontinuous fibers distributes randomly among the concrete block.Lightweight concretes can be produced with an over-dry density range of approximately 300 to a maximum of 2000 kg/m^3. In this paper, the Artificial Neural Networks are utilized to predict the effect of the addition of steel nails as fibers on the compressive strength of lightweight concrete with crushed bricks used as coarse aggregate. The study involves testing of cubic concrete samples with various mixing proportions and water cement ratios. The results showed thatthe highest value of the compressive strength of 7 days age for (1:2:4) proportion is obtained with fiber adding percentage 5% with w/c ratio 50% for fiber size 1". While for 1.5" fiber size, the 10% fiber addition with w/c of 50% has the greatest value of concrete compressive strength. It is also shown that the highest value of the compressive strength of 28 days for (1:2:4) proportion is obtained with fiber adding percentage 10% with w/c ratio 60% for fiber size 1". While for 1.5" fiber size, the 10% fiber addition with w/c of 50% has the greatest value of concrete compressive strength. It is concluded that the highest value of the compressive strength of 7 days for (1:1.5:3) proportion is obtained with fiber adding percentage 10% with w/c ratio 60% for fiber size 1". While for 1.5" fiber size, the 10% fiber addition with w/c of 50% has the greatest value of concrete compressive strength. Also, it is found that the highest value of the compressive strength of 28 days age for (1:1.5:3) mixing is obtained with fiber adding percentage of 10% and w/c equal 50%. The results of prediction showed that for the mixing proportion (1:1.5:3), the compressive strength decreases with increasing of fiber addition and the 1" nail size gives higher values of compressive strength than 1.5" size. Also the prediction results showed that for the mixing proportion (1:2:4), the compressive strength decreases with increasing the fiber addition ration and the 1.5" nail size gives the higher compressive strength than 1".

Keyword - Fiber Reinforced Concrete, Prediction of Compressive Strength, Neural Networks, Reinforced Concrete, Lightweight

INTRODUCTION

Fibers were used with brittle materials a long history at least 3500years ago, thesun-baked bricks were reinforced with straw to build the hillof AqarQufwith 57 m heightnear Baghdad. More recently times, asbestos fibers were used as reinforcement of cement products for about 100 years, cellulose fibers for 50 years at least, andsteel, polypropylene and glass have been used as fibers for the same aim for the past 45 years. The main objectives of the new concrete technology engineer isthe attempting to modify the propertiesof concrete by improving, the rheology or plastic cracking characteristics of the fresh concreteabout 6 hours after casting, the tensile or flexural strength, the impact strength and toughness, and durability, and controlling cracking and the mode of failure by means of post-cracking ductility [1].

Lightweight concretes is that type of concrete produced with a density range of approximately300 to 2000 kg/m^3, with cube strengths approximatelyranged 1 to more than 60 MPa and with thermal conductivities of 0.2 to 1.0 W/mK, compared with normal weight concrete that has approximately 2100 – 2500 kg/m^3 density, 15to greater than 100 MPacompressive strength and 1.6–1.9 W/mKthermal conductivity.The lightweight concrete can be produced by omitting the finer fraction of normal weight aggregate to create air-filled voids, including bubbles of gas in a cement paste or mortar matrix in order to form a cellular structure containing approximately 30 – 50 per cent voids (aerated or foamed concrete), or replacing, either wholly or partially, natural aggregates in a concrete mix with aggregates containing a large proportion of voids (lightweight aggregate concretes).In the present work, the third manner is utilized using the crushed recycled clay brick as a lightweight course aggregate.

An Artificial Neural Network (ANN) is a computational tool used to simulate the architecture and internal features of the human brain and nervous system [2]. It is a non–linear system of a large number of highly interconnected processing units, nodes or artificial neurons (Fig.1). Each input signal is multiplied by the associated weight value (wi) and summed at a neuron. The result is put through an activation function to generate a level of activity for the neuron. This activity is the output of the neuron. When the weight value at each link and the connection pattern are determined, the neural network is trained. This process is accomplished by learning from the training set and by applying for certain learning rule. The trained network can be used to generalize for those inputs that are not including in the training set. Comparing neural network with other digital computing techniques, neural network are advantageous because of their special features such as the possibility of non–linear modeling relationship between input and target especially for problem where the relationship aren't very well known and low sensitivity to error. Oreta and Kawashima (2003) [3] explored the application of (ANN) to predict the confined compressive strength and corresponding strain of circular concrete columns. Using available data from past experiments, an ANN model with input parameters consisting of the unconfined compressive strength, core diameter, column height, yield strength of lateral reinforcement, volumetric ratio of lateral reinforcement, tie spacing, and longitudinal steel ratio was found to be acceptable in predicting the confined compressive strength and corresponding strain of circular concrete columns subjected to limitations in the training data. The study showed the importance of validating the ANN models in simulating physical processes especially when data were limited. The ANN model was also compared to some analytical models and was found to perform well.

Ongpeng (2003) [4] used artificial neural network(ANN) modeling with Levenberg-Marquardt training algorithm to predict the confined ultimate compressive strength produced by wrapping carbon fiber reinforced polymer (CFRP) externally from circular sections reinforced with steel ties and longitudinal bars. The interaction of both confining materials was investigated. Using collected data from other references, training, testing, and validating different architectures of ANN models from existing models were done to come up with an acceptable model. With the acceptable ANN model, interaction of both confining materials was studied.

In the present work an attempt is made to use the artificial neural network model for the prediction of compressive strength of light weight fiber reinforced concrete, using nails as fibers and the crushed brick as a coarse aggregate. Artificial neural network model is to be developed using MATLAB in order to study the effects of various parameters on the behavior and compressive strength of this type of concrete.

II. EXPERIMENTAL WORK

In the experimental work of this study, 76 cubic samples (150*150*150) mm were tested with 7 days and 28 days ages. The mixing proportion used were (1:1.5:3) and (1:2:4). The water cement ratio is taken between 45% - 60%. The fibers used are nails with 1" and 1.5" size with adding ratios of 0-20% of the cement weight (Fig. 1). All the processes of the experimental work are performed in the Material Laboratory of the Civil Engineering Department-University of Basrah. The materials used in the tested sample were tested according to the Iraqi Specifications.

Fig. (1) The Nails used as Fibers

Fig. (2) Crushed Brick

III. NEURAL NETWORKS MODELLING

The computer program "MATLAB Neural Network Toolbox" was used for the neural network to investigate the compressive strength of lightweight fiber reinforced concrete. In order to find the relationship between input parameters and output parameters a feedforward backpropagation type neural network is used. The configuration and training of neural networks is a trial–and–error process due to such undetermined parameters as the number of nodes in the hidden layer, the learning parameter, and the number of training patterns.

Selection of Training Patterns

The data patterns were divided into two groups; training, and testing data. The training data were used to train the network in order to find the relationship between the input and output parameters.Preparing of training data is a matter of considerable importance in training the neural network. However, the neural networks interpolate data very well, but the extrapolation of data has not in the same confidence. Therefore, the training data should be selected in such a way that it includes data from all regions of interest.

Selection of Testing Patterns

After training of network, the weights and biases are fixed and the network can then be run with same or fresh sets of data. In testing the network at first it is necessary to run the network by using the training data to see whether the network produces good approximation to the known output for these data, and then prepare further data which have not been used in training phase and run the network with these data to check the accuracy of this net. This property of network is called generalization. The generalization depends on the size of the training data set, the architecture of the network, and the complexity of the problem. The number of testing data are taken randomly approximately (16%) from total database. A more information of the progress of training is given by convergence history (learning curve), which is obtained by evaluating the MSE for the testing data at intervals during the course of training.

Configuration of ANN

The successful application (speed of convergence and accuracy of prediction) of a neural network to a problem depends on selecting suitable configuration of the network. Method of trial and error was carried out to define the configuration of the artificial neural network, some aspects were fixed from beginning, including:

1) One node in output layer.
2) Use of feedforward backpropagation algorithm.

Input and Output Layers

The nodes in the input layer and output layer are usually determined by the nature of the problem. In this study the parameters which may be introduced as the components of the input vector consist of:-

1) The percentage of added fibers (A).
2) Water cement ratio (w/c).
3) The mixing ratio (C:S:G).
4) The size of single fiber (B).
5) Time of testing (T).

Normalizing Input and Output Data Set:-

Normalization of input and output data sets within a uniform range before they are applied to the neural network are essential to prevent larger numbers from overriding smaller ones, and to prevent premature saturation of hidden nodes, which impedes the learning process. The limitation of input and output values within a specified range are due to the large difference in the values of the data provided to the neural network.

Initialization of Weights

The first step in the neural network computation is the initialization of weight factors between the nodes of different layers. Since no prior information about the system being modeled is available, so that in this study two initialization functions are used: Widro-Hoff initialization function which changes the weight after each run and random initialization function with ranges [(-1 to 1), (-0.75 to 0.75), (-0.5 to 0.5), and (-0.25 to 0.25)]. From the comparison between the two initialization functions it is found that the Widro-Hoff gives better performance than other function. Therefore Widro-Hoff initialization function is used in this study.

Number of Hidden Layers and Nodes

The number of hidden layers and the number of nodes in one hidden layer are not straightforward to ascertain. No rules are available to determine the exact number. However, the choice of the number of hidden layer and number of nodes in the hidden layer depends on the network application. Although using a single hidden layer is sufficient in solving many functional approximation problems, some problems may be easier to solve with a two hidden layer configurations (Fig.(3)).

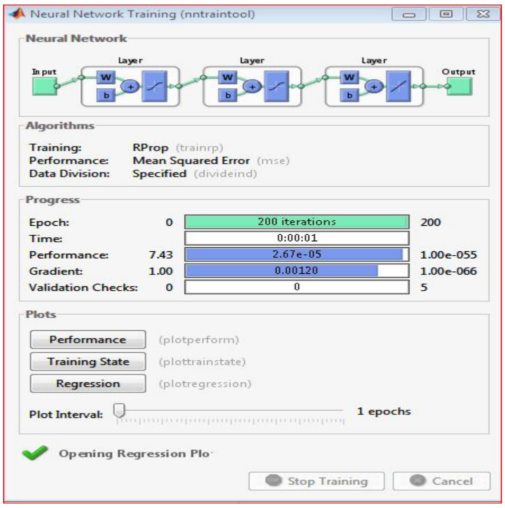

Fig. (3) Neural Network Training

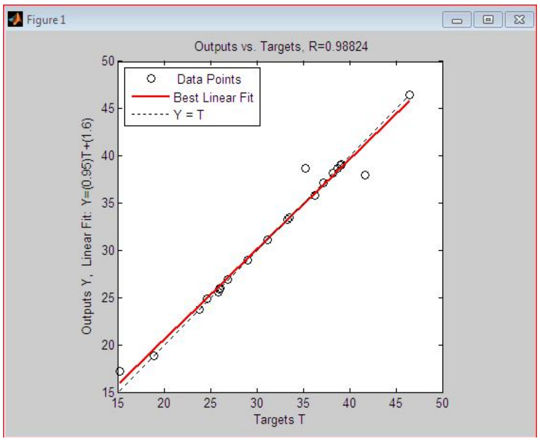

Fig. (4) Output VS. Target

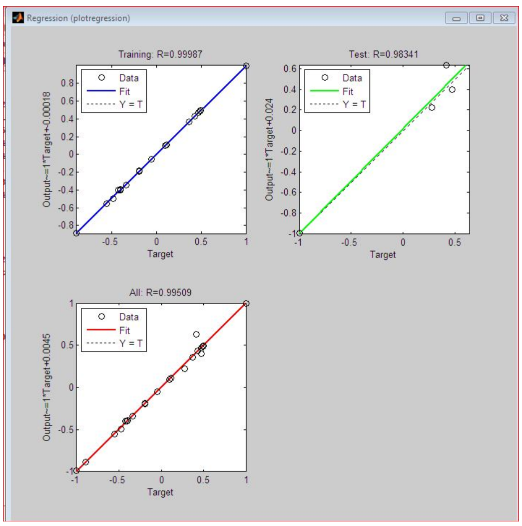

Fig. (5) Regression of Neural Network

Figure (4) presents the relationship between the target and output data. It can be noted that (R) value is approximately equal to one.

Figure (5) shows the regressions of the relations between target and output for each of training, testing, and all. It may be noted that the regressions are approximate to one.

Figure (6) shows the performance of the trained and tested neural. It may be noted that the performance is approximately equal to zero.

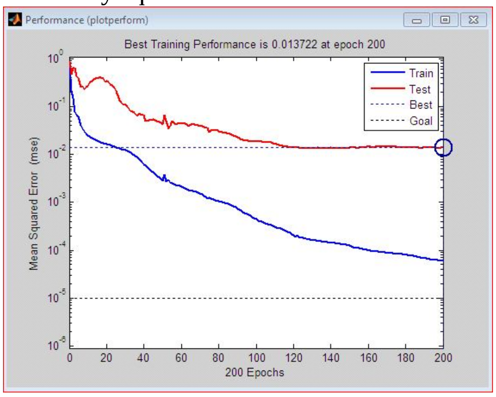

Fig. (6) Performance Of The Network

RESULTS AND DISCUSSION

Table (1) shows the results of the experimental work for 7 days age of concrete with 1" nail size

Fiber Addition (%)	Fiber size (in)	w/c (%)	fc (MPa)
0	1"	0.6	11.32
5		0.5	13.72
5		0.55	12.90
5		0.6	12.50
5		0.65	11.32
10		0.6	13.00
15		0.6	12.21
20		0.6	11.30
5	1.5'	0.6	10.49
10		0.6	10.43
10		0.55	12.77
10		0.5	12.83

Table (1): Results of Experimental Work for 7 Days Age for mixing (1:2:4)

It can be noted that the highest value of the compressive strength is obtained with fiber adding percentage 5% with w/c ratio 50% for fiber size 1". While for 1.5" fiber size, the 10% fiber addition with w/c of 50% has the greatest value of concrete compressive strength.

Table (2) presents the results of the experimental works for the mixing of (1:2:4) and 28 days age. The results show that the highest value of the compressive strength is obtained with fiber adding percentage of 10% and w/c equal 50%

Fiber Addition (%)	Fiber size (in)	w/c (%)	fc (MPa)
0	1"	60	14.3
5		60	14.8
10		60	15.2
10		50	15.89
10		55	15.61
20		60	12.91
5	1.5"	65	14.64

Table (2) Results of Experimental Work for 28 Days Age for mixing (1:2:4)

Table (3) presents the results of the compressive strength for 7 days of concrete and (1:1.5:3) mixing proportion,

Fiber Add. (%)	Fiber size (in)	w/c (%)	fc (MPa)
0	1"	60	12.43
5		60	14.08
5		50	13.61
5		55	12.60
5		65	10.22
10		60	15.08
15		60	10.89
20		60	9.21
5	1.5'	60	10.50
10		60	10.43
10		55	12.77
10		50	12.84

Table (3) Results of Experimental Work for 7 Days Age for mixing (1:1.5:3)

It can be notedthat the highest value of the compressive strength is obtained with fiber adding percentage 10% with w/c ratio 60% for fiber size 1". While for 1.5" fiber size, the 10% fiber addition with w/c of 50% has the greatest value of concrete compressive strength.

Table (4) presents the results of the experimental works for the mixing of (1:1.5:3) and 28 days age. The results show that the highest value of the compressive strength is obtained with fiber adding percentage of 10% and w/c equal 50%

Fiber Addition (%)	Fiber size (in)	w/c (%)	fc (MPa)
0	1"	50	18.4
5		50	19.4
10		50	18.25
20		50	15.12
10		55	15.1
10		45	19.3
10	1.5"	50	13.2

Table (4) Results of Experimental Work for 28 Days Age for mixing (1:1.5:3)

Table (5) shows the results of predicting of the compressive strength for 28 days age and (1:1.5:3) mixing. Water/cement ratio is taken to be 50%.

Fiber Add. (%)	Fiber size (in)	fc (MPa)
0	1"	21.08
3		21.36
6		21.53
9		21.60
12		21.15
15		19.99
18		17.56
21		15.72
0	1.5'	12.02
3		11.58
6		10.40
9		10.67
12		10.93
15		10.93
18		10.98
21		11.24

Table (5) Prediction of the Compressive Strength for 28 Days and (1:1.5:3) Proportions and w/c=45%

It can be observed from Table (5) that the compressive strength decreases with increasing of fiber addition and the 1" nail size gives higher values of compressive strength than 1.5" size.

Table (6) shows the results of predicting of the compressive strength for 28 days age and (1:2:4) mixing. W/C ratio is taken to be 50%.

Fiber Addition (%)	Fiber size (in)	fc (MPa)
0	1	14.86
3		14.47
6		13.64
9		13.05
12		13.20
15		13.92
18		14.38
21		13.86
0	1.5	15.15
3		15.27
6		15.36
9		15.40
12		15.13
15		13.70
18		12.76
21		12.84

Table (6) Prediction of the Compressive Strength for 28 Days and (1:2:4) Proportions and w/c=50%

It can be noted from this table that the compressive strength decreases with increasing the fiber addition ration and the 1.5" nail size gives the higher compressive strength than 1".

CONCLUSIONS

The most important conclusions that can be drawn are the followings:

1) Neural network model has been proved to be very effective in the predicting of the compressive strength of concrete and the selected variables (input parameters of neural network) greatly influence the training and generalization performance of network.
2) The highest value of the compressive strength of 7 days age for (1:2:4) proportion is obtained with fiber adding percentage 5% with w/c ratio 50% for fiber size 1". While for 1.5" fiber size, the 10% fiber addition with w/c of 50% has the greatest value of concrete compressive strength.
3) The highest value of the compressive strength of 28 days for (1:2:4) proportion is obtained with fiber adding percentage 10% with w/c ratio 60% for fiber size 1". While for 1.5" fiber size, the 10% fiber addition with w/c of 50% has the greatest value of concrete compressive strength
4) The highest value of the compressive strength of 7 days for (1:1.5:3) proportion is obtained with fiber adding percentage 10% with w/c ratio 60% for fiber size 1". While for 1.5" fiber size, the 10% fiber addition with w/c of 50% has the greatest value of concrete compressive strength.
5) The highest value of the compressive strength of 28 days age for (1:1.5:3) mixing is obtained with fiber adding percentage of 10% and w/c equal 50%
6) 6)For the mixing proportion (1:1.5:3), the compressive strength decreases with increasing of fiber addition and the 1" nail size gives higher values of compressive strength than 1.5" size.
7) For the mixing proportion (1:2:4), the compressive strength decreases with increasing the fiber addition ration and the 1.5" nail size gives the higher compressive strength than 1".

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