Prediction of Compressive Strength for different Curing Stages using Steepest Descent ANNs

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Abstract: A new ANNs training model is proposed to predict the compressive strength of Slurry Infiltrated Fibrous Concrete (SIFCON) with manufactured sand for various curing periods in this paper. All over the world, availability of natural sand is dwindling day by day due to its limited availability in the river beds. The alternative to this natural resource is the manufactured sand. The ANNs model is constructed, trained and tested for predicting the compressive strengths of various ages using Steepest Descent based weights updating method. The experimental data corresponding to compressive strength of the SIFCON specimens are obtained using the Universal Testing Machine (UTM) of capacity 300T. A total of 80 different SIFCON cube specimens of M20 grade mix using the manufactured sand is cast for different fibre fraction (8%, 10% and 12%) and tested for a different curing period such as 7, 28 and 56 days. In this paper, the compressive strength of different curing ages (14, 21, 35, 42, 49, 63, 70, 77, 84 and 91 days) is predicted for 8%, 10% and 12% fibre volume fraction. For the ANN training phase, different fibre configurations, curing of SIFCON cubes corresponding to various time periods, number of neurons, learning rate, momentum and activation functions were considered. The results show that the relative percentage error in the training set was 6.02% and the testing set was 15%. Research results demonstrate that the proposed Steepest Descent based ANN model is practical, gives high prediction accuracy and beneficial.

Keywords: Manufactured sand, Steepest Descent, ANN, compressive strength, SIFCON.

Introduction

Traditionally, concrete has been fabricated from a few well defined components: cement, water, fine aggregate, coarse aggregate, etc. In this paper, a new approach on concrete has been made, named as SIFCON, which is considered as a relatively new high performance concrete. SIFCON is a special type of steel fibre reinforced concrete. It differs from steel fibre reinforced concrete in two ways by mix and percent volume of fibres [1]. The matrix in SIFCON has no coarse aggregates, but a high cementitious content [2]. The percentage of fibres by volume can be anywhere from 4 to 20% even though the current practical range is from 4 to 12%. The proportions of cement and sand generally used for making SIFCON are 1:1, 1:1.5 or 1:2. The cement slurry made up of the stated proportions alone has some applications. The water cement ratio varies in-between 0.3 to 0.4. Percentage of super plasticizers vary from 2 to 5% by weight of cement [3].

The compressive strength of concrete is a major and important mechanical property, which is generally obtained by measuring concrete specimens after a standard curing of 28 days [4]. Conventional methods of predicting 28-day compressive strength of concrete are basically based upon statistical analysis by which many linear and nonlinear regression equations have been constructed to model such a prediction problem.

Conventional prediction models have been developed with a fixed equation form based on a limited number of data and parameters. If the new data is quite different from the original data, then the model should be updated to include its coefficients and also its equation form. ANNs do not need such a specific equation form. Instead of that, it needs sufficient input-output data. Also, it can continuously re-train the new data, so that it can conveniently adapt to the new data [5, 6]. ANN has been investigated to deal with problems involving incomplete or imprecise information (Noorzaei et al., 2007) [7]. Several authors have used ANNs in structural engineering. For example, Yeh (1998), Kasperkiewicz et al. (1995), Lai and Sera (1997) and Lee (2003) applied the NN for predicting properties of conventional concrete and high performance concretes [8-11]. Bai et al. (2003) developed neural network models that provide effective predictive capability with respect to the workability of concrete incorporating metakaolin (MK) and fly ash (FA) [12]. Guang and Zong (2000) proposed a method to predict 28-days compressive strength of concrete by using multilayer feed forward neural networks [13]. Dias and Pooliyadda (2001) used back propagation neural networks to predict the strength and slump of ready mixed concrete and high strength concrete, in which chemical admixtures and mineral additives were used [14]. In this paper, a feed forward and back

propagation ANN using the Steepest Descent method is used for the prediction of the SIFCON cube compressive strengths for different curing periods.
This paper is presented in the following three sections. It begins with the basic concepts of ANNs and implementation of Steepest Descent Algorithm based ANN in Section 2. Section 3 shows the test results and discussion on the predicted compressive strengths for different curing ages due to *Steepest Descent algorithms based* ANNs and the paper's conclusions in section 4.

Implementation of Steepest Descent algorithm for neural network training process

An Artificial Neural Network (ANN) is an interconnection of processing elements called neurons. Neurons are the basic computing elements that perform data processing in a network. The neurons incrementally learn from their experimental data to capture the linear and non linear trends in the complex data, so that it provides reliable predictions for new situations containing even partial information. The processing ability of the network is stored in the interneuron connection strengths called parameters or weights. The weights are acquired by adaptation process.
The Steepest Descent algorithm which is also known as an error back propagation algorithm is the first neural network training algorithm and is still widely used today. The implementation of neural network training using the Steepest Descent algorithm involves two steps: i) Calculation of observation or Jacobian matrix and ii) training process design.
The training process is designed using the following steps:

i) Estimate the error with the initial weights that are randomly generated
ii) Do an update using the following objective function, f (x), to adjust the weights.

$$f(x) = \frac{1}{2}\sum_{i=1}^{m} r_j^2(x) \qquad (1)$$

Where, r_j are called residuals and r_j = target value - ANN output
Each residual (r_j) represents the difference between computed quantities and their measured counterpart, and therefore represent the function of sought parameters

iii) With the new weights, estimate the mean squared error (MSE)
iv) Do an update using the following update equation of Steepest Descent algorithm to adjust the weights

$$[X_{K+1}] = [X_K] - \alpha_k \lfloor J^T R \rfloor \qquad (2)$$

Where, α_k is the learning constant (step size) and X is the vector consisting of x_1, x_2.....x_n.
R is the residual vector $(\hat{R}(x)) = [r_1(x), r_2(x), ..., r_m(x)]^T$
'g' is the gradient of the objective function.
K is the instant of time or epoch time
$\hat{J}$ is the Jacobian matrix which, in the case when $\hat{x}$ is n-dimensional vector will be m × n matrix,

v) With the new weights evaluate the mean square error
vi) If the current MSE is increased as a result of the update, then retract the step such as reset the weight vector to the previous value and decrease combination coefficient, α_k by a factor of 10 or by the same factor as iv.
vii) Go to step ii with new weights until the current mean square error is smaller than the required value.

Test Results and Discussions

The compressive strengths of the three specimens of different fibre configuration (8%, 10% and 12%) are tested using the UTM of capacity 300T in the laboratory (Fig.1). The compressive strength of the one each of average of the 3 specimens of SIFCON cube specimens referred to as S8 (SIFCON-MS 8%), S10 (SIFCON-MS 10%), and S12 (SIFCON-MS 12%) for 7 days, 28 days and 56 days are presented in the Table 1. Table 1 also illustrates the percent of increase in compressive strengths (SIFCON-MS 8%, SIFCON-MS 10% and SIFCON-MS 12%) of 28 days and 56 days when compared with 7 days.
From Fig.2, it can be seen that 12% fibre fraction has given the optimum strength volume. For 7 days, the compressive strength of the specimens of 12% fibre fraction is 11% more than that of the 8% fibre fraction and more than that of 1% more strength than that of the 10% fibre fraction. For 28 days, the compressive strength of the specimens of 12% fibre fraction is 17% more than 8% fibre fraction and 6% more strength than 10% fibre fraction. For 56 days, the compressive strength of the specimens of 12% fibre fraction is 21% more than 8% fibre fraction and 14% more strength than 10% fibre fraction.
Table 2 illustrates the predicted compressive strengths of the specimens obtained due to the proposed Steepest Descent based ANN (1-2-15-1 design). The proposed ANN consists of one input, 2 hidden layers with 15 neurons each and one output. The compressive strength is predicted for 14, 21, 35, 42, 49, 63, 70, 77, 84 and 91 days from the available compressive strength of 7, 28 and 56 days, which are obtained from testing the cube specimens in UTM of 300T in laboratory. From the Table 2 it is seen that, the predicted values are 88% accurate. The compressive strength obtained has gradually increased as the curing

period increases, an increase in strength is seen from 7 to 63 days and the compressive strength has seen to be stabilized after 63 days that is from 70 to 91 days.

Fig 1. Test procedure of the SIFCON specimens

Table 1. Values of compressive strength of SIFCON specimens obtained in the laboratory

S.No.	Mix	Compressive strength (MPa)			% increase or decrease in Compressive strength compared with 7 days		
		7 days	28 days	56 days	7 days	28 days	56 days
1	SIFCON-MS 8%	29.30	35.71	43.70	-	21.87	49.18
2	SIFCON-MS 10%	35.19	42.54	47.11	-	20.88	33.87
3	SIFCON-MS 12%	43.85	46.15	53.63	-	5.24	22.30

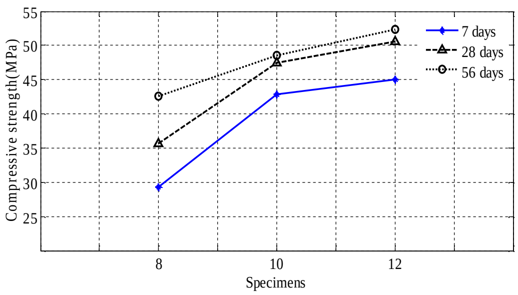

Fig 2. Variation of Compressive strength of SIFCON with fibre fraction

Table 2. Values of Predicted compressive strengths for different curing ages

Period of Curing (Days)	Compressive Strength of SIFCON Specimens for Percent Steel Fibers(MPa)		
	8%	10%	12%
7	26.6	35.19	43.85
14	29.43	39.71	44.76
21	32.47	41.53	45.83
28	35.56	42.54	46.14
35	40.92	42.68	46.14
42	41.69	43.84	46.37
49	42.93	44.11	48.32
56	45.78	47.11	53.63
63	46.89	51.82	56.62
70	46.89	51.85	56.62
77	46.89	52.94	57.16
84	46.89	52.94	57.18
91	49.69	53.19	57.18

Conclusions

The experimental investigation of the compressive strength of SIFCON with manufactured sand for various curing ages was carried out and the compressive strengths of concrete specimens are predicted using the Steepest Descent ***based ANN*** and the following conclusions are made.

- From the study, it can be stated that addition of steel fibres in SIFCON significantly increased the Compressive strength.
- In comparison with 8%, 10% and 12% steel fibres addition in concrete, 12% fibre addition showed the optimum value in compressive strength for all the curing periods (7, 28 and 56 days).
- The compressive strength is predicted for 14, 21, 35, 42, 49, 63, 70, 77, 84 and 91 days from the available compressive strengths of 7, 28 and 56 days, which are obtained from testing the cube specimens in UTM of 300T in laboratory, for 8%, 10% and 12% fibre volume fraction.
- The compressive strength obtained has gradually increased with the curing period i.e an increase in strength is seen from 7 to 63 days and compressive strength has got stabilized after 63 days curing period.
- The predicted values are 88% more accurate when compared to experimental results. Hence, it is concluded that this ANN can be used in the complex concrete structures design such as high raised buildings, dam, bridges etc.,

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