Prediction of Compressive Strength of GGBFS Concrete Subjected to High Temperatures using Artificial Neural Network

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Abstract
Granulated blast furnace slag is widely recycled to reduce the cost of construction as well as to reduce the carbon print on earth. Studies have reported use of GGBFS (Ground Granulated Blast Furnace Slag) as replacement of cement and its ability to improve the long term strength, durability, sulphate attack resistance etc. However, very limited studies have been reported on the compressive strength of GGBFS concrete subjected to high temperatures. In this work, the variation in compressive strength of GGBFS concrete subjected to high temperatures prior to loading is studied. For selecting the proper mix design, trial mixes were prepared and the one with optimum mix proportion was identified. Experimental results show that addition of around 20% of slag content gives much higher strength than the plain concrete. Also at higher temperatures, the difference in the ultimate strength of GGBFS samples is comparatively less. Using experimental data, ANN models were developed based on LM algorithm and was trained, validated and tested. Input parameters for ANN include the slag content, cement content and temperatures the samples are subjected to. Compressive strength is the output variable of this model. The results of the ANN modeling indicate good performance in the prediction of the compressive strength of the samples subjected to furnace temperatures.

Key Words: Compressive strength, GGBFS concrete, Artificial Neural Network

1. INTRODUCTION
Increased awareness of recycling industrial waste products has accelerated the use of blast furnace slag in construction industry. Granulated blast furnace slag (GBFS) is formed when molten slag is rapidly quenched in water. GBFS thus formed is fine, glassy, granular and non-crystalline and is found to have excellent binding properties when mixed with Portland cement after grinding. It has been reported that concrete made with the addition of GGBFS is economic and has improved long-term strength, durability, pore-structure and sulphate-attack resistance. [1-3]. In the presence of water and slaked lime, GGBFS undergoes hydration reactions which results in a much denser microstructure [4-6].

2. EXPERIMENTAL STUDY
2.1 Materials
The experimental study was done on materials conforming to IS standards. The sieve analysis shows that fine aggregates satisfy zone 3 grading requirements as per IS 383-1970 [7] indicating that the fine aggregate selected has good binding properties. The sieve analysis result of coarse aggregates also indicates that the selected materials conform to the grading requirements of IS 383-1970 [7]. The particle size distribution is shown in Fig. 1. The bulk density of the materials was found out in loose and dense states based on IS 2386( Part III, 1963) [8]. The cement adopted for making the samples was properly tested for specific gravity, normal consistency, setting time, fineness etc. to identify whether it satisfies the IS requirements. The Ground Granulated Blast Furnace Slag (GGBFS) required for the study is collected from Jindal Steel Works.

2.2 Mix Design
For deciding upon the mix design, 3 trial mixes were tried. As recommended by IS 10262-1982, for every trial mix, six cubes of 150 mm by 150 mm size were cast. Their strengths were tested in CTM. Based on the 7 day and 28 day compressive strengths, amount of cement content, fine aggregate and coarse aggregate, the best mix proportion for the experimental investigation was determined. Trial Mix 3 whose mix proportion is 0.45:1:1.98:2.923(water content: cement content: fine aggregate: coarse aggregate) was used for the experiment. This is because the desired strength of M30 concrete was achieved with minimum cement content of 430 kg/m$^3$ and a pump-able slump of 95 mm. The 7-day and 28-day compressive strengths of the three trial mixes are shown in Fig. 2.
Fig. 2 Compressive strengths of the three different trial mixes after 7-days and 28 days

2.3 Testing Procedure

Once the trial mix was fixed, the cubes were cast with different amounts of slag mixed with cement and were subjected to different temperatures. The amount of GGBFS used in the samples were 0%, 10%, 20%, 30%, 40% and 50% of the cement content. The study was conducted at room temperature (30°C), 200, 400, 600 and 800°C. The sample is subjected to temperature after proper curing. Since isotropic heating conditions were followed, it was assumed that the sample is heated uniformly. The heating was done with the help of a heating furnace whose maximum operating temperature is 1000°C. Once the sample attained the required bulk temperature, it was taken from the furnace and was allowed to cool. Fig. 3 (a) and (b) shows the test specimen at room temperature and one exposed to 800ºC respectively. These cooled samples were tested in a compression testing machine at room temperature for the residual compressive strength. The values of the compressive strength obtained for various cubes with different slag contents are shown in Fig. 4. The results indicate that the compressive strength of the samples gradually decreases for specimen exposed to higher temperatures. However for slag contents greater than 10%, it is observed that at 800°C, there is not much reduction in the residual strength of the different samples tested.

(a) Room temperature   (b) 800ºC
Fig. 3 Specimen subjected to various temperature conditions

3. PREDICTION OF EXPERIMENTAL RESULTS ADOPTING ARTIFICIAL NEURAL NETWORK (ANN)

ANN are inspired by the ability of the central nervous systems of human beings. A network of neurons form the base of ANN which mimics the human brain. Depending upon the inputs given to the neuron, the output is calculated based on certain functions. A simple form of neurons adopted in ANN for this study is shown in Fig 5. In this figure A = (A1, A2, A3,.....) represent the different inputs in the form of neurons to the model. Different weights are assigned to the inputs depending on the experimental observations. The activation function for this model is selected as sigmoid function as the behaviour of concrete samples are found to be non-linear. Based on the inputs and the corresponding weights assigned to each of these inputs from the experimental data, the ANN’s are trained by experience. The interconnections between the units are assumed to be unidirectional in this study. The learning algorithm adopted is back-propagation and is used in feed-forward neural network. Levenberg–Marquardt (LM) algorithm is adopted in this study as this is reported by several researchers for the studies on concrete [9-10]. Neural network toolbox available in MATLAB is used for the study.

The variables included in this study are the amount of cement, amount of slag content and the temperature the specimen are subjected to. The compressive strength of the specimen is the output variable in this study. From the 30 experimental data set, a total of 1500 sample values are generated for the study by adopting a standard normal distribution which is a well-established method. The generation of 1500 samples is justified as
the 30 experimental samples encompass almost the entire range of observations. For each considered temperature, at a particular slag content, a total of 50 samples were generated including the experimental observations. Among the 1500 data set, 70% of the data (1050) is used for training, 10% of the data (150) is used for validation and 20% of the data (300) is used for testing purposes. The inputs are selected randomly. Due to the heterogeneous nature of the samples, even though a good correlation is obtained between the predicted and observed values, noise is observed. However the RMSE values do not vary much and is found to be smaller than the standard deviation of the experimental data which is considered as a criteria for successful model.

The results of the ANN study are shown in Fig. 6 – 9. Fig. 6, 7 and 8 shows the measured compressive strengths and predicted compressive strengths by ANN model along with the corresponding statistical measure for training, validation and testing respectively. The solid line in the figures represents the best possible linear fit between the observed and predicted values. Higher R value indicates that the relationship between the variables is good. Since the R value for the validation and test data set are above 0.9, it indicates that there is a good correlation in the values. However, the scatter plot indicates that certain data points are outside the best fit region. Fig 9 shows the training performance for training, validation and testing stages for the selected algorithm. The performance of the model was evaluated by considering the epoch which gives the lowest root mean square error for the set selected for testing. The training performance reached the minimum at an iteration of around 15, but continued until 40 till the training stopped.

4. CONCLUSION
In this study, artificial neural work is adopted for predicting the compressive strength of GGBFS from the experimental results. The experimental results indicate that the addition of GGBFS improves the strength of the concrete at normal temperatures upto a slag content of 20%. However, when subjected to high temperatures
the strength of the samples shows a progressive decrease. However the comparison of strength of different mixes at higher temperatures indicate that the strength reduction is less. This is particularly significant as the use of GGBFS will reduce the carbon print thereby improving sustainability. The ANN model developed also predicts the compressive strength of the samples with good performance when LM algorithm is adopted. This indicates that by providing the inputs to the trained algorithm, it can be used as an alternate method to predict the compressive strength. The use of other training algorithms and the improvement on the results can also be studied.

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