Evaluation of the Strength of Recycled Aggregate Concrete using Artificial Neural Network

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Abstract— Recycled Aggregate Concrete (RAC), obtained by replacing Natural Aggregates (NA) with Recycled Aggregates (RA) obtained from different sources is highly complex in nature making it hard to predict the strength and study the performance of RAC. Many researchers have reported alternate statistical or mathematical methods in studying the concrete properties and Artificial Neural Network (ANN) is one such tool. Inspired by the biological neural network, ANN has the ability to learn from past examples, capture highly non-linear relationships and adapt itself to a similar situation effectively. Hence the study aims to determine the 7 day and 28 day compressive strength of RAC with suitable architecture under MATLAB program. In the present investigation 83 sets of data from 10 different published literature sources is used to train, test and validate the network. Here, two separate ANN models were developed for 7 and 28 day strength determination. The major conclusion was that the compressive strength of RAC can be determined with fairly high accuracy using ANN tool avoiding large amount of human effort and time into the experimental work.

Key words: Recycled Aggregate Concrete, MATLAB, ANN, Compressive Strength

I. Introduction

With rapid growth in construction industry and urbanization, significant amount of construction and demolition waste is being generated annually. Hence careful handling and disposal becomes very essential which would lead to environmental hazards if left unattended. Reuse and recycling of these hazardous wastes effectively and preservation of our natural resources without it being drained out completely become very crucial.

The replacement of Natural Aggregates (NA) by Recycled Aggregates (RA) obtained from such wastes is one such step in this regard. However this would lead to significant reduction in strength which when used in concrete will affect its performance.

This is mainly because the granular material obtained by crushing of construction and demolition waste termed as ‘recycled aggregate’ has different characteristics than those of natural aggregates [11]. Since RA is collected from varieties of sources the engineering properties of aggregates such as moisture content, permeability, strength characteristics, specific gravity, water absorption, shape and texture, resistance to freeze-thaw and so on was found to vary significantly. Recycled aggregate concrete shows inferior properties and performance primarily due to high water absorption and low density of RA [1].

Various methods to evaluate the properties of concrete prepared using different mix proportions are being explored in the recent past. Artificial Neural Network is one such tool gaining wide range of popularity. Significant amount of human effort and time can be reduced by adopting such mathematical or computational tools [12].

Several researchers have studied various properties of RAC with different mix proportions. M.V Jose (2002) reported an increase in the porosity considerably upon replacement of NA by RA and reduction in mechanical properties of RAC. Poon et al (2004) upon investigation of influence of moisture states of NA and RA suggested that an air dried aggregate that contains not more than 50% of RA is optimum for producing normal strength concrete which indicates how RA affects the reduction in strength of concrete. The investigation of A. Domingo et al (2009) revealed that when 100% NA was replaced by RA there was an increase in deformations by creep of 51% and by shrinkage of 70% as compared to control specimen. The experiments have indicated lower density, higher water absorption, reduction in static elastic modulus of elasticity of concrete containing RA than those with NA. It was observed that the presence of RA seemed to produce lower performance levels in terms of sustained load.

Further investigations were also carried out on evaluation of the properties of different types of concrete using mathematical or statistical tools [13], [14], [15]. However very few studies are carried out on RAC which exhibits highly unpredictable behavior due to the presence of RA obtained from different sources mainly due to the presence of attached motor/cement [14]. Thus our focus is to predict the compressive strength of recycled aggregate concrete using artificial neural network. The objective of our research is to develop ANN model with the best architecture based on data acquired from the literature using MATLAB program and to further study the suitability of the model in evaluating the compressive strength of concrete made with different types and sources of aggregates with minimum absolute error possible.

II. Artificial neural network

An Artificial Neural Network (ANN) is a computer based arrangement framework which is an emulation of biological neural system. It is a network consisting of several nodes comparable to neurons. The number of input nodes and output nodes correspond to the input and output parameters considered. The number nodes in the hidden layer are purely based on trial and error technique. The connection between these nodes carries weights which help in mapping between input and the output of the system. Artificial Neural Network is a technique that can be used for problems where no solution algorithm is known. It can be adopted effectively in solving highly non-linear problems.

The neural network is to be trained to reproduce the input-output relation by finding the optimal weight. Training consists of evaluating the outputs from input, comparing with the target values and reinitializing weights to obtain the desired output. The accuracy of prediction of the network was quantified by the root mean squared error difference (RMSE) between actual and predicted values, mean absolute percentage error (MAPE) and multiple co–efficient of determination (R^2).

$$RMSE = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(actual - predicted)^2}$$

$$R^2 = 1 - \frac{\sum(actual - predicted)^2}{\sum(actual - mean_{actual})}$$

$$MAPE = \frac{1}{N}\sum_{n=1}^{N}\frac{(Actual - Predicted)}{Actual}$$

III. METHODOLOGY

In the present work, two neural network models were developed. ANN I predicts the 7 day compressive strength of RAC and ANN II predicts the 28 day compressive strength of RAC.

A. Database

A total of 83 set of experimental data was collected from 10 different literature sources [1-10]. The range of data considered for the present investigation is shown in Table 1. 71 sets of data were used for training and validation of the network and 12 sets were used for testing the network for its accuracy.

B. Input and output parameters

The input parameters considered in this study for both ANN I and ANN II include Water (W), Cement (C), Sand, Natural Aggregate (NA), Recycled Aggregate (RA), Water/cement ratio (w/c), Fineness modulus of sand (FM), Maximum size of coarse aggregate (D_{ca}), Type of coarse aggregate (K_{CA}), Water absorption of coarse aggregate (w_m), Saturated Surface Dry Specific Gravity of coarse aggregate (SSD), Replacement ratio by volume (r_v), Additive (Ad), Impurity content (δ) and Conversion co-efficient (CF).

The output parameter considered for the first network (ANN I) is 7-day compressive strength and for the second network (ANN II) is 28-day compressive strength of recycled aggregate concrete.

C. Modeling

Two neural network models were developed for predicting 7 day and 28 day compressive strength of recycled aggregate concrete. The first model was developed to predict 7- day compressive strength (ANN I) and the second model was developed to predict 28-day compressive strength (ANN II). The details of the neural network models are shown in Table 2.

Parameters	Minimum	Maximum
C (kg/m^3)	255	410
W (kg/m^3)	148	271
S (kg/m^3)	606.9	972.95
NA (kg/m^3)	0	1187
R (kg/m^3)	0	1107
w/c	0.4	0.77
FM	2.11	5.81
D_{ca}(mm)	19	25
K_{CA}	1	6
W_m (%)	0.12	6.99
SSD	2.27	3.03
r_v (%)	0	100
Ad (%)	0	3.48
δ(%)	0	8
CF	1	1.25
7-day compressive Strength of RAC (f_{cu}) in MPa	10.53	57.10
28-day compressive Strength of RAC (f_{cu}) in MPa	17.64	72.3

Table 1 Range of data used in training and testing of models

Network Parameters	ANN I 7-day compressive strength	ANN II 28-day compressive strength
Network architecture	15-8-1	15-10-1
Training Function	TRAINLM	TRAINLM
Adaption Learning Function	LEARNGDM	LEARNGDM
Performance Function	MSE	MSE
Transfer Function	TANSIG	TANSIG

Table 2 Neural Network Models

IV. RESULTS AND DISCUSSIONS

After the process of training the network with the architecture adopted, the results of the predicted values are exported from MATLAB into the workspace. The data predicted is compared with the actual values of the compressive strength of RAC. Since 12 sets of data is considered in the current work, a comparison is drawn and absolute error and percentage error is tabulated as shown in Table 3 and Table 4. Fig.1 and Fig. 2 shows a plot between actual and predicted values over the 12 data points.

It can be observed that in ANN I the minimum absolute error is 0.057 MPa and maximum absolute error was found to be 3.085 MPa. The average relative error for the considered set of values is found to be 5.19%. The maximum and minimum values of percentage errors obtained from ANN I were 12.54% and 0.03% respectively.

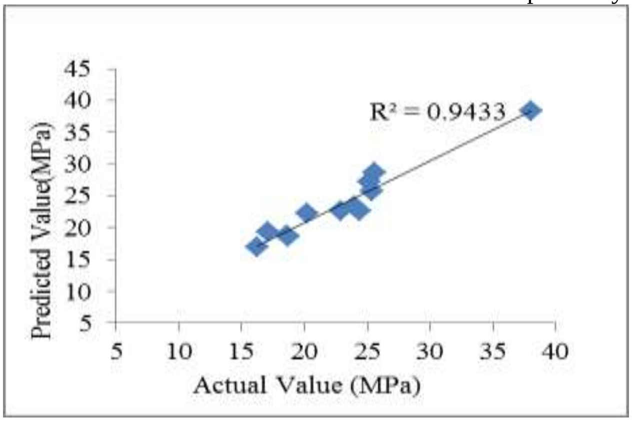

Fig. 1: Linear relationship between actual and predicted 7-day compressive strength values

Similarly in case of ANN II the minimum absolute error is 0.036 MPa and maximum absolute error was found to be 2.85 MPa. The average relative error for the considered set of values is found to be 2.55%. The maximum and minimum values of percentage errors obtained from ANN II were 8.03% and 0.16% respectively.

The values of RMSE, R^2 and MAPE for ANN I and ANN II are shown in Table 5.

Actual Value (MPa)	Predicted Value (MPa)	Absolute Error (MPa)	Percentage Error (%)
18.57	18.84	0.275	1.48
24	23.31	0.686	2.86
22.93	22.7	0.226	0.99
16.29	17	0.711	4.36
17.14	19.29	2.15	12.54
18.71	18.65	0.057	0.30
25.2	27.12	1.92	7.62
20.2	22.23	2.034	10.07
24.43	22.56	1.87	7.65
38	38.34	0.344	0.91
25.64	28.72	3.085	12.03
25.36	25.73	0.374	1.47

Table 3 Comparison between actual values and predicted values for ANN I (15-8-1)

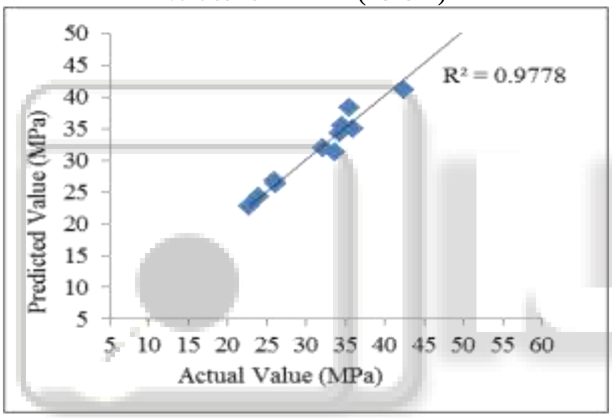

Fig. 2: Linear relationship between actual and predicted 28-day compressive strength values

Actual Value (MPa)	Predicted Value (MPa)	Absolute error (MPa)	Percentage Error (%)
26	26.72	0.721	2.77
33.6	31.36	2.23	6.64
32.1	31.9	0.198	0.62
22.8	22.76	0.036	0.16
24	24.19	0.188	0.78
26.2	26.36	0.157	0.60
42.4	41.09	1.306	3.08
34.6	35.5	0.904	2.61
34.2	34.3	0.102	0.30
53.2	54.51	1.31	2.46
35.9	34.97	0.924	2.57
35.5	38.35	2.85	8.03

Table 4 Comparison between actual values and predicted values for ANN II (15-10-1)

Performance Parameters	ANN I	ANN II
RMSE	1.49	1.25
R^2	0.943	0.977
MAPE	0.05	0.02

Table 5 Performance Parameters of the models.

V. CONCLUSIONS

In the present work the basic idea was to determine the compressive strength of recycled aggregate concrete at 7 days and 28 days. Hence two separate ANN models were designed, trained and tested under MATLAB. Back-propagation training algorithm was used in both the networks. Both ANN I and ANN II performed well in predicting the strength values. The following are the major conclusions drawn from this study.

ANN modelling appears to be a useful tool in predicting the compressive strength of recycled aggregate concrete.

Weights and biases which are the model parameters were optimized by changing internal number of neurons in the hidden layer and epochs to get architectures for the developed networks.

The correlation coefficients (R) and co-efficient of determination (R^2) for the overall response in both ANN I and ANN II were greater than 0.9 suggesting that the performance of these networks can be rated as good to excellent.

The mean relative error was found to be 5.19% for ANN I and 2.55% for ANN II which is considered to be well within the acceptable limits.

The comparison between the actual and predicted compressive strength values of RAC showed a maximum absolute error of 3.08MPa for ANN I and 2.85 MPa for ANN II indicating the models performed well in reaching the goal of this study.

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