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Prediction of Compressive Strength of Concrete Containing Industrial Wastes and Fibers Using Artificial Neural Network

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ABSTRACT

The present article consist of (i) Experimental investigation on strength of concrete containing industrial wastes such as fly ash, silica fume, copper slag and fibers (ii) Prediction of compressive strength of concrete containing the industrial wastes using Artificial Neural Network (ANN). The results of the experimental study are used to develop the ANN model to predict the strength of concrete and it was observed that ANN has high potential for predicting the strength of concrete containing industrial wastes.

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INTRODUCTION

It has been reported that manufacture of Portland cement accounts for 6-7% of total carbon-di-oxide emission produced by humans (http://www.builditgreen.org/attachments/wysiwyg/3). Therefore, to curb further declination of environment, it would be better to look for materials to replace cement with suitable substitute. While air pollution is the major concern with respect to cement production, solid waste, such as, fly ash and copper slag form the major concern in thermal power plants and copper industries, respectively. To utilize fly ash and copper slag in the construction industry as substitutes for cement and aggregates would thus provide an efficient way of disposing them. It is known that concrete has very low tensile strength and hence it is not usually considered in the design of concrete structures. Different kinds of fibers such as glass fibers, steel fibers etc., are being used in concrete to improve the tensile strength. Several studies (Poon, C.S., *et al*., 2000; Rafat Siddique, 2004; Medhat, H. *et al*., 2000; Malhotra, V.M., 1990; Montemor, M.F., *et al*., 2000; Khalifa, S., *et al*., 2009; Khalifa, S., *et al*., 2009; Khalifa, S., *et al*., 2011; Wei Wu, Weide Zhang, M. Guowei, 2010; Ha-Won Song, *et al*., 2010; Dotto, J.M.R., *et al*., 2004; Mazloom, M., *et al*., 2004; Yining Ding, Wolfgang Kusterle, 2000 *et al*., 2004; Thanongsak Nochaiya *et al*., 2010; Yu Zhu, *et al*., 2012; Cengiz Duran Atis and Okan Karahan, 2009; Osman Gencel, *et al*., 2012; Ozgur Eren and Tahir Celik, 1997; Mahmoud Nili, V. Afroughsabet, 2010; Mostafa Khanzadi, Ali Behnood, 2009; Chi Sun Poon, Lik Lan Yuk Lung Wong, 1999) have been made by various researchers to explore the properties of fresh and hardened concrete containing fly ash, silica fume, copper slag and fibers. But studies reported are very scarce which deal with replacing both cement and aggregates *simultaneously* with suitable substitutes. Towards this, the present study is envisaged to understand through experiments the effect of addition of fly ash and copper slag as replacement material for cement and fine aggregate, respectively, in strength of concrete. Defined quantity of silica fume, steel fibers and polypropylene fibers were added to the mix proportions considered for the study.

Modelling observed phenomena is one of the major concerns in Engineering. Artificial Neural Network (ANN) is one of the effective tools for modelling complex relations between input and output variables. In the present study, ANN model is developed to predict the compressive strength of concrete containing industrial wastes and fibers using the results of the experiments conducted. In ANN, the input variables are multiplied by weights and the outputs are determined. Higher the weight to any particular input variable, higher the influence of it in affecting the output. The performance of ANN model is improved by training the network by which the network learns by updating the architecture of the network and the weights. The training is made by using the results of the experiments.

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EXPERIMENTS - Materials and Testing Details:

The target compressive strength for the control specimen was chosen as 58MPa. Ordinary Portland cement, River sand and crushed granites (of size 20mm) were used for preparing concrete. Concrete cubes of size 150x150 mm were cast in a controlled environment in the moulds. The moulds were dismantled after 24 hours and the specimens were subjected to immerse curing for 28 days. After the curing period, the cubes were tested. Mix proportions for preparing the concrete are given in Table 1.

Table 1: Mix proportions (in kg/m^3) considered for experimental study

Mix ID	Cement	Fly ash	Silica fume	Fine aggregate	Copper slag	Coarse aggregate	Steel fiber	Polypropylene fiber
S0	400	-	-	652.0	-	1294	-	-
S1	216	160	24	456.4	195.6	1294	-	-
S2	176	200	24	456.4	195.6	1294	-	-
S3	136	240	24	456.4	195.6	1294	-	-
S4	216	160	24	391.2	260.8	1294	-	-
S5	176	200	24	391.2	260.8	1294	-	-
S6	136	240	24	391.2	260.8	1294	-	-
S7	216	160	24	326.0	326.0	1294	-	-
S8	176	200	24	326.0	326.0	1294	-	-
S9	136	240	24	326.0	326.0	1294	-	-
S10	216	160	24	456.4	195.6	1294	2	-
S11	176	200	24	456.4	195.6	1294	2	-
S12	136	240	24	456.4	195.6	1294	2	-
S13	216	160	24	391.2	260.8	1294	2	-
S14	176	200	24	391.2	260.8	1294	2	-
S15	136	240	24	391.2	260.8	1294	2	-
S16	216	160	24	326.0	326.0	1294	2	-
S17	176	200	24	326.0	326.0	1294	2	-
S18	136	240	24	326.0	326.0	1294	2	-
S19	216	160	24	456.4	195.6	1294	-	2
S20	176	200	24	456.4	195.6	1294	-	2
S21	136	240	24	456.4	195.6	1294	-	2
S22	216	160	24	391.2	260.8	1294	-	2
S23	176	200	24	391.2	260.8	1294	-	2
S24	136	240	24	391.2	260.8	1294	-	2
S25	216	160	24	326.0	326.0	1294	-	2
S26	176	200	24	326.0	326.0	1294	-	2
S27	136	240	24	326.0	326.0	1294	-	2
S28	216	160	24	456.4	195.6	1294	1	1
S29	176	200	24	456.4	195.6	1294	1	1
S30	136	240	24	456.4	195.6	1294	1	1
S31	216	160	24	391.2	260.8	1294	1	1
S32	176	200	24	391.2	260.8	1294	1	1
S33	136	240	24	391.2	260.8	1294	1	1
S34	216	160	24	326.0	326.0	1294	1	1
S35	176	200	24	326.0	326.0	1294	1	1
S36	136	240	24	326.0	326.0	1294	1	1

It can be seen from Table 1 that the amount of cement replaced by fly ash is varied from 40% to 60% (by weight). For each percentage of replacement of cement, the amount of fine aggregate replaced by copper slag is varied from 30% to 60% (by weight). Amount of silica fume and water-binder ratio are kept constant as 6% of cement and 0.35, respectively, for all the specimens. Amount of super plasticizer is varied from 2.0 to 2.2% by weight of the binder content. Amount of steel fibers and polypropylene fibers added are based on the percentage of volume of binder content. The percentage is 0.25% when both fibers are present and 0.5% when any one type of fiber is present.

Artificial Neural Network:

ANN is a computational model devised to work similar to Human brain. Studies on ANN are supposed to have started in early 1940s and the research activity on ANN has experienced three major periods of activity. The work by McCulloch and Pitt's (McCulloch, W.S. and W. Pitts, 1943) is the first that had set the momentum in ANN research to the peak in 1943. Then in 1960s, Rosenblatt's (Rosenblatt, R., 1962) perceptron convergence theorem and Minsky and Papert's (Minsky, M. and S. Papert, 1969) once again generated momentum on ANN research. But Minsky and Papert's work, which showed the limitation of simple perceptron, slowed down the progress of studies on ANN. It is the work by Rumelhart *et al*. (Rumelhart, D.E. and J.L. McClelland, 1986) in 1980s that popularized ANN which used back-propagation learning algorithm for multilayer perceptrons. After 1980s, together with the developments in the computer field, ANN has become very popular in modeling complex input-output relationships.

ANN contains nodes which are linked. While the computations are carried out at nodes, flow of information between nodes is carried out through linkages. Weights are multiplied to the information that is transferred from nodes. The procedure by which the weights are adjusted so as to achieve the desired output is called learning or training. In the present study, ANN is used to model the relationship between the input (FA-S, FA-CS, SUM) and the output (Strength). Since it was inferred earlier in this study that not both the ratios (fly ash-cement or copper slag-sand) should exceed 1.0, the sum of these ratios (SUM) has been considered as one of the input neurons for the ANN model.

The results of the specimens without any fibers have been considered to develop ANN model. Since only nine test results are available for specimens without fibers, results used to train the ANN are used to validate the strength predicted by the ANN. In the ANN model considered in this study, the number of neurons in the input layer and the output layer were three and one, respectively. One hidden layer with five neurons was considered since this resulted in minimum absolute percentage error between the strength predicted and strength determined from the experiments. The minimum and maximum values of the input and output neurons considered in the ANN model are:

	Min.	**Max.**
FA-S	0.35	0.74
FA-CS	0.49	1.23
Sum	1.17	2.76
Strength (N/mm^2)	23.45	53.69

In the ANN model developed feed-forward back propagation network has been used. In the back propagation network, the inputs are read and assigned weights to determine the output and the errors are determined. The signals are sent back or propagated back to adjust the weights assigned and train the network to minimize the error thus making the ANN model so powerful to identify the trend between the input and the output.

RESULTS AND DISCUSSION

Experimental study:

The results of compression tests are given in Table 2. Table 3 gives the relation between FA-C & CS-S and their corresponding percentages of replacement of cement & fine aggregate, respectively. The results of the tests are presented graphically in the Figures 1-11.

Table 2: Strength of specimens, N/mm^2

S.No.	Strength	S.No.	Strength	S.No.	Strength	S.No.	Strength
S0	54.40						
S1	48.87	*S10*	49.42	*S19*	48.56	*S28*	50.89
S2	42.32	*S11*	43.91	*S20*	46.76	*S29*	44.31
S3	32.77	*S12*	34.74	*S21*	31.60	*S30*	36.07
S4	52.46	*S13*	54.26	*S22*	47.85	*S31*	48.72
S5	49.47	*S14*	51.30	*S23*	41.54	*S32*	39.42
S6	47.38	*S15*	49.00	*S24*	38.78	*S33*	44.22
S7	53.69	*S16*	55.66	*S25*	50.94	*S34*	53.14
S8	49.48	*S17*	50.89	*S26*	39.83	*S35*	44.96
S9	23.45	*S18*	26.30	*S27*	28.30	*S36*	35.92

Table 3: FA-C and CS-S ratios in terms of % of materials replaced

FA-C ratio	FA in % of Cement	CS-S ratio	CS in % of Fine Aggregate
0.74	40	0.43	30
1.14	50	0.67	40
1.76	60	1.00	50

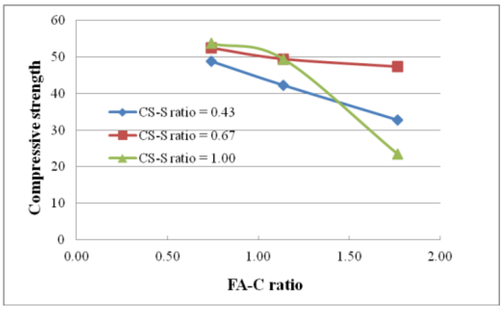

Fig. 1: Compressive strength vs FA-C ratio [Specimens S1-S9: without fibres]

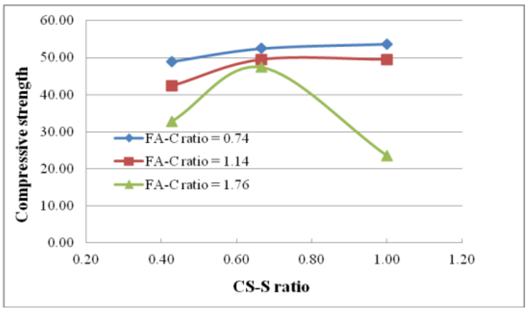

Fig. 2: Compressive strength vs CS-S ratio [Specimens S1-S9: without fibres]

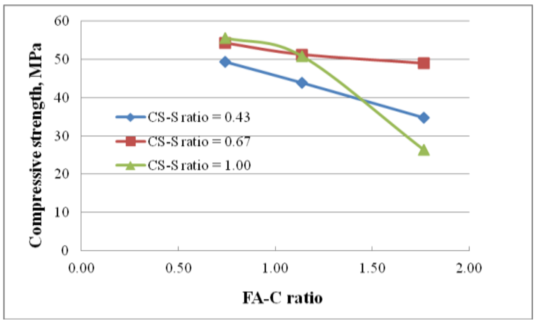

Fig. 3: Compressive strength vs FA-C ratio [Specimens S10-S18: with steel fibres]

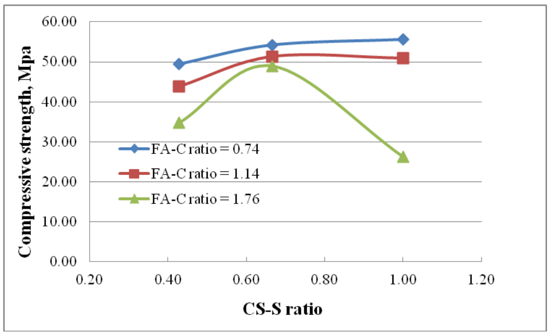

Fig. 4: Compressive strength vs CS-S ratio [Specimens S10-S18: with steel fibres]

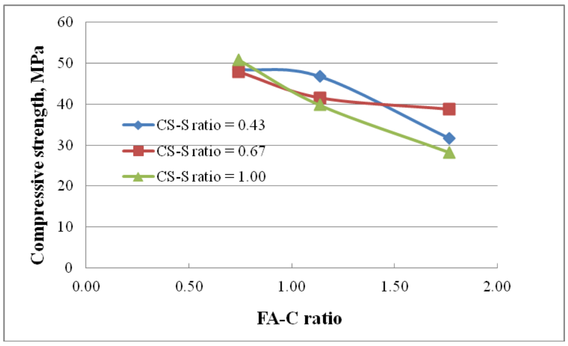

Fig. 5: Compressive strength vs FA-C ratio[Specimens S19-S27: with polypropylene fibres]

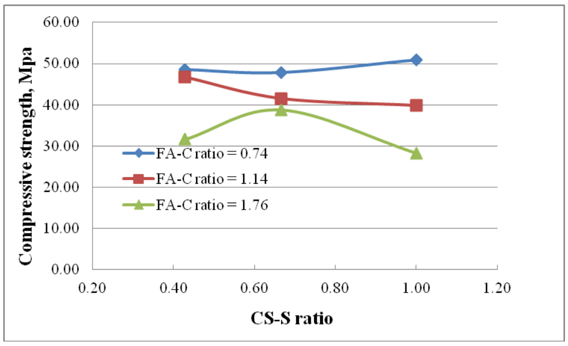

Fig. 6: Compressive strength vs CS-S ratio[Specimens S19-S27: with polypropylene fibres]

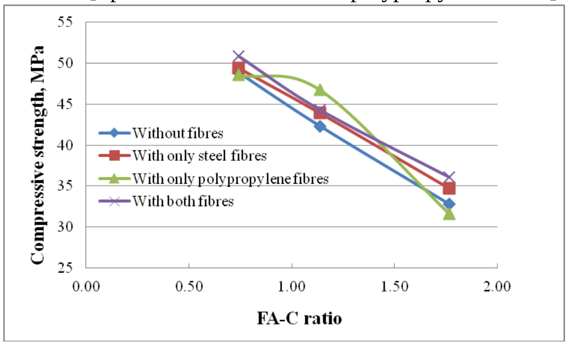

Fig. 7: Effect of addition of fibres (CS-S ratio = 0.43)

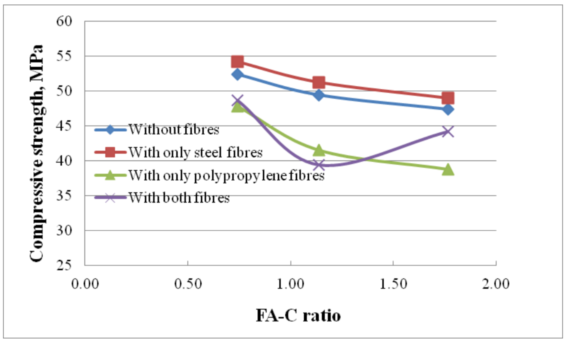

Fig. 8: Effect of addition of fibres (CS-S ratio = 0.67)

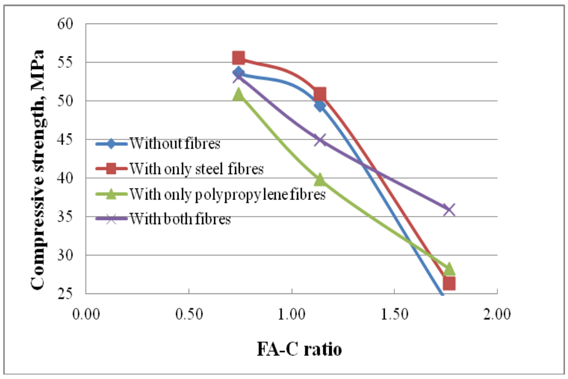

Fig. 9: Effect of addition of fibres (CS-S ratio = 1.0)

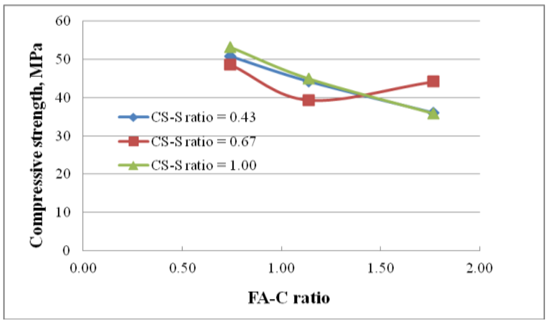

Fig. 10: Compressive strength vs FA-C ratio [Specimens S28-S36: with both fibres]

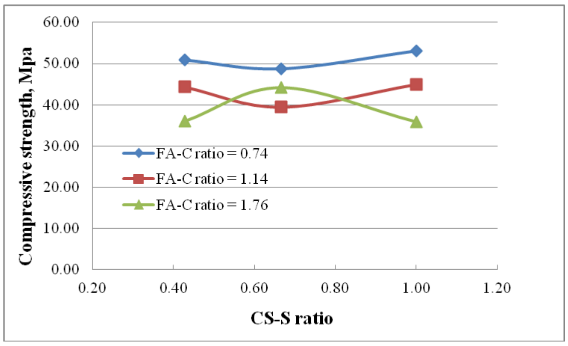

Fig. 11: Compressive strength vs CS-S ratio[Specimens S28-S36: with both fibres]

Inferences made from the results are:

(i) for a given copper slag-fine aggregate ratio, increase in fly ash-cement ratio decreased the strength of the concrete and, the rate of decrease in the strength decreased with increase in copper slag-sand ratio.

(ii) for a given fly ash-cement ratio, increase in copper slag-fine aggregate ratio increased the strength of the concrete.

(iii) for a given copper slag-fine aggregate ratio, the strength of concrete seem to vary linearly with variation in fly ash-cement ratio and for a given fly ash-cement ratio, the strength of concrete seem to vary non-linearly with variation in copper slag-fine aggregate. It is also interesting to note that, as long as both ratios (viz., fly ash-cement or copper slag-sand) are not ≈ ≥ 1.0, there seem to be no abrupt change in the trend of variation of strength.

(iv) Generally, for all the specimens considered for this study, it is noted that the addition of steel fibers increased the strength by around 3% on the average, but addition of polypropylene fibers decreased the strength by around 3% on the average.

(v) Irrespective of the presence of fibers, the variation in the strength (with respect to control mix) was found to be within ±7% when the fly ash used was 40% and copper slag used was 50%. Therefore, rreplacing 40% of cement by fly ash and 50% of fine aggregate by copper slag (with or without fibers) seem to be the optimum replacement percentages to achieve comparable strength to that of the control mix.

Artificial Neural Network:

The strength predicted using the ANN model developed in this study is presented in Table 4 and the same are presented in the Figure 12.

Table 4: Strength predicted, N/mm^2

Mix ID	S1	S2	S3	S4	S5	S6	S7	S8	S9
Exp.	48.9	42.3	32.8	52.5	49.5	47.4	53.7	49.5	23.5
ANN	51.6	42.3	32.7	51.9	49.6	47.5	51.9	48.8	23.5

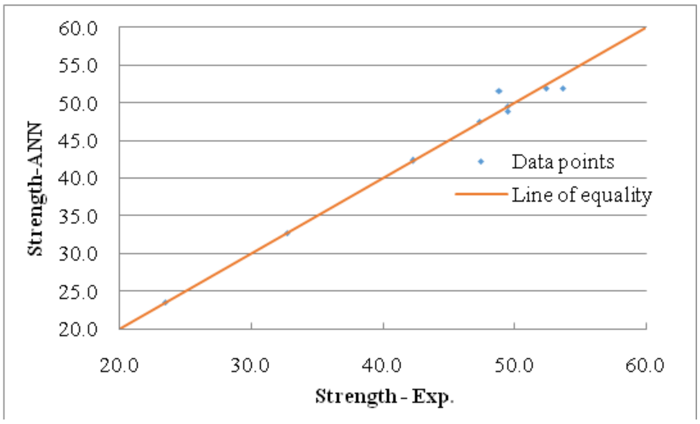

Fig. 12: Comparison of strengths

It is observed from Figure 12 that the strength determined from the experiments and predicted using the ANN model developed in this study are almost equal, thus proving the ability of ANN model to predict the strength of concrete containing fly ash and copper slag as replacement material for cement and fine aggregate, respectively.

Conclusion:

It is inferred from the study reported in this paper that it seems to be necessary to replace fine aggregate also by copper slag if fly ash is used for replacing cement in concrete. It is also found that replacing 40% of cement by fly ash and 50% of fine aggregate by copper slag (with or without fibres) seem to be the optimum replacement percentages to achieve comparable strength to that of the control mix. Also, ANN model was developed, using the results of the experiments, to model the relationship between the input and output variables for concrete containing industrial wastes and was seen that the strength predicted by ANN model were close to the experimental results which shows high potential for ANN to be used for modelling.

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