World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:8, No:3, 2014

Predictive Models for Compressive Strength of High Performance Fly Ash Cement Concrete for Pavements

S. M. Gupta, Vanita Aggarwal, Som Nath Sachdeva

Abstract**—**The work reported through this paper is an experimental work conducted on High Performance Concrete (HPC) with super plasticizer with the aim to develop some models suitable for prediction of compressive strength of HPC mixes. In this study, the effect of varying proportions of fly ash (0% to 50% @ 10% increment) on compressive strength of high performance concrete has been evaluated. The mix designs studied were M30, M40 and M50 to compare the effect of fly ash addition on the properties of these concrete mixes. In all eighteen concrete mixes that have been designed, three were conventional concretes for three grades under discussion and fifteen were HPC with fly ash with varying percentages of fly ash. The concrete mix designing has been done in accordance with Indian standard recommended guidelines. All the concrete mixes have been studied in terms of compressive strength at 7 days, 28 days, 90 days, and 365 days. All the materials used have been kept same throughout the study to get a perfect comparison of values of results. The models for compressive strength prediction have been developed using Linear Regression method (LR), Artificial Neural Network (ANN) and Leave-One-Out Validation (LOOV) methods.

Keywords**—**ANN, concrete mixes, compressive strength, fly ash, high performance concrete, linear regression, strength prediction models.

I. Introduction

HIGH performance concrete (HPC) is a concrete which performs better than conventional concrete in terms of workability, strength and durability [1]. HPC has been tried in the past by using various mineral admixtures like fly ash, slag, bottom ash, silica fume and waste glass etc. in addition to the components of ordinary concrete [2]. The use of industrial by products in concrete can address the three major problems associated with concrete industry, namely, consumption of virgin materials for production of cement, environmental degradation due to production of greenhouse gases by cement industry and disposal of fly ash and lack of durability of conventional concrete structures [3].

Concrete has been the most popular construction material for civil infrastructure since its inception. Though there is no dearth of information available on concrete and fly ash, an exhaustive study is required to develop some models which can predict the compressive strength of concrete by input of quantities of its constituent materials without actually conducting the trial mixes testing. Concrete is a cast-in-situ material for which a lot of experimental testing and time is needed. As compressive strength of concrete is a property which acts as the basic index of all the other properties of concrete, there is a shear need to develop some models to predict the compressive strength of concrete. Investigators [4] and [5] described a model for design of concrete mixes involving the direct computation of ingredients using formulae without use of any tables or charts. In the present study also such models have been developed and compared for compressive strength prediction of concrete within the adopted scope, using Linear Regression method (LR), Artificial Neural Network (ANN) and Leave-One-Out Validation (LOOV) methods.

S. M. Gupta is Professor in Civil Engineering Department, National Institute of Technology, Kurukshetra, 136119, Haryana, India (phone: +911744233348; fax: +91238350; e-mail: sm_gupta85@rediffmail.com).

Vanita Aggarwal is formerly research scholar of Civil Engineering Department, National Institute of Technology, Kurukshetra, 136119, Haryana, India, and presently Professor in M.M. Engineering College (Deemed University), Mullana, District Ambala, India (phone: +918059930707; e-mail: aggarwal_vanita@rediffmail.com).

Som Nath Sachdeva is Professor in Civil Engineering Department, National Institute of Technology, Kurukshetra, 136119, Haryana, India (phone: +911744233347; fax: +91238350; e-mail: snsachdeva@ yahoo.co.in).

II. Research Significance

The topic is of importance especially in Indian scenario, as very small proportion of construction industry is incorporating fly ash in concrete. The reason is either ignorance about the suitability of fly ash in HPC concrete or is lack of confidence in the test results available, as most of the research in the said area has been carried out abroad. Moreover, there is no consistency in the properties of fly ash available from different sources [6]. So, the test results of one place cannot be utilized as such for other places. The aim of the present research is to evaluate the performance of HPC with varying percentages of fly ash in terms of compressive strength. Compressive strength is the most important property that affects the performance of concrete pavements [7]. The objective of using fly ash as an admixture to concrete is to reduce heat of hydration, make an economical concrete with improved durability and workability and to safeguard environment from hazards of CO_2 emissions from cement industry and landfills of fly ash disposal [8]. All fly ash mixtures exhibited substantially higher rates of strength gain as compared with non-fly ash control mixes [9].

III. Experimental Investigations

For achieving the objectives of the present study, an experimental program was planned to investigate the effect of varying percentages of fly ash from 0% to 50% at 10% increment by weight of cement, on compressive strength of concrete. The investigations for compressive strength on concrete with and without fly ash at different ages were conducted. The ingredients for high volume fly ash concrete were cement, fly ash, fine aggregates, coarse aggregates and water. Laboratory tests were conducted on cement, fine aggregates, coarse aggregates, whereas test results of fly ash were performed through a professional laboratory.

The effect of replacing cement with fly ash in varying percentage (0%, 10%, 20%, 30%, 40%, and 50%) on compressive strength of high volume fly ash concrete at moist curing was to be carried out by cube testing at the age of 7 days, 28 days, 90 days, and 365 days.

The specimens were tested on a motorized UTM. Specimens were taken out from the curing tank at respective ages of testing and tested immediately on removal from the water, while they were still in the wet condition. The position of the cube when tested was at right angles of that as cast. The axis of the specimens was carefully aligned with the centre of thrust of the spherically seated plate. The load was applied gradually and without shock and increased continuously at the rate of approximately 14N/mm^2/ minute till the failure of the specimen and thus the compressive strength was found out [10], [11].

IV. Materials Used

A. Cement

Ordinary Portland cement of 43 grade conforming to [12] was used. The cement was tested in accordance with the methods of test specified in [12].

B. Fine Aggregate

For preparation of concrete mix, fine aggregates conforming to IS grading zone-II were used.

C. Coarse Aggregate

20 mm and 10 mm size coarse aggregates were used in 60:40 proportions.

D. Fly Ash

Fly ash with specific gravity 2.25 of class-F obtained from Panipat thermal power plant was used.

E. Potable Water

Potable tap water was used for the preparation of all concrete specimens**.**

F. Chemicals Used

Super plasticizer based on poly carboxylic technology was used for high strength concretes.

G. Concrete Mix Proportions

The final mixes reached after trial testing in laboratory in accordance with [13] for various concrete grades under consideration with varying percentages of fly ash are reported in Table I.

Table II gives compressive strength results for various HPC mixes used for modeling in the present study. The results have been used to develop a response for compressive strength at 7 days, 28 days, 90 days and 365 days.

TABLE I
MIX PROPORTIONS FOR HPC MIXES

Sr. No.	Mix grade	Cement (kg)	Fly Ash as % of Ce-Ma	Fly Ash (kg)	F.A. (kg)	C.A.(kg)	Water (lit)	S.P. % by wt. of Ce-Ma*	**Water/ Ce-Ma* ratio**
1	$M30F_0$	410.0	-	-	683.1	1180.2 (63.6%)	172.2	-	**0.420**
2	$M30F_{10}$	405.9	10	45.1	651.1	1154.6	175.0	-	**0.388**
3	$M30F_{20}$	360.8	20	90.2	645.6	1144.8	175.0	-	**0.388**
4	$M30F_{30}$	315.7	30	135.3	640.1	1135.0	175.0	-	**0.388**
5	$M30F_{40}$	270.6	40	180.4	634.6	1125.2	175.0	-	**0.388**
6	$M30F_{50}$	225.5	50	225.5	629.0	1115.5	175.0	-	**0.388**
7	$M40F_0$	420.0	-	-	673.9	1195.1 (64.2%)	163.8	0.8	**0.390**
8	$M40F_{10}$	415.8	10	46.2	641.1	1167.1	167.0	0.8	**0.361**
9	$M40F_{20}$	369.6	20	92.4	635.6	1157.0	167.0	0.8	**0.361**
10	$M40F_{30}$	323.4	30	138.6	630.0	1146.9	167.0	0.8	**0.361**
11	$M40F_{40}$	277.2	40	184.8	624.5	1136.8	167.0	0.8	**0.361**
12	$M40F_{50}$	231.0	50	231.0	618.9	1126.7	167.0	0.8	**0.361**
13	$M50F_0$	450.0	-	-	655.6	1204.0 (65%)	157.5	0.8	**0.350**
14	$M50F_{10}$	445.5	10	49.5	624.6	1172.5	160.0	0.8	**0.323**
15	$M50F_{20}$	396.0	20	99.0	618.7	1161.6	160.0	0.8	**0.323**
16	$M50F_{30}$	346.5	30	148.5	612.9	1150.6	160.0	0.8	**0.323**
17	$M50F_{40}$	297.0	40	198.0	607.1	1139.7	160.0	0.8	**0.323**
18	$M50F_{50}$	247.5	50	247.5	601.2	1128.7	160.0	0.8	**0.323**

* CeMa: Cementitious Material (Cement + Fly ash)

TABLE II
COMPRESSIVE STRENGTH OF HPC MIXES

Sr. No. of mix	Mix	Compressive strength (MPa)			
		7 days	28 days	90 days	365 days
1	$M30F_0$	28.2	39.1	43.4	43.8
2	$M30F_{10}$	27.5	38.7	45.7	46.5
3	$M30F_{20}$	26.6	38.0	48.5	49.9
4	$M30F_{30}$	25.3	36.6	51.2	52.7
5	$M30F_{40}$	22.5	33.5	46.2	47.2
6	$M30F_{50}$	20.8	31.1	38.6	39.2
7	$M40F_0$	35.5	49.3	55.2	56.2
8	$M40F_{10}$	34.9	48.9	57.3	59.2
9	$M40F_{20}$	33.7	47.6	61.6	63.7
10	$M40F_{30}$	32.4	45.9	63.5	65.6
11	$M40F_{40}$	30.7	43.9	58.9	61.0
12	$M40F_{50}$	27.7	40.8	51.4	51.8
13	$M50F_0$	42.3	58.8	63.5	65.3
14	$M50F_{10}$	41.2	57.6	66.2	67.4
15	$M50F_{20}$	40.8	57.0	69.8	70.7
16	$M50F_{30}$	38.2	53.6	71.4	73.6
17	$M50F_{40}$	35.2	50.2	66.3	68.3
18	$M50F_{50}$	33.0	47.0	58.5	60.3

V. MODELING OF RESULTS

A. Linear Regression (LR)

Linear regression technique was applied on a set of 12 HPC mixes chosen randomly out of a total of 18 mixes under consideration. The rest 6 mixes were used for validation purpose of linear regression technique. The expressions proposed on the basis of linear regression technique for cube compressive strength of 12 mixes are given below at their respective ages:

fck_{7days} = 0.1082*C - 0.0599*FA + 0.2477*CA + 0.1774*Fly Ash – 0.0294*W + 0.5278*SP - 262.57

fck_{28days}= + 0.0366*C - 0.2631*FA + 0.3157*CA + 0.0291*Fly Ash - 0.1533*W + 0.3521*SP – 142.35

fck_{90days}= + 2.3331*C + 2.4304*FA + 2.8665*CA + 3.2565*Fly Ash + 6.8966*W + 7.3946*SP – 7143.52

$fck_{365days}$= + 2.4666*C + 2.4936*FA +3.2281*CA + 3.4813*Fly Ash + 7.7683*W + 7.9504*SP – 7818.04

where fck is the cube compressive strength at given age and C, FA, CA, W and SP stand for the quantities of cement, fine aggregate, coarse aggregate, water and super-plasticizer in Kg.

The percentage error in the proposed equations is tabulated in Table III for results obtained for various ages of the mixes. The validation of above equations has been checked for 6 mixes and the percentage error in respective cases is reported in Table IV.

The acceptance of above equations was assessed by calculating the mean absolute error from percentage error reported in Table V. The output of linear regression models in predicting the compressive strength of HPC mixes at 7 days, 28 days, 90 days and 365 days is shown in Figs. 1-4 respectively.

TABLE III
COMPARISON OF ACTUAL AND PREDICTED COMPRESSIVE STRENGTH RESULTS AT VARIOUS AGES USING LINEAR REGRESSION

Sr. No.	Mix	fck at 7 days (N/mm^2)		% error	fck at 28 days (N/mm^2)		% error	fck at 90 days (N/mm^2)		% error	fck at 365 days (N/mm^2)		% error
		Act.	Pred.		Act.	Pred.		Act.	Pred.		Act.	Pred.	
1.	$M30F_0$	28.2	28.1	0.4	39.1	39.2	-0.3	43.4	43.9	-1.2	43.8	44.2	-0.9
2.	$M30F_{20}$	26.6	26.8	-0.8	38.0	38.3	-0.8	48.5	49.5	-2.1	49.9	50.9	-2.0
3.	$M30F_{30}$	25.3	25.1	0.8	36.6	36.3	0.8	51.2	49.7	2.9	52.7	51.3	2.7
4.	$M30F_{50}$	20.8	20.8	0.0	31.1	31.1	0.0	38.6	38.7	-0.3	39.2	39.3	-0.3
5.	$M40F_0$	35.5	35.5	0.0	49.3	49.1	0.4	55.2	54.5	1.3	56.2	55.5	1.2
6.	$M40F_{10}$	34.9	35.6	-2.0	48.9	49.7	-1.6	57.3	59.7	-4.2	59.2	61.3	-3.5
7.	$M40F_{30}$	32.4	32.1	0.9	45.9	45.6	0.7	63.5	60.1	5.4	65.6	62.2	5.2
8.	$M40F_{40}$	30.7	30.3	1.3	43.9	43.5	0.9	58.9	60.5	-2.7	61.0	62.8	-3.0
9.	$M50F_0$	42.3	42.4	-0.2	58.8	58.9	-0.2	63.5	63.8	-0.5	65.3	65.6	-0.5
10.	$M50F_{20}$	40.8	40.0	2.0	57.0	55.9	1.9	69.8	68.9	1.3	70.7	70.4	0.4
11.	$M50F_{30}$	38.2	38.0	0.5	53.6	53.6	0.0	71.4	69.0	3.4	73.6	70.7	3.9
12.	$M50F_{40}$	35.2	36.1	-2.6	50.2	51.3	-2.2	66.3	69.4	-4.7	68.3	71.3	-4.4

TABLE IV
ACTUAL AND PREDICTED COMPRESSIVE STRENGTH RESULTS AT VARIOUS AGES FOR VALIDATION OF LINEAR REGRESSION TECHNIQUE

Sr. No.	Mix	fck at 7 days (N/mm^2)		% error	fck at 28 days (N/mm^2)		% error	fck at 90 days (N/mm^2)		% error	fck at 365 days (N/mm^2)		% error
		Act.	Pred		Act.	Pred		Act.	Pred		Act.	Pred.	
1.	$M30F_{10}$	27.5	28.5	-3.5	38.7	40.2	-3.9	45.7	49.4	-8.1	46.5	50.4	-8.4
2.	$M30F_{40}$	22.5	23.7	-5.4	33.5	34.2	-2.1	46.2	49.9	-8.0	47.2	51.6	-9.3
3.	$M40F_{20}$	33.7	36.0	-6.9	47.6	47.6	0.0	61.6	60.1	2.4	63.7	61.8	3.0
4.	$M40F_{50}$	27.7	29.2	-5.4	40.8	41.4	-1.5	51.4	55.5	-7.9	51.8	56.3	-8.6
5.	$M50F_{10}$	41.2	44.8	-8.7	57.6	58.1	-0.9	66.2	68.8	-3.9	67.4	70.0	-3.9
6.	$M50F_{50}$	33.0	35.9	-8.8	47.0	48.9	-4.0	58.5	63.4	-8.3	60.3	65.2	-8.1

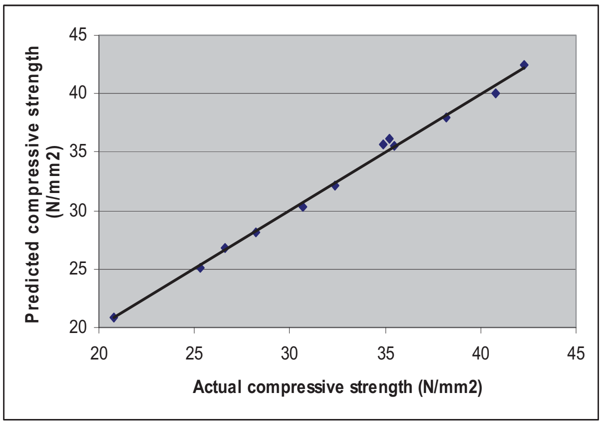

Fig. 1 Actual compressive strength versus predicted compressive strength at 7 days using linear regression model

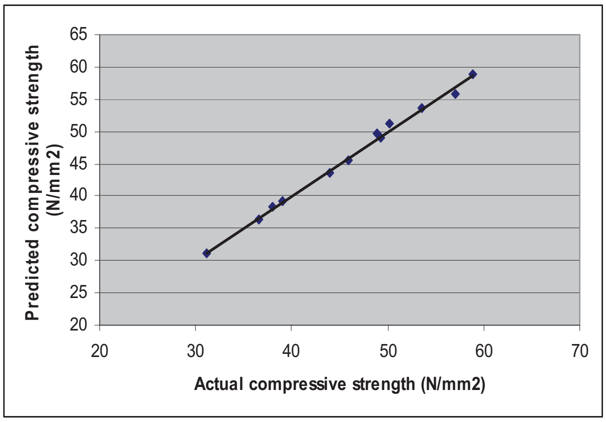

Fig. 2 Actual compressive strength versus predicted compressive strength at 28 days using linear regression model

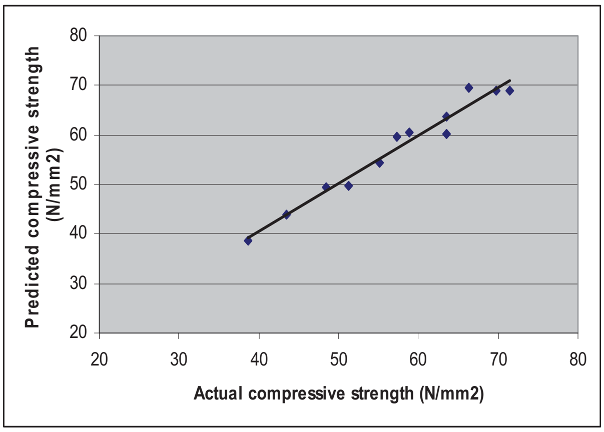

Fig. 3 Actual compressive strength versus predicted compressive strength at 90 days using linear regression model

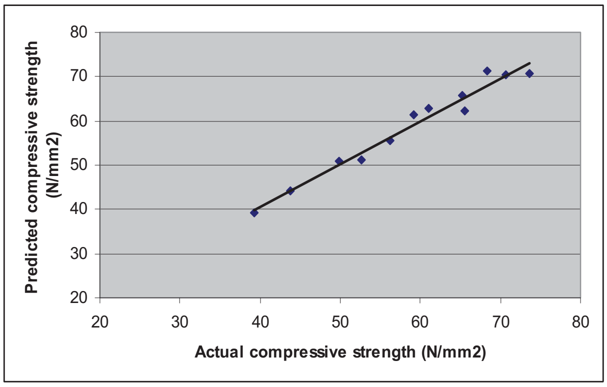

Fig. 4 Actual compressive strength versus predicted compressive strength at 365 days using linear regression model

TABLE V
SUMMARY OF COEFFICIENTS BY LINEAR REGRESSION MODELS FOR COMPRESSIVE STRENGTH OF FLY ASH MIXES

Strength	Age	Adjusted R Square	Standard Error
Compressive strength	7 days	0.9887	0.6901
	28 days	0.9902	0.8475
	90 days	0.9259	2.8152
	365 days	0.9306	2.8375

B. *Artificial Neural Network (ANN)*

In the artificial neural network modeling, the training of the model was carried out by the available 18 sets of experimental data. Mean absolute error from percentage error at various ages is calculated and given in Table VI.

TABLE VI
SUMMARY OF COEFFICIENTS BY ARTIFICIAL NEURAL NETWORK MODELS FOR COMPRESSIVE STRENGTH OF FLY ASH MIXES

Strength	Age	Correlation coefficient	Mean absolute error	Root mean square error
Compressive strength	7 days	0.9888	0.8021	0.9649
	28 days	0.9864	1.1313	1.3666
	90 days	0.9715	1.8285	2.3496
	365 days	0.9726	1.8323	2.4550

The comparison of results suggest that an artificial neural network model can more effectively be used to predict the cube compressive strength of HPC mixes as the correlation coefficients obtained by ANN are better than those obtained from linear regression especially for later ages of concrete.

C. *Leave-One-Out Validation (LOOV)*

Leave-one-out technique of modeling the test results is a modified form of ANN in which all the input data expect one case is used to build up the model through training whereas the validation of results is done on the left out case. This is repeated by the software with different sets of training data every time in all possible cases and the correlation coefficient is calculated and reported. In the leave-one-out modeling, the training of the model was carried out by the available 18 sets of experimental data. The correlation coefficients are observed to be even better than ANN model except for 90 days model.

TABLE VII
SUMMARY OF COEFFICIENTS BY LOOV TECHNIQUE FOR COMPRESSIVE STRENGTH OF FLY ASH MIXES

Strength	Age	Correlation coefficient	Mean absolute error	Root mean square error
Compressive strength	7 days	0.9950	0.5404	0.6294
	28 days	0.9941	0.6832	0.8810
	90 days	0.9625	1.4799	2.5219
	365 days	0.9846	1.1527	1.6953

VI. CONCLUSION

1. Due to better performance of fly ash mixes in respect of compressive strength, these fly ash mixes qualify as high performance concrete mixes.
2. Though fly ash up to 50% of cementitious material can be used in HPC mixes, 30% fly ash replacement to cement is found to be the most efficient.
3. The compressive strength at 90 days should be the governing criterion to evaluate the performance of fly ash based HPC mixes rather than 28 days strength.
4. The higher correlation coefficients for compressive strength by LOOV technique suggested that LOOV models can better be used for prediction of compressive strength of HPC mixes at various ages than linear regression or artificial neural network method.

REFERENCES

[1] Mehta, P. K. and Gjorv O. E., (1982), ‘Properties of Portland Cement Concrete containing Fly ash and Condensed Silica Fume’, Cement and Concrete Research Journal, Vol. 12, No. 5, pp.587-595.
[2] Bhanumathidas N. and Kalidas N., (2002), ‘Prevention is Better than Cure – Concrete Is No Exception’, Master Builder, 4(4), pp 1-7.
[3] Malhotra, V. M. (2003). “Concrete Technology for Sustainable Development”, Sustainable Development in Cement and Concrete Industries, Proceedings Two-Day International Seminar, Milan, Italy, pp 17-18.
[4] Provincs, S. and Provincs, J. S. (1996). “Novel aspects in Computerisation of Concrete Proportioning”, Concrete International, Vol. 18, No. 12, pp 54 – 58.
[5] Ganju, T. N. (1996). “Spread Sheeting Mix Designs”, Concrete International, Vol. 18, No.12, pp 35 – 38.
[6] Rao, B. K. and Kumar Vimal, (1996), ‘Fly Ash in High Strength Concrete’, Recent Advances in Civil Engineering, National Seminar, September 28, pp.115-121.
[7] Kumar B., Tike G. K. and Nanda P. K., (2007), ‘Evaluation of Properties of High Volume Fly Ash Concrete for Pavements’, Journal of Materials in Civil Engineering, Vol.19, No. 10, pp. 906-911.
[8] American Coal Ash Association, (1995), ‘Fly Ash Facts for Highway Engineers’, Federal Highway Administration, Report No. FHWA-SA-94-081, Washington, DC, December.
[9] Mullick, A. K., (2006), ‘High Performance Concrete for Bridges and Highway Pavements’, Proceedings of National Conference on Advances in Bridge Engineering, pp.51-63.
[10] Shetty M. S., (2002), ‘Concrete Technology- Theory and Practice’, S. Chand & co. Ltd., New Delhi.
[11] Neville A. M. and Brooks J. J., (2009), Concrete Technology, 8th edition, Pearson Education Ltd., Noida.
[12] IS: 8112:1989, ‘43 Grade Ordinary Portland Cement Specifications’, Bureau of Indian Standards, New Delhi.
[13] IS: 10262:2009, ‘Recommended Guidelines for Concrete Mix Design’ Bureau of Indian Standards, New Delhi.