Regression Models for the Prediction of Compressive Strength of Concrete with & without Fly ash

Palika Chopra
Lecturer and Ph. D Scholar,School of Mathematics and Computer Applications
Thapar University, Patiala-147004, INDIA

Dr. R. K. Sharma
Professor,School of Mathematics and Computer Applications
Thapar University,Patiala-147004, INDIA

Dr. Maneek Kumar
Professor and Head,Department of Civil Engineering
Thapar University, Patiala-147004, INDIA

Abstract- A mathematical analysis using statistical techniques for the prediction of compressive strength of concrete was performed for the concrete data obtained from laboratory experimental work done in this study. The variables used in the prediction models were the mix proportioning elements. The multiple non-linear regression models yielded excellent correlation coefficients for the prediction of compressive strength at different curing ages (28,56 & 91 days) as well as for other variations which include use of fly as a partial replacement for cement and variation in the zone of coarse aggregates.

Keywords- Mathematical model, Concrete, Compressive Strength, Multiple Regression, Statistical Analysis.

I. INTRODUCTION

Concrete is a wonder construction material which has changed the way construction is being carried out during the last century. Having the capability to be formed into any shape and size, it has transformed itself leading to development of many appealing structures. From a simple material easily formed by just adding coarse aggregates, sand, cement and water in desired proportions, it caught the fascination of researchers many decades ago. By playing around with its basic ingredients researchers have been able to develop concretes which not only have very high compressive strength, but have good durability properties as well. The results of compressive strengths vary not only for different concrete mixtures, but for the same mixture as well, which has been attributed to various factors (ACI214R-02).

Statistical procedures provide tools of considerable value when evaluating the results of strength tests. Information derived from such procedures is also valuable in refining design criteria and specifications. Statistical methods also have the added attraction that once fitted they can be used to perform predictions quickly and simpler to implement in software. Prediction of concrete strength, therefore, has been an active area of research and a considerable number of studies have been carried out. Many attempts have been made to obtain a suitable mathematical model which is capable of predicting strength of concrete at various ages with acceptable high accuracy.

The aim of the present study is to predict compressive strength of concrete for a given sample, as accurately as possible. For this purpose, multiple regression analysis is used for predicting the compressive strength of concrete using four variables, namely, water-cementations ratio, fine aggregate-cementitious ratio, coarse aggregate-cementitious ratio and cementitious content. Regression models have been developed for partial replacement of cement with fly ash (0 and 15 percent), zones of aggregates(A,B and C) and curing ages(28,56 and 91 days).

II. EXPERIMENTAL DATASET

Data for the present work has been taken from the experiments conducted by Kumar (2003). For generating a reliable data bank on concrete compressive strength, he has considered seven parameters,namely, water-cementitious material ratio, cementitious content,water content,percentage partial replacement of cement by fly ash, workability,aggregate zones and curing ages in his experiments. The experiments were performed in controlled laboratory conditions. Table 1 shows the variations in the values of parameters as taken by Kumar (2003).As can be observed from the Table 1, coarse aggregates are divided into three zones. A set of 15 cubes for each of mixes so proportioned were cast and tested after 28,56 and 91 days of curing. Thus, an extensive data bank for analyzing compressive strength of concrete has been generated and the same has been used in the present work.

Table 1 Range of values of various parameters

Water-cementitious ratio	0.42 – 0.55
Cementitious content	350 – 475 @ 25 kg/m^3
Water content	180-230 @ 10 kg/m^3
Percentage replacement of cement by fly ash	0 and 15 per cent
Workability	Medium and high
Coarse Aggregates, Zones	A, B and C
Curing ages, days	28, 56, 91

The physical properties of the materials used in the study are shown in Table 3. Ordinary Portland Cement (OPC) of 43 grade(*as per IS:8112-1989*) was used. It has a specific gravity of 3.12 and attained a compressive strength of 46.50MPa after 28 days of curing. The fine aggregates used had a specific gravity of 2.54 and belonged to zone – II of the grading zones as per IS:383-1970. Three types of coarse aggregates were used in varying proportions, splitting them into three zones as shown in Table 2. The 20mm coarse aggregates had a specific gravity of 2.61, the 10mm aggregates had a specific gravity of 2.63 and 4.75 aggregates had a specific gravity of 2.58. Only fly ash was used, as a mineral admixture, as a partial replacement of cement to study the effect on compressive strength of concrete. The physical properties of fly ash used are shown in Table 4.

As the aim of the study is studying the effect of mix proportions on the compressive strength of concrete, different mix proportions were used. The details of the mix proportions using different zones of coarse aggregates are shown in Tables 5 to 10. The compressive strength test was performed and evaluated in accordance with IS:519. Specimens were immersed in water until the day of testing at 28, 56 and 91 days.

Table 2: Zones of Aggregates

Zone	**Percentage passing 20mm sieve and retained on 10mm sieve, CA-I**	**Percentage passing 10mm sieve and retained on 4.75mm sieve, CA-II**	**Percentage passing 4.75mm sieve and retained on 2.36 mm sieve, CA-III**	**Fineness modulus**
A	67	33	-	6.67
B	50	50	-	6.50
C	-	50	50	5.50

Table 3: Physical Properties of Materials

Materials	**Properties**
Ordinary Portland Cement (OPC)	Grade: 43, as per IS:8112-1989

	Specific Gravity: 3.12 7 days compressive strength: 35.50 MPa 28 days compressive strength: 46.50 MPa
Fine aggregates (FA)	Zone: III Fineness modulus: 2.09 Specific Gravity: 2.54
Coarse Aggregates – I (CA-I)	Specific Gravity: 2.61
Coarse Aggregates – I (CA-II)	Specific Gravity: 2.63
Coarse Aggregates – I (CA-III)	Specific Gravity: 2.58

Table 4 Physical properties of fly ash

S. No.	Property	Observed values
1.	Specific gravity	1.99
2.	Lime reactivity – average compressive strength at Blaine 3389 cm^2/gm	47.87 kg/cm^2
3.	Colour	Grey (blackish)
4.	Fineness modulus	0.68

III. MODELING OF DATASET AND METHOD

In this study, the mean value of compressive strength of concrete at 28,56 and 91 days are predicted and the output of one is used as one of the input variable for the prediction of another like the predicted compressive strength of 28 days(output of 28 days) is entered as one of the input variable to predict the compressive strength of 56 days and the output of 28 days and 56 days are accommodated as input variables to predict the compressive strength of 91 days. Other than this, 91 days compressive strength is also predicted using only strength of 28 days and also using only strength of 56 days. The final form of the regression equations for different cases is provided as below:

$$f_{c28} = A_0 (W/CM)^{A_1} (FA/CM)^{A_2} (CA/CM)^{A_3} \quad \text{.........(1)}$$

$$f_{c56} = A_0 (W/CM)^{A_1} (FA/CM)^{A_2} (CA/CM)^{A_3} (f_{c28}/CM)^{A_4} \quad \text{......... (2)}$$

$$f_{c91} = A_0 (W/CM)^{A_1} (FA/CM)^{A_2} (CA/CM)^{A_3} (f_{c28}/CM)^{A_4} (f_{c56}/CM)^{A_5} \quad \text{......... (3)}$$

$$f_{c91,28} = A_0 (W/CM)^{A_1} (FA/CM)^{A_2} (CA/CM)^{A_3} (f_{c28}/CM)^{A_4} \quad \text{..........(4)}$$

$$f_{c91,56} = A_0 (W/CM)^{A_1} (FA/CM)^{A_2} (CA/CM)^{A_3} (f_{c56}/CM)^{A_4} \quad \text{..........(5)}$$

where, f_{c28} is the compressive strength of concrete after 28 days of curing, f_{c56} is the compressive strength of concrete after 56 days of curing, f_{c91} is the compressive strength of concrete after 91 days of curing. In the equations from (1) to (5), in predicting the strength for higher ages, the strength of concrete at lower ages has also been considered in the model developed. The regression coefficients so obtained for each of the cases is provided in Tables 5 to 10.

Table5. Regression coefficients of multiple regression models predicting compressive strength of Concrete with Zone A of aggregates without any replacement of cement with fly ash

Without replacement of cement by fly ash					
	f_{c28}	f_{c56}	f_{c91}	$f_{c91,28}$	$f_{c91,56}$
A_0	3.1688	15.0896	26.3395	14.1329	30.8196
A_1	-3.1459	-2.6449	-1.5201	-1.8367	-1.5043
A_2	0.7646	0.8674	0.2932	0.3850	0.3429
A_3	0.1286	0.0058	-0.1769	-0.0292	-0.1599
A_4		0.4406	-0.4689	0.0481	
A_5			0.6463		0.2355
Correlation Coefficient	0.9416	0.9484	0.9711	0.9534	0.9609

Table6. Regression coefficients of multiple regression models predicting compressive strength of Concrete with Zone A of aggregates with 15% replacement of cement with fly ash

With 15% replacement of cement by fly ash					
	f_{c28}	f_{c56}	f_{c91}	$f_{c91,28}$	$f_{c91,56}$
A_0	8.4570	1.8925	17.8367	18.4700	18.7979
A_1	-2.1654	-2.4073	-1.0491	-1.0127	-1.0562
A_2	0.2990	0.0837	-0.0544	-0.0716	-0.0355
A_3	-0.2019	0.2156	-0.0703	-0.1155	-0.0669
A_4		-0.4584	-0.0341	-0.1510	
A_5			-0.1067		-0.1140
Correlation Coefficient	0.9670	0.9289	0.9842	0.9805	0.9841

Table7. Regression coefficients of multiple regression models predicting compressive strength of Concrete with Zone B of aggregates without any replacement of cement with fly ash

Without replacement of cement by fly ash					
	f_{c28}	f_{c56}	f_{c91}	$f_{c91,28}$	$f_{c91,56}$
A_0	4.9848	9.4214	2.9227	2.9093	3.7531
A_1	-2.6623	-2.0157	-2.6871	-2.6907	-2.5446
A_2	0.5947	0.4259	0.5915	0.5923	0.5726
A_3	0.1152	0.1029	0.3159	0.3161	0.2954
A_4		-0.0037	-0.2122	-0.2176	
A_5			-0.0050		-0.1716
Correlation Coefficient	0.9756	0.9333	0.9748	0.9748	0.9743

Table8. Regression coefficients of multiple regression models predicting compressive strength of Concrete with Zone B of aggregates with 15% replacement of cement with fly ash

With 15% replacement of cement by fly ash					
	f_{c28}	f_{c56}	f_{c91}	$f_{c91,28}$	$f_{c91,56}$
A_0	10.4992	3.5841	20.3021	23.0852	18.0747
A_1	-1.8512	-2.8598	-1.1693	-0.9357	-1.0801
A_2	0.1232	0.6016	0.0316	-0.1184	-0.0796
A_3	-0.1086	0.3275	-0.0189	-0.1252	-0.0667
A_4		0.0263	0.2148	-0.0935	
A_5			-0.2478		-0.1308
Correlation Coefficient	0.9885	0.9471	0.9946	0.9874	0.9922

Table9. Regression coefficients of multiple regression models predicting compressive strength of Concrete with Zone C of aggregates without any replacement of cement with fly ash

Without replacement of cement by fly ash					
	f_{c28}	f_{c56}	f_{c91}	$f_{c91,28}$	$f_{c91,56}$
A_0	0.2970	4.152	1.5065	2.4590	2.1313
A_1	-6.0311	-3.4970	-4.7240	-4.1082	-4.3820
A_2	2.3580	1.3572	1.8668	1.5940	1.7299
A_3	0.1728	-0.0013	0.1001	0.0914	0.0786
A_4		0.1490	-0.156	0.1438	
A_5			0.3275		0.1874
Correlation Coefficient	0.9784	0.9581	0.9893	0.9876	0.9889

Table10. Regression coefficients of multiple regression models predicting compressive strength of Concrete with Zone C of aggregates with 15% replacement of cement with fly ash

With 15% replacement of cement by fly ash					
	f_{c28}	f_{c56}	f_{c91}	$f_{c91,28}$	$f_{c91,56}$
A_0	154.1932	6.6923	19.5303	23.1378	17.4536
A_1	1.3580	-1.8834	-0.9190	-0.7240	-1.1048
A_2	-1.4933	-0.0180	-0.2415	-0.3368	-1.1340
A_3	-0.1184	0.0518	0.0397	0.0328	0.0375
A_4		-0.1823	-0.0590	-0.1117	
A_5			-0.0559		-0.0986
Correlation Coefficient	0.9945	0.9636	0.9780	0.9579	0.9680

IV.CONCLUSION

Table 5, Table 7, and Table 9 have the regression coefficients of multiple regression models predicting compressive strength of concrete with zone A, zone B and zone C of aggregates respectively without any replacement of cement with fly ash. Table 6, Table 8, and Table 10 have the regression coefficients of multiple regression models predicting compressive strength of concrete with zone A, zone B and zone C of aggregates respectively with 15% replacement of cement with fly ash. In Table 5 and Table 6 ,during the curing days, f_{c28} , $f_{c91,}$ $f_{c91,28}$ and $f_{c91,56}$

correlation coefficients of with fly ash are 0.9670, 0.9842, 0.9805 and 0.9841 respectively, are better than without fly ash. In f_{c56} only correlation coefficient is 0.9289 , when replaced with fly ash. In Table 7 and Table 8 ,during the curing days, f_{c28} , f_{c91}, $f_{c91,28}$ and $f_{c91,56}$ correlation coefficients of with fly ash are 0.9885,0.9946,0.9874 and0.9922. respectively, are better than without fly ash. In the curing day of f_{c56}, when replaced with fly ash the correlation coefficient is 0.9471, but it is still better than without replacement of fly ash. In Table 9 and Table 10 is with the results of zone C. Zone C aggregates have better correlation coefficients when it is without replacement of fly ash. During the curing days of f_{c28} , f_{c56}, f_{c91}, $f_{c91,28}$ and $f_{c91,56}$; correlation coefficients of without fly ash are 0.9784,0.9581,0.9893,0.9876and 0.9889 respectively and correlation coefficients with fly ash are 0.9945,0.9636,0.9780,0.9579and 0.9680 respectively. Therefore, it has been seen that zone A and zone B aggregates are giving better correlation coefficients, when replaced cement 15% with fly ash; and zone C aggregates are working better without fly ash.

REFERENCES

[1] Akkurt, S., G. Tayfur and S. Can, 2004. Fuzzy logic model for the prediction of cement compressive strength. Cement Concrete Res., 34: 1429-1433.

[2] Hwang, K., T. Noguchi and F. Tomosawa, 2004. Prediction model of compressive strength development of fly-ash concrete. Cement Concrete Res., 34: 2269-2276.

[3] Hwang, K., T. Noguchi and F. Tomosawa, 2004. Prediction model of compressive strength development of fly-ash concrete. Cement Concrete Res., 34: 2269-2276.

[4] Kheder, G.F., Al-Gabban, A.M. and Suhad, M.A., 2003. "Mathematical model for the prediction of cement compressive strength at the ages of 7 and 28 days within 24 hours".Materials and Structure. Vol. 36, pp. 693-701.

[5] Kumar, M., 2002. 'Reliability Based Design Of Structural Elements' Thesis submitted for degree of Doctor of Philosophy, T.I.E.T Patiala

[6] Mehta, P.K. and P.J.M. Monteiro, 2006. Concrete, Microstructure, Properties and Materials. 3rd Edn., McGraw-Hill, USA.

[7] Namyong, J.,Sangchun, Y. and HongBum, C., 2004.Prediction of compressive strength of concrete based mixture proportions. Asian Architect Build.Eng.,3: 9-16.

[8] Popovics, S. and Ujhelyi, J.,2008. Contribution to the concrete strength versus water-cement ratio relationship. J.Mater.Civil Eng.,20:459-463.

[9] Popovics, S., 1990. Analysis of concrete strength versus water-cement ratio relationship. ACI Mater. J., 87: 517-529.

[10] Popovics,S. and Popovics, J.S., " Novel Aspects in computerization of Concrete Proportioning ", Concrete International,December 1996,pp.54-58.