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Prediction of compressive strength of concrete using multiple regression model

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Abstract. In construction industry, strength is a primary criterion in selecting a concrete for a particular application. The concrete used for construction gains strength over a long period of time after pouring the concrete. The characteristic strength of concrete is defined as the compressive strength of a sample that has been aged for 28 days. Neither waiting for 28 days for such a test would serve the rapidity of construction, nor would neglecting it serve the quality control process on concrete in large construction sites. Therefore, rapid and reliable prediction of the strength of concrete would be of great significance. On this backdrop, the method is proposed to establish a predictive relationship between properties and proportions of ingredients of concrete, compaction factor, weight of concrete cubes and strength of concrete whereby the strength of concrete can be predicted at early age. Multiple regression analysis was carried out for predicting the compressive strength of concrete containing Portland Pozolana cement using statistical analysis for the concrete data obtained from the experimental work done in this study. The multiple linear regression models yielded fairly good correlation coefficient for the prediction of compressive strength for 7, 28 and 40 days curing. The results indicate that the proposed regression models are effectively capable of evaluating the compressive strength of the concrete containing Portaland Pozolana Cement. The derived formulas are very simple, straightforward and provide an effective analysis tool accessible to practicing engineers.

Keywords: concrete; compressive strength; admixture; regression analysis; predicted strength; predictive tools

1. Introduction

The concrete is a versatile construction material owing to the benefits it provides in terms of strength, durability, availability, adoptability and economy. It is a heterogeneous mix of cement, water and aggregates. Great efforts have been made to improve the quality of concrete by various means in order to raise and maximize its level of performance. Using same ingredients with little adjustments in the micro- structure (and probably adding specific materials), it is possible to obtain some of the special types of concrete such as high performance concrete (HPC), self compacting concrete (SCC) and roller compacted concrete, high volume fly ash concrete (HVFAC), etc. The

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development of these concretes has brought forth the need for admixtures, both- mineral and chemical, to improve the performance of concrete.

The admixtures may be added in concrete in order to enhance some of its properties desired specially. Very fine materials such as fly ash, a product of coal-burning power plant, render the fresh concrete more plastic. Other admixtures including various fats, sugars and minerals are used to increase or decrease the rate of hardening of concrete or to give it colour and increase durability and resistance to weathering. Contrary to the ordinary concrete, the concrete containing different admixtures has extra- ordinary rheological properties, especially its super workability and flow ability that make it superior as compared to other concrete mixes. There have been many studies (Thorpe and Corden 1983, Murata 1984, Kumar *et al*. 1989, Khayat 1995, Khayat and Guizani 1997, Zang *et al*. 1997, Khayat 1999, Mustafa *et al*. 2005, Yamada *et al*. 2006, Perumal *et al.* 2007, Perumal and Elangovan 2007, Laskar and Talukdar 2008, Plank *et al.* 2009) which reported the effect of different types of admixtures and in few cases, that of the inclusion of fibers on rheological behaviour as well as strength properties of the various types of the concrete.

In construction industry, strength is a primary criterion in selecting a concrete for a particular application. Concrete used for construction gains strength over a long period of time after pouring. The characteristic strength of concrete is defined as the compressive strength of a sample that has been aged for 28 days.

Neither waiting 28 days from such a test would serve the rapidity of construction nor would neglecting it serve the quality control process on concrete in large construction sites. Therefore, rapid and reliable prediction of the strength of concrete would be of great significance. For example, it provides a chance to do the necessary adjustment on the mix proportion used to avoid the situation where concrete does not reach the required design strength or by avoiding concrete that is unnecessarily strong and also for more economic use of raw materials and fewer construction failures, hence reducing construction cost.

Prediction of the compressive strength of concrete, 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.

2. Methods of prediction of strength of concrete

A number of improved prediction techniques have been proposed by including empirical or computational modeling, statistical techniques and artificial intelligence approach.

Many attempts have been made for modelling the aspect of the strength of concrete through the use of the computational techniques such as finite element analysis. These techniques are often based on the complex thermodynamic equations that underpin the aging of concrete and require non-proprietary mathematical tools.

A number of research efforts have concentrated on using multivariable regression models to improve the accuracy of the predictions. Statistical models have the attraction that once fitted, they can be used to perform predictions much more quickly than other modelling techniques and are correspondingly simpler to implement in software. Apart from its speed, statistical modelling has the advantage over other techniques that are mathematically rigorous and can be used to define confidence interval for the predictions. This is especially true when statistical modelling is compared with the artificial intelligence based techniques. Statistical analysis can also provide insight into the key factors influencing 28 days' compressive strength through correlation analysis.

Some of the studies which used regression approach include those by Kheder *et al.* (2003), Hwang *et al.* (2004), Jee *et al.* (2004), Rajmane *et al.* (2007), Popovics and Ujhelyi (2008), Zain and Abd (2009).

As strengthening of the concrete is a complex non-linear process dependent on many variables, it is a problem well suited to the artificial intelligence concept known as Artificial Neural Network (ANN). Most of the research confined to the prediction of compressive strength recognizes that neural nets are appropriate for the problem.

In last few decades, Artificial Neural Networks (ANN) technology, a sub- field of the artificial intelligence have been used in evaluating and predicting different rheological and strength parameters of various types of concretes (Nagesha *et al*. 2003, Jain *et al*. 2003, Bai *et al.* 2003, Oztas *et al.* 2006, Topcu and Sarydemir 2007, Prasada *et al*. 2009, Al- Salloum *et al.* 2012).The most important property of ANN in the problems of concrete technology is its capability of learning directly from the examples.

Few studies (Kewalramani *et al.* 2006, Yeh 2007) used either approach for modelling the strength and flow behaviour of concrete. Sonebi and Civic (2009) explored the potential use of the neurofuzzy (NF) approach, one of the soft computing tools, for modeling fresh and hardened properties of self consolidating concrete (SCC) containing pulverized fuel ash (PFA). Recently, Mousavi *et al*. (2010) reported modeling of compressive strength of HPC mixes using a combined algorithm of genetic programming and orthogonal least squares

3. Scope of the present work

Based on the above review of literature, the present work was aimed at establishing a predictive relationship which could be complementary to the existing workability tests routinely carried out during concreting. It purports to recognize mathematically the heterogeneous nature of concrete using the properties of ingredients and the wet concrete. Predictive approach based on regression analysis is attempted.

The data required for this was generated in the laboratory. In the trial mixes, Ordinary Portland Cement was used and plasticizer was added for the effect of workability. Polypropylene fibers were added. Fly ash was also used in the concrete mix. The formulae using three variables such as water cement ratio, cement contents and compaction factor; and six variables which included cement contents, fine aggregates, coarse aggregates, water cement ratio, compaction factor and weight of the cubes were proposed to be developed to predict the strength after curing for 7, 28 and 40 days.

4. Experimental programme

4.1 Materials

The materials used in the present investigation include cement, sand, aggregates, water and admixtures. The ACC Portland Pozzolana Cement (fly ash based) confirming to the requirements as stipulated in IS: 8112-1976 was used. The creek sand – Kolshet, Ghodbandar was brought into use. As regards the coarse aggregates Metal I, Metal II was used from Nerul (New Mumbai) quarry. The potable water was added for obtaining concrete mix. The physical properties of the constituents of concrete obtained through various laboratory tests are summarized in Table 1.

Table 1 Properties of materials

Property	Value
Cement	
Consistancy	30%
Sp. Gravity	2.91
Fineness	3.0%.
Soundness	3 mm
Compressive Strength	(N/mm^2)
• 7 Days' Curing	31.69
• 28 Days' Curing	51.81
Sand	
Sp. Gravity	2.6.
Fineness Modulus (F.M.)	3.12.
Coarse Aggregates	
Sp. Gravity	2.86.
Fineness Modulus (F.M.)	
• Metal I	3.82
• Metal II	3.38

The admixture in the form of Plasticizer (trade name- Supercon® - 100) was also used in the present investigation. Supercon® - 100 is a pure melamine based superplasticizer which when added to concrete / mortar / plaster modifies the properties of concrete such as workability, strength, permeability, cohesion etc. The plasticizer, Supercon® - 100, renders the mix very cohesive. It is capable of reducing the permeability by upto 94%. It enhances resistance against thermal stresses. It increases workability and reduces w/c ratio.

Though its application is normally found in case of generalized reinforced cement concrete construction, it is highly recommended in the construction of water tanks, basements, foundations, floorings, bridge decks, etc. The technical specification of Supercon® - 100 are given in Table 2. The Supercon® - 100 is added to concrete / mortar / plaster between 0.5% to 2% by weight of cement, mix after stirring in little water and then the solution is added after adding other ingredients in the mixer. Supercon® - 100, when added in fresh concrete / mortar / plaster disperse cement uniformly in the mix. Due to deflocculation action on cement agglomerates the entrapped water is released and would be available for workability.

4.2 Testing of specimens

The experimental programme involved tests on 112 concrete cubical specimens of size 150×150×150mm.This is further divided into two groups. For first group, 8 trials were carried out and in each trial, 7 cubes were cast. Therefore, 56 concrete cubes were cast without adding plasticizer and in second group same procedure is followed by adding plasticizer and replacing cement by fly ash. Cement, sand, coarse aggregate were thoroughly mixed in dry state so as to obtain uniform color. The required percentages of admixture are added to the water calculated for the particular mix. This water is added to the dry mix with a view to obtain uniform mixture. The compaction factor test was carried out and the respective values were recorded for all mixes. The moulds with standard dimensions i.e., 150×150×150mm were poured with concrete in 3 layers by poking with tamping rod and vibrated by the table vibrator. The vibrator was used for 30 second and it was maintained constant for all specimens.

The samples were air dried for a period of 24 hours and then they were weighed to find out their weight before curing. Thereafter they were immersed in water. After curing for 7, 28 and 40 days', they were weighed to find out their weight in saturated surface dry condition (SSD). The cubes were tested for compressive strength on the compression testing machine and results were recorded.

Table 2 Technical specifications for plasticizer

Base	Sulphonated Melamine Formaldehyde resin
Dosage	0.5% upto 2% as per Workability requirements
Colour	Clear to Little Hazy
Water	Between 15% to 20%
Reduction:	(Conforms to IS 9103 – 1999
	ASTM – C – 494 Type F)
pH	> 8.0
Stability	12 months in closes container
Packing	5 Kgs, 30 Kgs, 230 Kgs

5. Methodology of investigation

Multiple Regression Analysis technique was adopted to develop equations and predict the strength of concrete cube samples. The data generated in the laboratory was apportioned into two parts. One part was used for the analysis and remaining one was used for validation.

The data of 20 trials of mixes was used for the analysis. From the data of 10 trials without plasticizers 3 equations were developed and the data of other 10 trials done by adding plasticizers, fibres and fly ash was used for the validation of results and vice-versa. 'Multiple Regression and Correlation Analysis' was applied to derive the equations.

In Multiple Regression Analysis, various formulae (Refer Appendix) were developed, by varying the input parameters to predict the strength of concrete cube corresponding to 7, 28 and 40 days' curing. Selection of equations with different inputs (Appendix), which would help the user to predict the strength of concrete cube with available data / input parameters, are based on the results of analysis and the validation of formula.

6. Results and discussion

6.1 Prediction of the strength using regression model

The formulae, derived by regression analysis were applied on 20 trial mixes, to predict the strength of concrete cubes after 7, 28 and 40 days' curing. The compressive strength of the concrete observed experimentally and that predicted using the regression models are shown in Tables 5 -7. The figures in bracket mentioned in each table indicate the number of trials.

From Table 5(i) in which the actual and predicted strength of the concrete without plasticizers are reported, it is observed that the either formulae give fairly satisfactory results. However, the formula with three variables is found to predict the 7 days' strength fairly better as compared to the formula containing six variables. The strength predicted by the regression model using six variables is found to underestimate the actual strength for the seven trials by 8.81% on an average. The corresponding underestimation in respect of the model using three variables is 8.42% for seven trials on an average. However, for the next three trials, the predicted strength is found to overestimate the actual strength by 6% and 6.13% on an average in respect of the model with six variables and three variables, respectively.

Table 5(i) Summary of actual and predicted strength in MPa for 7 days without plasticizers

Trial	Actual	Predicted with six variables	Percentage Difference	Predicted with 3 variables	Percentage Difference
1	32.59	29.25	-10.24	29.64	9.05
2	30.67	26.55	-13.43	26.05	15.06
3	20.59	20.27	-1.55	20.49	0.48
4	25.19	21.43	-14.92	21.26	15.60
5	18.37	16.97	-7.62	17.41	5.23
6	19.56	19.24	-1.63	19.09	2.40
7	15.71	13.78	-12.28	13.96	11.13
8	14.74	15.39	4.41	15.61	5.90
9	13.04	13.26	1.69	12.59	3.45
10	11.27	12.61	11.88	12.29	9.05
		Av: -8.81% (07) Av: + 6% (03)		Av: -8.42% (07) Av: + 6.13% (03)	
		Coefficient of correlation			
		0.99		0.98	

Table 5 (ii) Summary of actual and predicted strength in MPa for 7 days with plasticizers

Trial	Actual	Predicted with six variables	Percentage Difference	Predicted with 3 variables	Percentage Difference
1	30.23	33.25	10	33.21	9.85
2	26.23	29.83	13.72	29.54	12.62
3	20.59	22.64	9.95	23.61	14.66
4	17.34	21.66	25	20.14	16.15
5	17.19	16.88	-1.80	16.97	-1.28
6	17.33	18.18	4.90	17.51	1.04
7	15.85	16.70	5.36	15.80	-0.32
8	14.23	12.48	-12.30	15.33	7.73
9	12.45	11.93	-4.17	13.07	4.98
10	13.64	12.78	-6.30	12.52	-8.21
		Av: -11.49 % (04) Av: + 6.14 % (06)		Av: -9.58 % (03) Av: + 3.27 % (07)	
		Coefficient of correlation			
		0.99		0.99	

Further, when the strength of the concrete with plasticizers observed experimentally and predicted using the mathematical model developed based upon the properties of the ingredients as reported in Table 5(ii) are compared, it is seen that the although all the formulae give satisfactory results, the formula with three variables is found to predict the 7 days' strength more fairly. In respect of the strength predicted using six variables, the percentage underestimation and overestimation of the actual strength is 11.49 and 6.14 on an average for four and six trials, respectively. The corresponding values in respect of the formula with three variables are 9.58 and 3.27 on an average for three and seven trials, respectively.

From Table 6(i), it is observed that the all the formulae give fairly satisfactory results in respect of the actual and predicted strength for 28 days' curing. However, the formulae with three variables and six variables are found to predict the 28 days' strength fairly better as compared to the formula containing seven variables. In respect of seven trials, the predicted strength using six variables is found to underestimate the actual strength on an average by 7.62%. For next three trials, the average overestimation of the actual strength is found to be 3.28%. The predicted strength is observed to underestimate the actual strength by 7.42% for the seven trials whereas for remaining three trials, it is found to overestimate the actual strength by 5.44% in respect of the formula using three variables. For the strength predicted using seven variables, the actual strength is found to be underestimated on an average by 8% in case of seven trials while in case of the remaining trials, the actual strength is found to be overestimated by 9.92%.

The values of the actual compressive strength observed in respect of 28 days' curing and with plasticizers along with that predicted using the regression model developed in the present study are mentioned in Table 6(ii).

The percentage variation between the actual strength and the predicted one using three, six and seven variables is found to be in the range of 5.41- 9.82 which indicates the satisfactory agreement in the results. However, the regression model with six variables is found to predict the 28 days' compressive strength slightly better than the model using six, three and seven variables in respect of the concrete with plasticizers.

Table 6(i) Summary of actual and predicted strength in MPa for 28 days without plasticizers

Trial	Actual	Predicted with six variables	Percentage difference	Predicted with three variables	Percentage difference	Predicted with seven variables	Percentage difference
1	46.97	47.53	1.20	45.79	-2.51	54.05	15.07
2	43.41	39.06	-10.02	40.70	-6.24	43.31	-0.23
3	30.67	32.69	6.58	33.00	7.60	32.80	6.94
4	37.48	33.69	-10.11	33.27	-11.23	40.12	7.04
5	29.19	28.89	-1.03	27.86	-4.56	32.29	10.62
6	29.04	29.64	2.07	29.44	1.38	28.92	-0.41
7	26.82	22.76	-15.14	22.47	-16.22	25.55	-4.74
8	22.37	22.19	-0.80	24.01	7.33	20.14	-9.97
9	21.34	19.36	9.28	19.63	-8.01	19.18	-10.12
10	19.41	18.06	-6.96	18.80	-3.14	15.02	-22.62
		Av: -7.62 % (7)		Av: -7.42 % (7)		Av: -8.01 % (6)	
		Av: + 3.28 % (3)		Av: + 5.436 % (3)		Av: + 9.92 % (4)	
				Coefficient of correlation			
		0.98		0.97		1	

In case of four trials, the predicted strength using six variables is found to underestimate the actual strength by an average 5.57% and for the remaining trials, overestimate by 7.68% on an average. The predicted strength using three variables is found to underestimate the actual strength by 6.53% on an average for three trials and overestimate by 5.41% for the remaining seven trials. The strength predicted by the regression model with seven variables underestimates the actual strength by 9.82% on an average for the seven trials and for the remaining trials, overestimates the actual strength by 5.58%.

When the values of the actual strength of the concrete corresponding to 40 days' curing and the one predicted using three, six and seven variables without plasticizers are compared, the percentage variation is found in the range of 3.035-10.47. However, the predicted strength with the model using seven variables underestimates the actual strength on an average by 7.52% in case of six trials and overestimate by 3.84% in case of four trials. Further, the model with three variables is found to under-estimate the actual strength by 10.40% on an average in case of six trials whereas in remaining four trials, it is found to overestimate the actual strength by 3.04%. The strength predicted by the model using six variables is found to underestimate the actual strength by average value of 10.47% in respect of five trials whereas overestimate by average value of 4.05% in case of four trials. For one trial, the predicted strength matches totally with the actual one.

Along similar lines, when the values of the strengths are compared in the context of addition of the plasticizers, the percentage variation is observed in the range of 2.14- 12.47. The under-estimation of the actual strength is found to be 4.67% on an average in case of seven trials whereas overestimation, 2.14% on an average for the three trials. Further, the predicted strength using regression model involving three variables is found to underestimate the actual strength on an average by 6.41% in case of two trials and overestimates it by average value of 10.46% in eight trials. The predicted strength using six variables is found to underestimate the actual strength by the average value of 4.9% for two trials and overestimate by the average value of 12.47% for the eight trials.

Table 6(ii) Summary of actual strength and predicted strength in MPa for 28 days with plasticizers

Trial	Actual	Predicted with six variables	Percentage difference	Predicted with 3 variables	Percentage difference	Predicted with 7 variables	Percentage difference
1	44.89	46.46	3.5	46.83	4.32	41.28	-8.04
2	42.67	42.42	-0.59	42.22	1.05	37.98	-10.99
3	34.23	34.79	1.64	35.52	3.77	30.68	-10.37
4	28.89	33.12	14.64	31.24	8.14	27.22	-5.78
5	27.11	26.32	-2.91	27.36	0.92	27.03	-0.30
6	26.22	28.06	7.07	27.36	4.35	27.60	5.26
7	24.00	27.03	12.63	25.28	5.33	25.64	6.83
8	21.78	23.23	6.66	24.18	11.02	22.79	4.64
9	20.00	19.36	-3.20	19.07	-4.65	19.178	-4.11
10	21.19	17.89	-15.57	18.245	-13.90	15.02	-29.17
		Av.: -5.57% (4)		Av.: -6.54 % (3)		Av.: -9.82 % (7)	
		Av.:+ 7.68% (6)		Av.:+ 5.41 % (7)		Av.:+ 5.58 % (3)	
		Coefficient of correlation					
		0.99		0.99		0.99	

In respect of the 40 days' curing, the regression model using seven variables is found to predict the strength fairly better in respect of the concrete with and without plasticizer. The model using three variables fairly predicts the strength as compared to the model involving six variables. However, the more close variation is observed in the results obtained in respect of the concrete prepared with plasticizers.

The coefficient of correlation being in the range of 0.97-1 in all the cases seen above indicates that there exists a very good agreement in the results obtained experimentally and predicted using regression equation. When the percentage of variation between the actual and predicted strength of the concrete corresponding to different curing periods is considered, agreement between either two strength parameters is found to be much better for the data corresponding to 28 days' curing, followed by that in respect of the data corresponding to 7 days curing.

Table 7(i) Summary of actual and predicted strength in MPa for 40 days without plasticizers

Trial	Actual	Predicted with 6 variables	Percentage difference	Predicted with 3 variables	Percentage difference	Predicted with 7 variables	Percentage difference
1	53.34	47.07	-11.75	47.92	-10.16	48.00	-10.01
2	51.56	41.98	-18.58	42.16	-18.23	43.96	-14.74
3	34.67	34.94	0.78	34.63	-0.12	35.15	1.38
4	40.00	35.11	-4.23	36.35	9.13	36.56	-8.60
5	32.00	30.16	-5.75	30.44	-4.88	30.57	-4.47
6	30.67	32.47	5.87	32.43	5.74	32.27	5.22
7	30.67	26.97	-12.06	24.57	-19.89	28.51	-7.04
8	26.23	26.63	1.52	26.69	1.75	26.68	1.72
9	22.23	22.23	0.00	22.53	1.35	22.17	-0.27
10	20.89	22.57	8.04	21.58	3.30	22.36	7.04
		Av: -10.47 % (05)		Av: -10.40 % (06)		Av: -7.52 % (06)	
		Av.:+ 4.05 % (04)		Av.:+ 3.04 % (04)		Av.:+ 3.84 % (04)	
		Coefficient of correlation					
		0.98		0.97		0.99	

Table 7(ii) Summary of actual and predicted strength in MPa for 40 days with plasticizers

Trial	Actual	Predicted with six variables	Percentage difference	Predicted with 3 variables	Percentage difference	Predicted with 7 variables	Percentage difference
1	46.67	53.21	14.01	53.58	14.81	47.98	2.81
2	44.45	48.44	8.98	49.35	11.02	45.24	1.78
3	36.45	38.85	6.58	40.01	9.77	35.21	3.41
4	31.12	38.73	24.45	35.46	13.95	26.91	13.53
5	28.00	30.60	9.28	30.82	10.07	28.51	1.82
6	28.45	32.02	12.55	31.66	11.28	27.90	1.93
7	26.67	30.17	13.12	27.45	2.92	26.28	1.46
8	24.89	27.57	10.77	27.36	9.92	24.55	1.37
9	24.0	22.23	-7.38	22.526	-6.14	22.166	7.64
10	23.12	22.56	-2.42	21.575	-6.68	22.35	3.33
		Av: -4.90 % (02)		Av: -6.41 % (02)		Av: -4.67 % (07)	
		Av.:+ 12.47 % (08)		Av.:+ 10.46 % (08)		Av.:+ 2.14 % (03)	
		Coefficient of correlation					
		0.99		0.99		0.99	

6.2 Sensitivity studies

The data obtained in respect of the concrete cubes prepared with and without admixtures for various trials in the present study is studied further to evaluate the effect of various parameters such as water cement ratio, compaction factor, curing period and cement content on the compressive strength of the concrete. The effect of water cement ratio and cement content is also seen on the compaction factor.

Fig. 1 illustrates the effect of water cement ratio with and without plasticizer on the compressive strength of concrete for different periods of curing. It is seen that with increase in water cement ratio, the compressive strength of the concrete decreases in respect of all the periods of curing considered in the present study in case of the concrete made without plasticizer. The similar analogy is seen in respect of the concrete made by adding admixtures. Further, the compressive strength of the concrete obtained is on higher side when plasticizer are not added in the concrete in respect of all the curing periods such as 7 days, 28 days and 40 days. The malemine based admixture (plasticizer) although enhances the workability has got the retarding effect, which in turn, delays the setting time and this can be attributed to the reduction in the strength of the concrete in the presence of admixture.

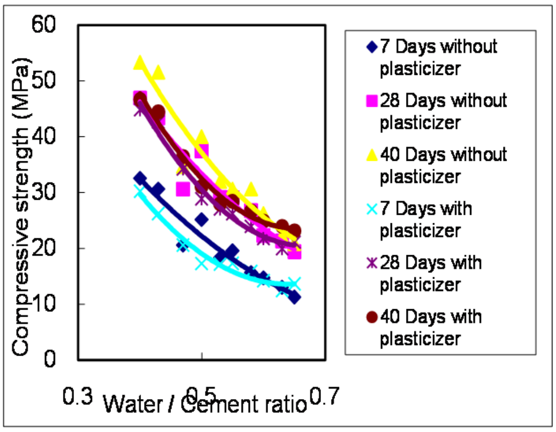

Fig. 1 Effect of water cement ratio on compressive strength of concrete

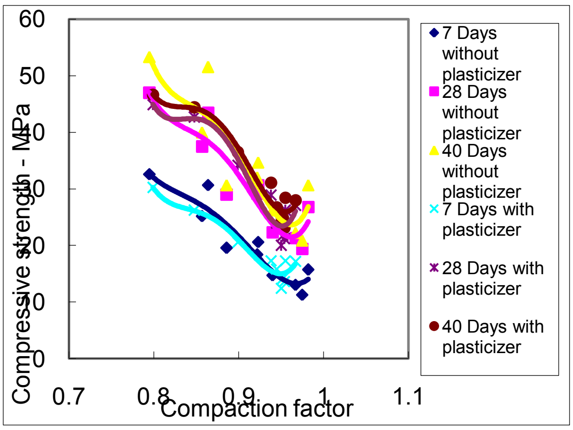

Fig. 2 Effect of compaction factor on compressive strength of concrete

The effect of compaction factor on compressive strength of concrete for different periods of curing is indicated in Fig. 2. With increase in compaction factor, the compressive strength of concrete is found to decrease in respect of all the periods of curing considered in the present study in either case, i.e., with and without admixtures. The compressive strength of concrete obtained is on higher side in absence of plasticizer for all the curing periods such as 7 days, 28 days and 40 days.

Fig. 3 shows the effect of curing period on compressive strength of concrete. It is observed that with increase in curing period, compressive strength of the concrete increases for both the cases-with and without plasticizer. Further, the trend observed regarding the higher compressive strength in respect of the concrete without plasticizer is observed here as well.

The effect of water cement ratio on compaction factor is illustrated in Fig. 4. In case of concrete without plasticizer, the compaction factor is found to increase with the increase in water cement ratio up to 0.47. Thereafter, it is found to decrease up to water cement ratio of 0.53 and then, again increase up to water cement ratio of 0.65. However, for the concrete prepared by adding the plasticizer, the compaction factor is found to increase consistently up to the water cement ratio of 0.53 and thereafter, it becomes approximately stable up to 0.65.

The effect of the cement contents in concrete on compaction factor in respect of the concrete with and without plasticizer is depicted in Fig. 5. It indicates that for lesser cement contents, the compaction factor is on higher side and with increase in cement contents, the compaction factor is observed to decrease in respect of either case of concrete, i.e., the concrete with and without plasticizer.

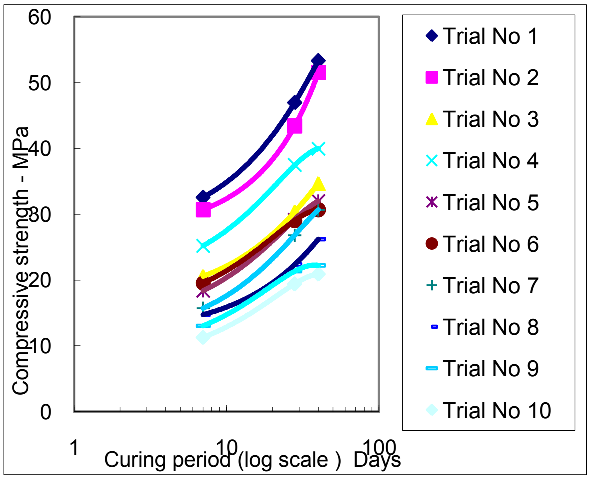

Fig. 3 Effect of curing period on compressive strength of concrete

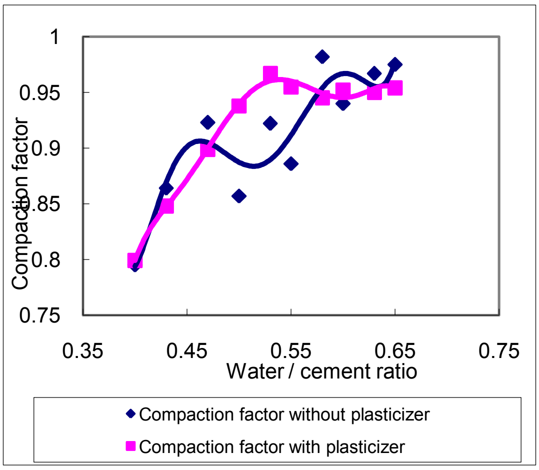

Fig. 4 Effect of water cement ratio on compaction factor

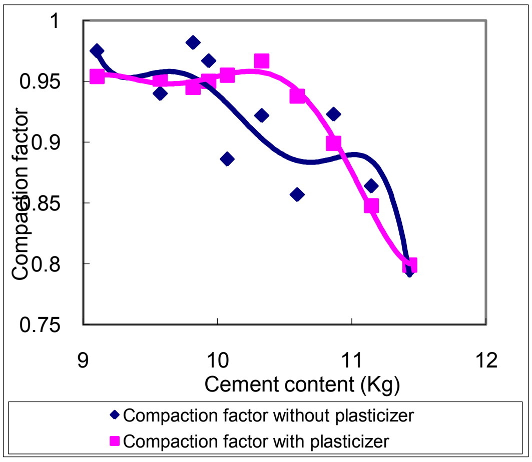

Fig. 5 Effect of cement content on compaction factor

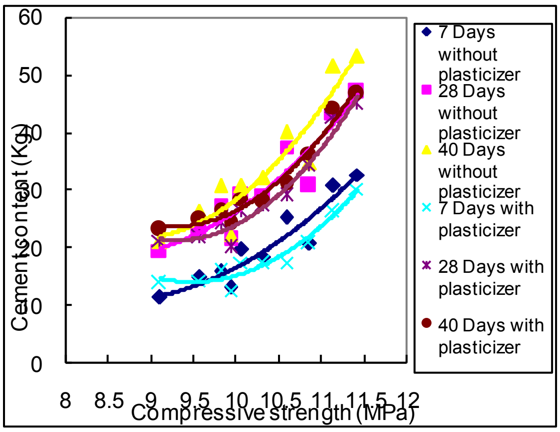

Fig. 6 Effect of cement content on compressive strength

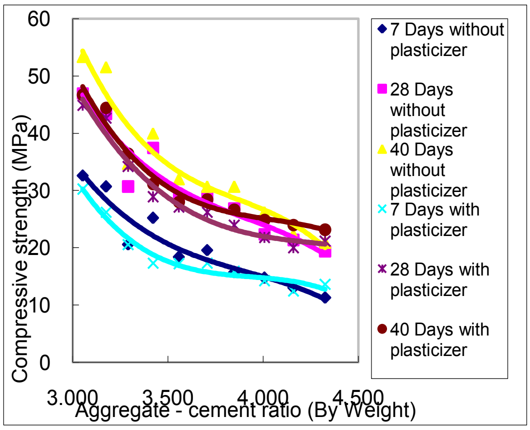

Fig. 7 Effect of aggregate cement ratio on compressive strength

The effect of cement contents on the compressive strength of concrete is shown in Fig. 6. It shows that with increase in cement content compressive strength is found to increase in respect the concrete mix prepared without adding plasticizers and for all the periods of curing. Similar is the analogy observed in respect of the concrete mix prepared by adding plasticizers. Further, the higher strength is observed in the respect of the concrete mix prepared without plasticizer.

The effect of aggregate- cement ratio on compressive strength in respect of the concrete with and without plasticizer and for all periods of curing is shown in Fig. 7. It reveals that with increase in aggregate cement ratio compressive strength of concrete decreases. This is attributed to the fact that due to higher aggregate cement ratio less paste is available for binding the aggregates which further renders leaner concrete.

7. Conclusions

Earlier and accurate estimation of concrete strength are valuable to the construction industry. The presence of such a model as developed in the present study would possibly obtain the balance and equality between controlling the quality (quality control process) and economics (saving time and expenses). This model could be used in construction to make the necessary adjustments on mix proportion used, to avoid situations where concrete does not reach the required design strength or by avoiding concrete that is unnecessarily strong.

The Multiple regression analysis is effectively used as a predictive tool in the present study. Regression analysis as is well-known, gives explicit formula which can be directly used to predict the strength of concrete. The prediction of the strength of concrete cube with the regression analysis is easy and handy tool. The formulae developed in the present study are capable of predicting 7, 28 and 40 days' strength of the concrete containing Portland Pozollana cement. It may be noted that the formulae developed in this study are applicable in respect of the concrete mix containing melamine based chemical admixture

Furthermore, the existing variables in the model yielded reasonable results. Also, it is not preferred to load the prediction model with large numbers of variables because it is preferred to use a model with lesser numbers of variables with most higher possible accuracy to assure the rapid and easy use of the model. In the presented work many factors are considered which are believed to affect strength and workability of concrete. The sensitivity studies revealed that the effect of admixtures is not much significant on the strength of the concrete. The strength is observed to be slightly higher in respect of the concrete mix prepared without admixtures. However, the admixture is found to enhance the workability aspect.

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Abbreviations

7 Strength	Concrete cube strength after 7 days of curing. (MPa)
28 Strength	Concrete cube strength after 28 days of curing. (MPa)
40 Strength	Concrete cube strength after40 days of curing. (MPa)
fa	Mean size of fine aggregate (mm)
ca	Mean size of coarse aggregate (mm)
comp	Compaction factor
wc	Water /cement ratio
cement	Quantity of cement content (kg)
weight 7	Weight of 7 days concrete cube – after 24 Hrs (kg)
weight 28	Weight of 28days concrete cube – after 24 Hrs (kg)
weight 40	Weight of 40 days concrete cube – after 24 Hrs (kg)

.

Appendix

Equations without plasticizer	
7 Days' strength	
06 Variables	304.492 – 1.744 ×fa – 0.414 × ca – 8.103 × cement -126.411 × wc – 52.009 × comp – 9.131 × weight 7
03 Variables	334.408 – 42.342 × comp – 206.949 × wc – 16.148 × cement
28 Days' strength	
06 Variables	-23.855 + 13.823 × fa – 0.505 ca + 7.685 ×cement – 17.374 × wc – 40.177 × comp + 2.216 ×weight 28
03 Variables	306.358 – 49.767 ×comp – 191.489 × w c – 12.525 × cement
07 Variables	-255.987 + 4.731 × fa – 0.100 × ca + 10.387 × cement + 104.194 × wc + 30.404 × comp + 7. 391 × weight 28 + 1.570 × strength 7
	40 Days' strength
06 Variables	83.672 + 27.535 × fa – 0.437 × ca -1.789 × cement – 155.135 × wc + 0.207 × comp +4.250 × weight 40
03 Variables	710.833 – 22.431 × comp – 477.982 × wc – 39.204 × cement
07 Variables	-21.460 – 1.288 × fa + 0.547 × ca + 6.409 × cement + 85.215 × wc – 3.048 × comp -11.792 × weight 40 + 1.991 × strength 7
Equations with plasticizer	
7 Days' strength	
06 Variables	508.96 – 5.89 × fa – 0.145 × ca – 26.23 × cement – 282.52 ×wc -37.80 × comp -3.42 × weight 7
03 Variables	358.382 – 34.196 × comp – 219.106 × wc – 18.714 × cement
28 Days' strength	
06 Varaibles	369.53 – 1.91 × fa – 0.16 × ca – 21.60× cement – 278.64 × wc – 39.45 × comp + 8.152 × weight 28
03 Variables	451.57 – 42.06 × comp – 287.45 × wc -22.58 × cement
07 Variables	-525.51 + 8.07 × fa +0.15 × ca + 22.56 × cement + 192.17 × wc + 10.62 × comp + 20.57 × weight 28 + 1.42 × strength 7
40 Days' strength	
06 Varaibles	460.016 – 3.289 × fa – 0.066 × ca – 18.720 × cement – 237.463 × wc – 60.754 × comp – 5.920 × weight 40
03 Variables	375.846 – 57.112 × comp – 222.110 × wc – 16.943 × cement
07 Variables	249.350 – 0.566 × fa + 0.034 × ca – 6.047 × cement – 100.924 × wc – 47.751 × comp – 7.765 × weight 40 + 0.436 × strength 7