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Potential for Utilising Concrete Mix Properties to Predict Strength at Different Ages

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Abstract: In this study, the potential for utilising properties of concrete as a powerful tool to predict its compressive strength at different ages has been realised. Novel mathematical models were proposed and developed using multiple non-linear regression equations to predict the concrete strength. The variables used in the prediction models, such as the mix proportion elements, were statistically analysed. According to the analysis, the models provided a good estimation of compressive strength and yielded good correlations with the data used in this study. The correlation coefficients were 0.995 for the prediction of 7- and 28-day compressive strength. Moreover, the proposed models proved to be a significant tool in predicting the compressive strength of different concretes despite variations in the data used to validate the model.

Key words: Compressive strength, statistical analysis, mix proportion, regression model, concrete, prediction

INTRODUCTION

Concrete is a construction material that is widely used throughout the world. The advantages of concrete include its low cost, availability of construction, workability, durability and convenient compressive strength, which make it popular among engineers and builders (Abd *et al*., 2008). However, these advantages are strongly dependent on correct mixing, placing and curing. In the 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 (Hamid-zadeh *et al*., 2006).

Waiting 28 days to complete such a test would not suit the construction industry's need for speed, while neglecting the test would not satisfy the quality control process of concrete at large construction sites. Therefore, rapid and reliable prediction of the strength of concrete would be of great significance (Kheder *et al*., 2003). The ability to rely on model predictions would enable mix proportion adjustments in advance of placing and curing; this prediction-based technique would enable the avoidance of situations in which the concrete is too weak or unnecessarily strong and would facilitate a more economic use of raw materials and fewer construction failures, hence reducing construction costs.

Prediction of compressive strength for cement and concrete, therefore, has been an active area of research. A considerable number of studies have been carried out in this area (Zain and Suhad, 2009; Kheder *et al*., 2003; Zain *et al*., 2002; Tsivilis and Parissakis, 1995; Zelic *et al*., 2004; Akkurt *et al*., 2004; Hwang *et al*., 2004; Sang *et al*., 2003). Many attempts have been made to obtain a suitable mathematical model that is capable of predicting the strength of concrete at various ages with acceptably high accuracy (Popovics, 1990; Jee *et al*., 2004; Steven *et al*., 2002; Mehta and Monteiro, 2006). This study proposes a mathematical model to predict concrete strength using concrete characteristics from its mix proportion elements.

STATISTICAL ANALYSIS FOR STRENGTH PREDICTION

The strengthening of concrete is a complex process involving many external factors. Multiple attempts have been made to model this process. A number of improved prediction techniques have been proposed by including empirical or computational modelling, statistical techniques and artificial intelligence approaches. Some models have used computational techniques such as finite element analysis, whereas others have used multivariable regression models to improve prediction accuracy. Statistical models are attractive in that, once fitted, they generate predictions much more quickly than other modelling techniques and are correspondingly simpler to implement in software.

There are many factors affecting concrete strength. Water to cement ratio (w/c) consider to be one of the most important factor in this respect. Many research works attempt to utilise this factor in models relating strength of concrete with factors affecting it. Popovics (1990) augmented Abram's model, a widely accepted equation relating the water/cement ratio (w/c) of concrete to its

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strength, with additional variables such as slump; he used least squares regression to determine equation coefficients. This approach improved strength prediction and provided insights into concrete compositions.

Apart from its speed, statistical modelling has two advantages over other techniques: it is mathematically rigorous and it can be used to define confidence intervals for the predictions. These advantages are particularly apparent when comparing statistical modelling with artificial intelligence techniques. Statistical analysis can also provide insight into the key factors influencing 28-day compressive strength through correlation analysis. For these reasons, statistical analysis was chosen as the technique for strength prediction in this study.

EXPERIMENTAL PROGRAM

This study was conducted in National University of Malaysia-UKM between 2007 and 2010. The physical properties of the materials used are shown in Table 1. Locally produced Ordinary Portland Cement (OPC) was used; its chemical composition is shown in Table 2. The fineness modulus was 2.82 for the fine aggregate. The coarse aggregate was 20 mm maximum size crushed stone; its specific gravity was 2.7. No admixtures or additives were used in this study; only the ordinary constituents of concrete (cement, sand, gravel, water) were used to study the effect of an ordinary mix proportion on the compressive strength of concrete. Since the aim of this study was to determine the effect of mix proportions on the compressive strength of concrete, different mixes were used. The details of all mix proportions are shown in Table 3.

Compressive strength tests were performed and evaluated in accordance with BS 1881: Part 116:1983. Specimens were immersed in water until the day of testing.

Table 1: Physical properties of materials

Materials	Properties
Cement (C)	Specific Gravity: 3.1
Ordinary Portland Cement (OPC)	Specific surface (by Blain): 3500 $cm^2\ g^{-1}$
Fine Aggregate (FA)	Specific Gravity: 2.60
Sand (S)	Fineness Modulus: 2.34
Coarse Aggregate (CA)	Specific Gravity: 2.7
Crushed stone	Maximum Particle Size: 20 mm

Table 2: Chemical Composition of OPC

Oxide	Percent
Silicon dioxide (SiO_2)	22.10
Aluminum Trioxide (Al_2O_3)	5.96
Ferric oxide (Fe_2O_3)	3.04
Calcium oxide (CaO)	61.50
Magnesium oxide (MgO)	2.50
Sodium oxide (Na_2O)	0.16
Loss on ignition (L.O.I)	1.50
Insoluble residue (I.R)	1.10
Lime saturation factor (L.S.F)	0.85

Table 3: Details for mix proportions

Mix no.	Water ($kg\ m^{-3}$)	Cement ($kg\ m^{-3}$)	Sand ($kg\ m^{-3}$)	Aggregate ($kg\ m^{-3}$)	W/C	Density ($kg\ m^{-3}$)
1	180	400	600	1200	0.45	2333
2	195	390	588	1170	0.50	2323
3	209	380	570	1140	0.55	2310
4	222	370	555	1110	0.60	2300
5	234	360	540	1080	0.65	2293
6	245	350	525	1050	0.70	2275
7	146	325	650	1300	0.45	2268
8	160	320	640	1280	0.50	2244
9	173	315	630	1260	0.55	2234
10	186	310	620	1240	0.60	2203
11	198	305	610	1220	0.65	2176
12	210	300	600	1200	0.70	2148
13	233	517	517	1034	0.45	2430
14	252	504	504	1008	0.50	2421
15	270	491	491	982	0.55	2378
16	287	479	479	958	0.60	2374
17	304	468	468	936	0.65	2356
18	320	457	457	914	0.70	2352

MODELLING THE PREDICTION OF CONCRETE COMPRESSIVE STRENGTH

The most popular regression equation used in the prediction of compressive strength is:

$$f = b_0 + b_1\, w/c \tag{1}$$

where, f is the compressive strength of concrete, w/c is the water/cement ratio and b_0 and b_1 are coefficients. Equation 1 is the linear regression equation for Abram's Law (Popovics, 1990), which relates the compressive strength of concrete to the w/c ratio of the mix. According to this law, an increase in the w/c ratio leads to a decrease in concrete strength. The original formula for Abram's Law is:

$$f = \frac{A}{B^{w/c}} \tag{2}$$

where, f is the compressive strength of concrete and A and B are empirical constants.

Lyse (Jee *et al*., 2004) established a formula similar to that of Abram, but he related the compressive strength to the cement/water (c/w) ratio rather than the water/cement ratio. According to Lyse, the strength of concrete increases linearly with increasing c/w ratio. The general form of this popular model is:

$$f = A + Bc/w \tag{3}$$

where, f is the compressive strength of concrete, c/w is the cement/water ratio and A and B are empirical constants.

The quantities of cement, fine aggregate and coarse aggregate were not included in the model and did not influence the predicted concrete strength. Thus, any concrete mix with the same w/c ratio is predicted to have an equivalent strength, but this is not empirically true. Therefore, models should take into account the influence of mix constituents on the concrete strength to yield more reliable and accurate predictions of concrete strength.

Consequently, Eq. 1 was extended to include other variables in the form of multiple linear regression equations. The resulting Eq. 4 has been used widely to predict the compressive strengths of various types of concrete:

Equation 1 is linear least squares regression and Eq. 4 multiple linear regression:

$$f = b_0 + b_1 w/c + b_2 CA + b_3 FA + C \quad (4)$$

where, f is the compressive strength of concrete, w/c is the water/cement ratio, C is the quantity of cement in the mix, CA is the quantity of coarse aggregate in the mix and FA is the quantity of fine aggregate in the mix.

According to Eq. 4, all of the variables relate to the compressive strength in a linear fashion; however, this is not always true, because the variables involved in a concrete mix and affecting its compressive strength are interrelated to each other and the additive action does not always increase strength. Thus, there is a need for another type of mathematical model that can reliably predict strengths of concrete with high accuracy. Consider the general form of the multiple linear regression as below:

$$Y = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + ...a_mX_m \quad (5)$$

multiple linear regression

For situations in which the multiple dependencies are curvilinear (non-linear), logarithmic transformation can be applied to this type of regression (Steven *et al*., 2002):

$$\log(y) = \log(a_0) + a_1\log(X_1) + a_2\log(X_2) + a_3\log(X_3) + ...a_m\log(X_m) \quad (6)$$

This equation can be transformed back to a form that predicts the dependent variable (Y) by taking the antilogarithm to yield:

$$Y = a_0 X_1^{a_1}.X_2^{a_2}.X_3^{a_3}.......X_m^{a_m} \quad (7)$$

This equation is called the multivariable power equation (Steven *et al*., 2002). In engineering, when variables are dependent on several independent variables, this functional dependency is best characterised by Eq. 7, which gives more realistic results. In this study, the Multivariable Power Equation was found to be very suitable for predicting the strength of concrete. The factors affecting this strength were the elements of the concrete mix itself.

RESULTS AND DISCUSSION

It is very important to analyse the effects of mix constituents on the strength of concrete. The mix design is the specific combination of raw materials that are used in a particular concrete to achieve a given target strength. In 28-day compressive strength, the significant factor was the concrete composition. Concrete theory suggests that the water-to-cement ratio (w/c) of concrete would be the primary factor influencing the strengthening process, affecting both the final strength and the rate of hardening. Additionally, decreasing water content has been shown to increase the strength of concrete.

Furthermore, strength is related to density; the denser the concrete, the higher the strength. The w/c-strength relationship in concrete can be easily explained: an increase in the w/c ratio increases the porosity of the cement paste at a given degree of hydration and this increase in porosity weakens the whole matrix and leads to a decrease in the concrete strength. This relationship would be clearer in high-strength concrete where very low w/c ratios are used to achieve a large increase in compressive strength. This increase would be attributed mainly to a significant improvement in the strength of the interfacial transition zone at very low w/c ratios (Mehta and Monteiro, 2006). This explanation is well represented in Fig. 1 which shows the relationship between the

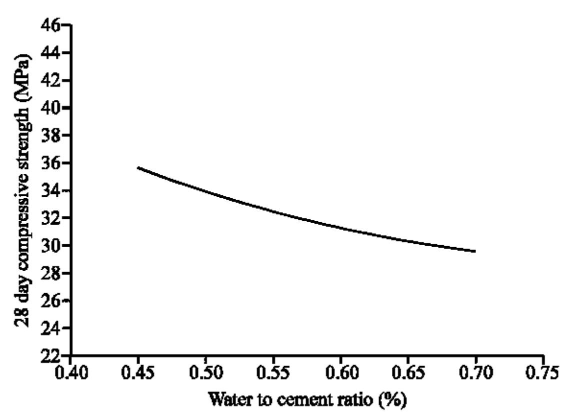

Fig. 1: Relationship between 28 days compressive strength and (w/c) ratio

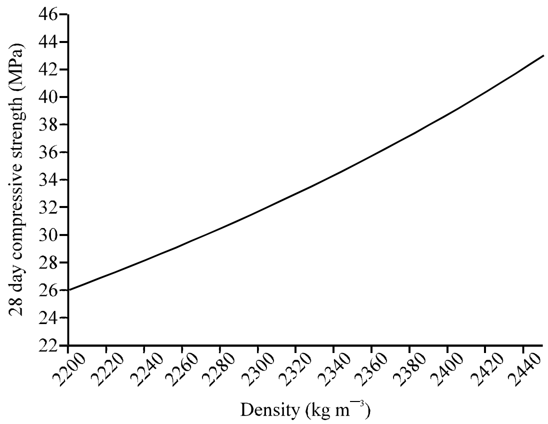

Fig. 2: Relationship between 28 days compressive strength and density

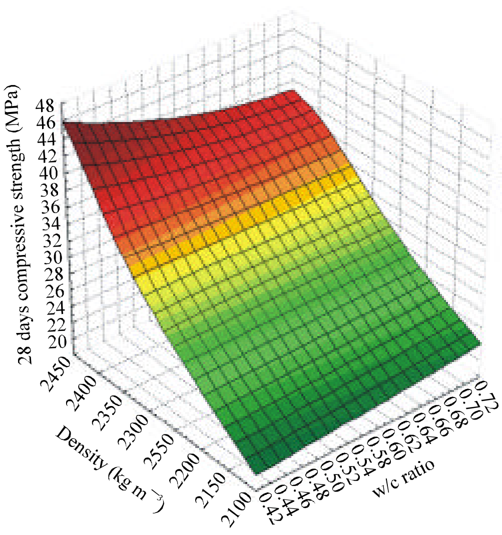

Fig. 3: The combined effect of both density and water-to-cement ratio on 28-day compressive strength

28 days compressive strength and the water to cement ratio (w/c) for the concrete used in this study. Furthermore, it is well known that strength is related to density and the denser the concrete the higher the strength as shown in Fig. 2.

The combined effect of both the w/c ratio and the density is well represented in Fig. 3 and 4, which show a 3D relationship between the 28-day compressive strength and 7-day compressive strength with both density and w/c ratio. From this relationship, the highest compressive strength of concrete occurred for the area of maximum density and minimum w/c ratio. This outcome makes logical sense given that a decreased w/c ratio leads to increased strength and lowered permeability for an overall increase in density (Popovics, 1992). Figure 1 clearly

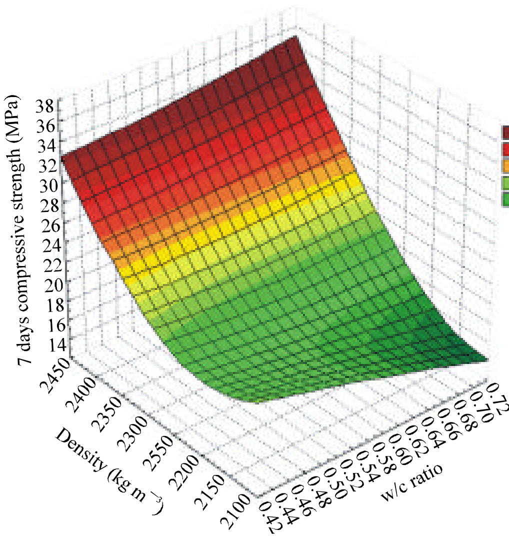

Fig. 4: The combined effect of both density and water-to-cement ratio on 7-day compressive strength

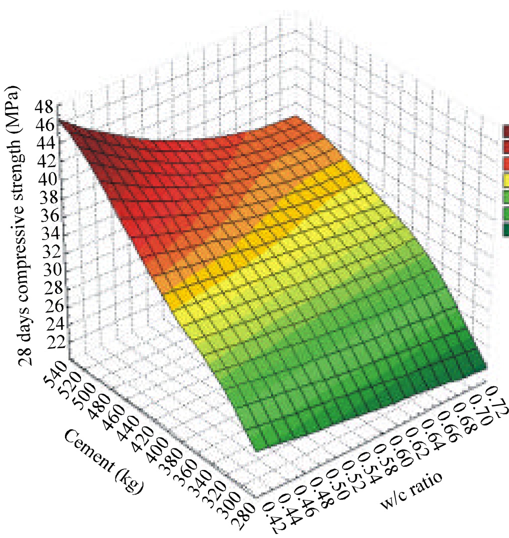

Fig. 5: The combined effect of both cement content and water-to-cement ratio on 28-day compressive strength

shows this trend for the 28-day compressive strength. The density of concrete is higher at 28 days due to the continued hydration process and reactions between cement constituents.

Furthermore, the strength of concrete is highly affected by the cement content, as shown in Fig. 5. The maximum strength obtained in this study resulted from using a high cement content with a minimum w/c ratio. On the other hand, increased cement content led to increased density and consequently increased the strength of

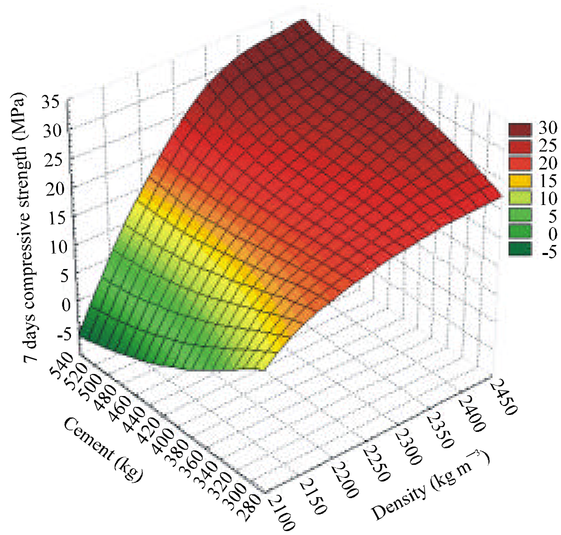

Fig. 6: The combined effect of both cement content and density on 7-day compressive strength

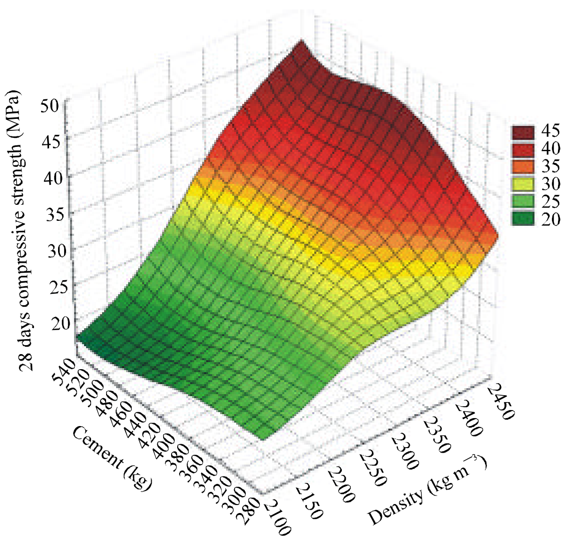

Fig. 7: The combined effect of both cement content and density on 28-day compressive strength

concrete at both 7 and 28 days, as shown in Fig. 6 and 7. The amount of fine and coarse aggregate used in the mix, as well as any other additional materials added to the mix, would also significantly affect the strength development of the concrete, since these materials are added to the mix to improve a specific property of the concrete.

Additives can include fly ash, silica fume and slag or an admixture like superplasticiser. Strength is also affected by the quality of the constituent materials and the mixing and curing methods (Zain *et al*., 2002). The compressive strength of concrete also depends on the W/B ratio. The

Table 4: Correlations between 7- and 28-day compressive strength and variables used in the proposed model

Variable	7 days compressive strength	28 days compressive strength
Water/cement(w/c)	-0.38	-0.41
Water (W)	0.58	0.53
Cement (C)	0.97	0.95
Sand (FA)	-0.73	-0.69
Aggregate (CA)	-0.73	-0.70
Density (ñ)	0.98	0.98

Table 5: Regression coefficients for the 7- and 28-day compressive strength prediction models

Coefficient	7 days prediction model	28 days prediction model
A_0	55.57930	0.4205
A_1	2.59659	24.8764
A_2	-2.55698	-24.8485
A_3	-5.76375	-5.8418
A_4	4.73262	05.4781
A_5	-3.17057	-25.1339
A_6	2.11258	3.0282
C.C	0.995388	0.995379
Variance explained	99.047%	98.8%

lower the W/B ratio, the higher the strength of the concrete, because strength of concrete is mainly determined by the strength of the paste and the strength of its bond to the aggregate and w/c ratio plays a great role in this stage (Neville, 1996). Table 4 shows the relationship between the compressive strength at 7 and 28 days and the variables collected from the experimental work. These table entries were used in the proposed model. The relationship between 7 and 28 days and the variables in Table 4 is represented by the correlation coefficient between each variable and each strength. Table 5 reveals that some variables correlate significantly with the predicted strength at the specified age. The highest correlation was for density, followed by the cement content in the mix.

After analysing the influence of mix constituents on the compressive strength at 7 and 28 days, the proposed model was used to predict the compressive strength at the specified ages while incorporating all of the variables mentioned previously. The final form of the proposed strength prediction model for both ages was:

$$f_7 = a_0 C^{a_1}.W^{a_2}.FA^{a_3}.CA^{a_4}.\ ^{a5}.w / c^{a6} \quad (8)$$

$$f_{28} = a_0 C^{a_1}.W^{a_2}.FA^{a_3}.CA^{a_4}.\rho^{a5}.w / c^{a6} \quad (9)$$

The regression coefficients of the prediction model above, for the predictions of 7- and 28-day compressive strength, respectively, are given in Table 5. The value of the coefficient of correlation (CC) is also given.

Figure 8 and 9, show the relationship between the actual and predicted values of the compressive strength

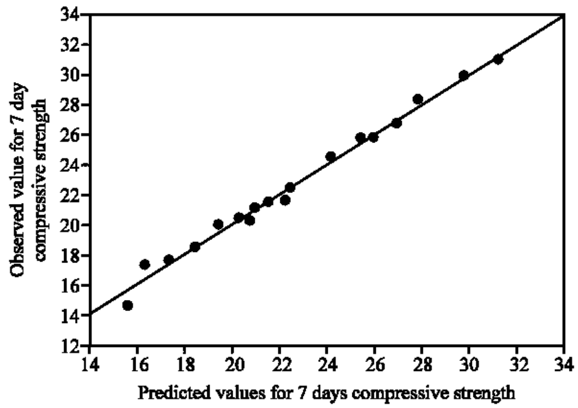

Fig. 8: Relationship between the observed and predicted values for 7-day compressive strength

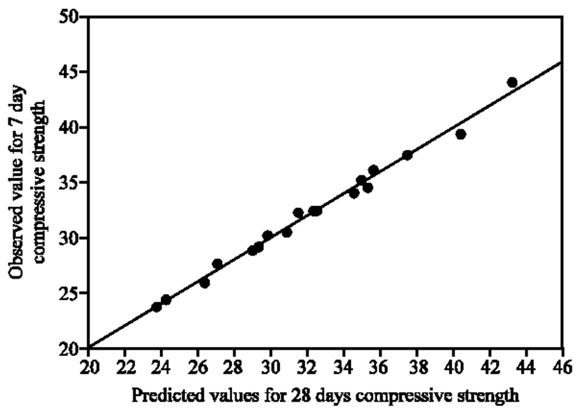

Fig. 9: Relationship between the observed and predicted values for 28-day compressive strength

at 7 and 28 days, respectively. Almost 99% of the data are located on the line of equality, which means that the actual and predicted values for the concrete compressive strength were identical. The correlation coefficients provide further evidence of this agreement: 0.99538 for the 7-day prediction and 0.99537 for the 28-day prediction. Moreover, the 7-day prediction explained almost 99.047% of the variance while the 28-day prediction explained 98.8% of the variance.

COMPARISON WITH OTHER DATA

To validate the proposed model presented in this study, the model was tested using data from other researchers (Jee *et al*., 2004). Table 6 shows the full details of the data imported and used to verify the proposed model. The data consist of 59 different kinds of mixtures with specified compressive strengths of 18-27 MPa, w/c ratios of 0.39-0.62, maximum aggregate sizes of 25 mm and slumps of 12-15 cm. This data set was selected for its large number of concrete mixes (large number of samples), which came from different ready-mix concrete plants.

Table 6: Details of mix proportions for data from (Jee *et al*., 2004)

			Weight of unit volume (kg m^{-3})				Compressive strength (MPa)		
No.	w/c %	S/a %	W	C	S	g	Agent	7 days	28 days
1	60.21	51.19	174	289	933	900	0.86	15.5	21.2
2	59.74	52.07	184	308	927	860	0.91	16.3	24.2
3	60.60	52.04	183	302	926	860	0.91	16.3	23.0
4	57.48	52.70	173	301	961	863	0.90	21.5	26.2
5	60.32	50.90	190	315	904	862	0.47	18.6	24.0
6	61.49	51.20	190	309	911	859	0.46	17.4	22.5
7	59.55	46.09	184	309	821	975	0.92	15.8	22.6
8	50.00	48.47	164	328	886	942	1.64	23.2	34.7
9	47.83	45.10	176	368	805	988	0.77	19.1	26.9
10	49.44	48.80	178	360	858	914	1.08	23.3	30.7
11	52.35	47.88	178	340	839	931	0.51	22.6	28.8
12	44.47	44.90	165	371	810	1000	1.85	20.7	27.6
13	44.69	47.60	164	367	847	940	1.84	18.9	28.5
14	48.56	49.63	169	348	882	902	1.74	24.1	31.8
15	48.92	49.40	181	370	866	887	1.11	23.0	30.5
16	50.00	49.51	171	342	885	913	1.71	23.0	31.6
17	49.73	49.93	181	364	865	874	1.09	21.6	31.7
18	44.75	48.77	179	400	835	894	2.80	22.0	30.2
19	45.34	46.14	180	397	790	939	2.78	22.4	30.2
20	46.56	43.90	183	393	759	981	1.18	20.4	29.7
21	50.00	45.99	175	350	804	955	1.05	16.0	29.8
22	47.04	44.71	183	389	778	962	1.17	19.8	26.7
23	47.30	44.71	184	389	778	962	1.17	18.1	25.3
24	48.04	47.09	184	383	810	924	1.15	20.1	27.8
25	48.41	47.41	183	378	807	902	1.13	22.0	29.1
26	48.41	47.41	183	378	818	924	1.13	22.8	29.2
27	47.79	47.59	184	385	812	922	1.16	21.2	27.6
28	45.69	48.32	175	383	846	905	0.77	22.8	28.9
29	46.76	50.31	173	370	889	878	1.11	21.3	27.3
30	46.74	50.49	179	383	879	862	1.15	21.2	27.6
31	44.21	49.01	168	380	868	903	1.90	21.1	29.1
32	47.77	46.10	182	381	812	956	0.80	20.0	26.2
33	45.14	47.20	172	381	815	940	1.91	21.5	28.3
34	48.41	47.41	183	378	807	923	1.13	20.7	27.5
35	45.89	43.50	184	401	754	978	2.01	23.7	31.3
36	48.56	45.80	185	381	800	946	1.91	21.9	28.7
37	45.69	48.30	175	383	863	888	1.92	20.6	28.2
38	47.78	45.14	172	360	794	965	1.08	21.0	27.7
39	45.87	44.00	189	412	730	947	1.65	25.0	30.9
40	45.99	43.96	189	411	732	951	1.44	20.7	30.7
41	42.76	46.29	180	421	784	927	0.85	22.7	30.0
42	40.89	42.47	184	450	713	977	1.35	22.6	30.7
43	40.62	42.01	184	453	704	983	1.59	23.6	31.0
44	41.97	47.49	183	436	804	889	0.87	22.8	29.8
45	44.1	48.32	187	424	812	882	1.27	22.4	30.2
46	43.57	46.8	183	420	785	920	1.26	22.8	30.7
47	44.31	46.61	183	413	780	921	1.24	23.9	30.1
48	44.31	46.61	183	413	791	923	1.24	23.6	30.9
49	40.98	46.42	168	410	811	936	2.05	22.6	33.3
50	42.45	47.71	180	424	813	891	1.27	22.9	30.8
51	44.31	46.61	183	413	783	956	0.87	20.8	29.3
52	48.4	47.6	196	405	786	879	0.61	22.4	30.7
53	45.17	48.5	187	414	818	883	1.24	22.8	29.5
54	44.31	46.61	183	413	780	900	1.24	25.9	34.3
55	44.31	46.6	183	413	783	914	1.24	24.5	32.4
56	39.37	45.2	176	447	760	970	1.34	24.7	29.4
57	43.75	44.7	182	416	771	954	2.08	23.4	30.8
58	41.47	45.5	175	422	782	937	0.84	23.7	31.5
59	43.85	44.59	171	390	768	969	1.17	24.9	30.6

Table 7: Observed (actual), predicted values of the 28 days compressive strength and difference between both of them

No.	Observed	Predicted	Difference
1	21.2	24.94	-3.74
2	24.2	25.28	-1.08
3	23.0	25.49	-2.49
4	26.2	25.95	0.24
5	24.0	24.11	-0.11
6	22.5	23.91	-1.41
7	22.6	24.36	-1.76
8	34.7	28.16	6.53
9	26.9	26.35	0.54
10	30.7	27.49	3.2
11	28.8	26.52	2.27
12	27.6	29.19	-1.59
13	28.5	30.84	-2.34
14	31.8	29.61	2.18
15	30.5	27.86	2.63
16	31.6	28.31	3.28
17	31.7	28.67	3.02
18	30.2	31.18	-0.98
19	30.2	30.71	-0.51
20	29.7	28.15	1.54
21	29.8	28.57	1.22
22	26.7	27.96	-1.26
23	25.3	27.74	-2.44
24	27.8	28.22	-0.42
25	29.1	29.72	-0.62
26	29.2	28.01	1.18
27	27.6	28.43	-0.83
28	28.9	28.90	0.00
29	27.3	29.18	-1.88
30	27.6	29.29	-1.69
31	29.1	30.84	-1.74
32	26.2	26.37	-0.17
33	28.3	30.83	-2.53
34	27.5	28.79	-1.29
35	31.3	28.95	2.34
36	28.7	27.76	0.93
37	28.2	29.72	-1.52
38	27.7	29.30	-1.60
39	30.9	30.98	-0.08
40	30.7	30.46	0.23
41	30.0	30.40	-0.40
42	30.7	31.44	-0.74
43	31.0	31.92	-0.92
44	29.8	30.66	-0.86
45	30.2	30.26	-0.06
46	30.7	30.64	0.05
47	30.1	30.80	-0.70
48	30.9	29.90	0.99
49	33.3	32.38	0.91
50	30.8	31.21	-0.41
51	29.3	28.59	0.70
52	30.7	28.76	1.93
53	29.5	29.80	-0.30
54	34.3	31.80	2.49
55	32.4	30.89	1.50
56	29.4	31.50	-2.10
57	30.8	29.95	0.84
58	31.5	30.94	0.55
59	30.6	31.37	-0.77

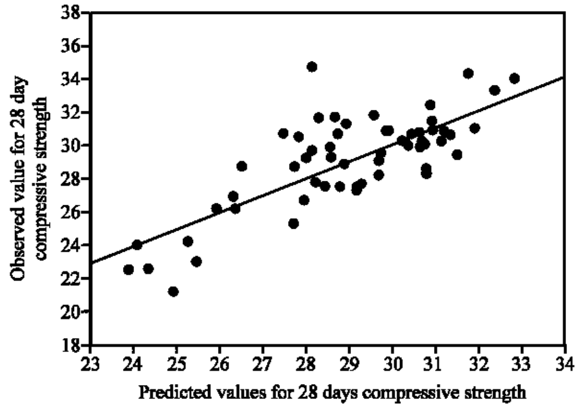

Fig. 10: Relationship Between the Observed and Predicted Values for 28 Days Compressive Strength (Jee *et al*., 2004)

Success of the model with this data set would provide good proof that the proposed model was valid even for ready-mix concrete.

Variations in the concrete strength of the test specimens depend on how well the materials and concrete manufacturing and testing processes are controlled. Construction practices may cause considerable variations in the strength of in-situ concrete due to inadequate mixing, poor compaction, delay and improper curing (Jee *et al*., 2004). The variables used to validate the model were those available from the data set. The correlation coefficient was 0.7579 for the prediction of the 28-day compressive strength and 0.7267 for the 7-day prediction; these were considered to be good results given the variations in the data.

Some relationships presented in previously published studies can predict the 28-day compressive strength from 7-day values (Hamid-zadeh *et al*., 2006), or even from earlier values (Kheder *et al*., 2003). If we use the 7-day strength to predict the 28-day strength, the coefficient of correlation in this data set improves significantly, from 0.7579 to 0.866, which proves the importance of this concept (using early strength to predict strength at later ages). Using this model, the observed (actual) and the predicted values of 28 days compressive strength with the difference between them are given in Table 7 and the relationship is plotted in Fig. 10.

CONCLUSIONS

In this study, mathematical regression models for the prediction of concrete compressive strength at 7 and 28 days were proposed and developed using non-linear regression. The models, which relied on knowledge of the mix constituents, are as follows:

$$f_7 = a_{55.579}C^{-2.557}.W^{2.597}.FA^{-5.764}.CA^{4.733}.\rho^{2.113}.w/c^{-3.171}$$

$$f_{28} = a_{0.421}C^{-24.849}.W^{24.876}.FA^{-5.842}.CA^{5.4781}.\rho^{3.028}.w/c^{-25.134}$$

The importance of the influence of mix constituents on the strength of concrete was demonstrated. Previously models proposed by other researchers for predicting concrete compressive strength do not incorporate variables from the mix proportions elements that are affecting strength of concrete. The models developed in this research were proven effective with another set of data, despite variations in test results of the concrete in question. The concept of using early-age strength to predict strength at later ages proved to be valid and could be used successfully.

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