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Prediction of compressive strength of concrete based on accelerated strength

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Abstract. Moist curing of concrete is a time consuming procedure. It takes minimum 28 days of curing to obtain the characteristic strength of concrete. However, under certain situations such as shortage of time, weather conditions, on the spot changes in project and speedy construction, waiting for entire curing period becomes unaffordable. This situation demands early strength of concrete which can be met using accelerated curing methods. It becomes necessary to obtain early strength of concrete rather than waiting for entire period of curing which proves to be uneconomical. In India, accelerated curing methods are used to arrive upon the actual strength by resorting to the equations suggested by Bureau of Indian Standards' (BIS). However, it has been observed that the results obtained using above equations are exaggerated. In the present experimental investigations, the results of the accelerated compressive strength of the concrete are used to develop the regression models for predicting the short term and long term compressive strength of concrete. The proposed regression models show better agreement with the actual compressive strength than the existing model suggested by BIS specification.

Keywords: ordinary portland cement; concrete; compressive strength; accelerated compressive strength; normal curing; accelerated curing

1. Introduction

Curing of concrete is a process of controlling the rate and the extent of moisture loss from concrete during the process of hydration of cement. In order to obtain good quality concrete, an appropriate mix after appropriate compaction must be followed by curing in a suitable environment during the early stages of hardening. Curing must be undertaken for a reasonable period of time if concrete is to achieve its potential strength and durability. It is essential, if the concrete is to perform its intended function over the design life of the structure whereas; excessive curing time may lead to increase in the construction cost of the project and unnecessary delays.

In construction industry, strength of concrete is one of the primary criterion in selecting a

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concrete for a particular application. The characteristic strength of concrete is defined as the compressive strength of a specified specimen that has been aged for 28 days. The hardening process and strength-gaining rate of concrete under normal conditions are slow; it affects the production rate of concreting plants. Therefore, it is beneficial to provide a desired strength level of concrete in a short time by accelerating its hardening process using various methods. Also, off late a trend has been set in construction industry to develop economical concrete as well as to complete the project within a short time. Hence, the rapid and reliable prediction of the strength of concrete would be of great significance. The aim of the present study is to establish the prediction models between the accelerated compressive strength of concrete and normal compressive strength of concrete.

2. Methods of accelerated curing

Various techniques of accelerated curing of concrete in general are classified as heat water techniques, oven curing techniques, maturity methods, pressure and elevated temperature technique and expanded polystyrene moulds technique. ACI (214.1 R) suggests two procedures, which can be used to provide an indication of 28 days strength of concrete only after 24 hours. These methods are: warm water method (23 to 24 hours at 35°±3℃) and boiling water method (23 hours at 21℃ and 3.5 hours at 100℃).

ASTM C 684 recommends three different accelerated curing techniques, namely- warm water method (24 hours at 35°±3℃), boiling water method (23 hours at 21℃ and 3.5 hours at 100℃) and autogenous curing method (5 hours at 150℃ with external pressure). The British standards (BS: 1881- Part 112) provide three curing temperature 35°, 55° and 85°± 2℃ for accelerating the rate of gain of strength. The IS: 9013-1978 recommends two methods of accelerated curing: warm water method and boiling water method.

3. Literature review

There have been many investigations reported in the literature related to accelerated curing of concrete. Some of the prominent investigations are reviewed briefly in the subsequent paragraphs.

Moist-cured test specimens do not always give reliable results at very early ages since slight changes in the first few hours after casting may have considerable effects on early strength (Neville 1973). Therefore, the methods for earlier determination of concrete strength with satisfactory reliability had been researched for over 30 years. The first reported study on accelerated strength determination dates back to 1927 (Gerend 1927). After a dormant period of about 30 years, systematic efforts on the subject were made by some of the researchers (Malhotra 1973, Ramkrishnan 1978).

Tan *et al.* (1995) studied the effect of curing conditions on strength and permeability of concrete. Silica fume has a significant effect on the resistance to water penetration. For the concretes both with and without silica fume and with w/c of 0.5, the 28 day compressive strengths of 3 and 7 days moist curing were higher than those of 28 days moist curing. Resheidat *et al.* (1996) investigated the strength of accelerated using the boiling water method. The correlation between the 28-day compressive strength and the corresponding accelerated strength was established for prediction of concrete strength at 28 days. Maltais *et al.* (1997) discussed the influence of fly ash and curing temperature on cement hydration and compressive strength development of mortars. Test results shows that the rate of cement hydration of fly ash tends to increase at early age and an increase of the curing temperature no detrimental effect on the long-term compressive strength of the fly ash mixtures. Also an elevation of the curing temperature reduces the long-term compressive strength of the mortar mixture.

Tokyay (1999) presented the relationships between the standard compressive strength at 7, 28, and 90 days and early strength attained by autogeneous curing, warm water curing and boiling water curing. Further, a regression expression was proposed to predict the strength of concretes containing high-lime and low-lime fly ashes as partial cement replacement. Bakharev *et al.* (1999) investigated the effect of curing temperature on microstructure, shrinkage, and compressive strength of alkali-activated slag (AAS) concrete. Paya *et al.* (1999) developed a mathematical model for the mechanical properties at early age of mortars containing fly ashes in 15-60% replacement range and cured in 20-80℃ range.

Ozkul (2001) presented the relation between 28-day strength of normal cured concrete and accelerated strength by using ordinary Portland cement and tras cement under two different accelerated curing conditions, warm water and boiling water. Almukhtar (2001) investigated the development of compressive strength of concrete by using different curing regimes such as standard curing warm water method and boiling water method and two equations are developed from standard curing and accelerated curing to predict the 28 day compressive strength. Pheeraphan *et al.* (2001) investigated the prediction of later-age compressive strength of normal concrete, made with rapid-hardening and ordinary Portland cement, based on the accelerated strength of concrete cured with microwave energy.

Kaszy’nska (2002) analyzed the results of tests on heat of hydration and compressive strength of high-performance concrete cured in variable thermal conditions and to determine a relation between the amount and kinetics of heat generation and the early age compressive strength of high-performance concrete cured in the massive structure, where the temperature in concrete changes continuously. Ho *et al.* (2002) reported the potential benefits of steam-cured concrete, particularly on mixes incorporating mineral admixtures such as Portland cement, fly ash, slag and silica fume. It was observed that that steam-cured concrete were more porous as compared with standard-cured specimens. Mixes with silica fume have the best performance in precast manufacturing due to their high early strength development.

Kheder *et al.* (2003) developed a mathematical model predicting portland cement compressive strength at ages 7 and 28 days within 24 hours only by considering the ultrasonic pulse velocity (UPV) and mortar density variables. Topcu *et al*. (2004) analyzed the effect of accelerated curing of concrete at different temperatures for different periods (6 or 18 h). A concrete subjected to accelerated curing will be tested and a relationships developed by regression analysis in between accelerated curing and normal curing compressive strength. Yazic *et al.* (2005) investigated the compressive strength of concrete, volume stability of mortar bar specimens; and setting times of pastes by steam curing on concrete incorporating ASTM Class- C fly ash replacing the cement up to 70%. Ahmed (2005) presented the mathematical models for early prediction of the 28 and 90-day compressive strength after warm water curing at 35℃ for 24 or 48-hour by using micro silica and fly ash as replacement to cement.

Tantawi and Gharaibeh (2006) developed a theoretical model using nonlinear regression analysis to estimate the consolidated strength at 7 and 28 days by knowing its strength after 6 hours of casting. Tanyildizi *et al*. (2007) reported the effect of high temperature on compressive strength and splitting tensile strength of lightweight concrete containing fly ash using experimentation and statistics. Zain *et al.* (2008) developed a new mathematical models using non-linear regression equation for the prediction of concrete compressive strength at 7 and 28 days. Singh *et al.* (2008) investigated the mathematical model for early prediction of 28 days compressive strength for OPC and PPC by boiling water method. Krishna Rao *et al*. (2010) investigated the influence of type of cement (OPC, PPC, OPC+10% SF), age (1, 3, 7, 14 and 28 day) and type of curing (conventional wet curing, membrane forming compound curing and accelerated curing) on M40 grade concrete. Sajedi *et al*. (2010) reported that the curing techniques and curing duration have crucial effects on the strength and other mechanical properties of mortars. Udoeyo *et al.* (2010) investigated the efficiency of the boiling water method of accelerated strength testing to predict the 28-day compressive strength of laterized concrete (concrete containing laterite as full or partial replacement of sand). Altan *et al.* (2011) investigated strength development of alkali activated slag (AAS) mortars, using alkali hydroxide and sodium silicate, at room temperature and elevated temperature. Siddique *et al.* (2011) investigated the mechanical properties of concrete i. e. mass loss, compressive strength, splitting tensile strength, and modulus of elasticity subjected to temperatures of 100, 200 and 350°C by using GGBFS as partial replacement in a designed M34 concrete mix.

In view of the above aforementioned literature available, present work is aimed at establishing a predictive relationship between the accelerated compressive strength of concrete and normal compressive strength of concrete using regression technique. The data required for this was generated in the laboratory. The formulae using three independent variables viz: cement content, compaction factor and accelerated strength and one dependent variable which is accelerated strength are proposed to predict the characteristic strength of concrete.

4. Experimental programme

4.1 Materials

The materials used in the present investigation include cement, sand, aggregates and water. The Ordinary Portland Cement 53 Grade confirming to the requirements as stipulated in IS: 12269-2013 was used. The river sand –Vaitarna, Khaniwade is brought into use. The coarse aggregates Metal 1: M1 (MAS-10 mm), Metal 2: M2 (MAS-20 mm) was used from place Jasai (New Mumbai) quarry. Potable water is used for obtaining concrete mix. The physical properties of the

Table 1 Physical properties of cement

Fineness(Specific surface m^2/kg)	340
Normal consistency (%)	29
Compressive Strength (MPa) 3 days 7 days 28days	 41 52 67
Setting time(in minutes) Initial Final	 130 215
Soundness: Le-chatelier(mm)	1.5

Table 2 Properties of aggregates

Property	Fine Aggregates FA	Coarse Aggregates	
		M1	M2
Specific Gravity	2.79	2.81	2.82
Fineness Modulus	4.38	6.10	7.01

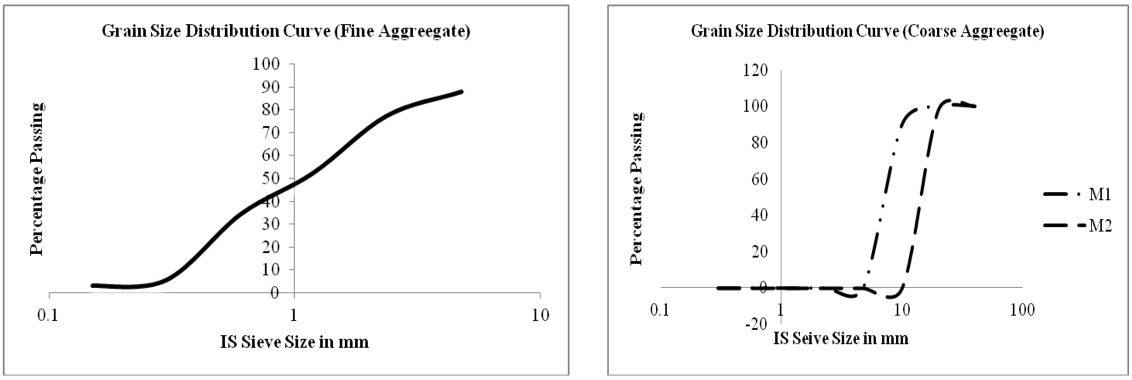

Fig. 1 Grain Size distribution curve of Fine aggregates and Coarse aggregates

Table 3 Particulars of the proportions for different mix proportions

Mix	Cement (kg)	Water (kg)	Proportion C:FA:M1:M2	w/c ratio
1	400	160	1: 1.6: 1.08: 2.19	0.4
2	430	159	1: 1.52: 1.06: 2.14	0.37
3	408	159	1: 1.56: 1.06: 2.14	0.39
4	450	162	1: 1.39: 0.94: 1.89	0.36
5	410	160	1:1.55: 1.05: 2.12	0.39
6	471	160	1: 1.32: 1.07: 1.59	0.34
7	385	155	1: 1.68: 1.05: 2.3	0.4
8	402	157	1: 1.59: 1.07: 2.18	0.39
9	421	160	1: 1.5: 1.01: 2.06	0.38

ingredients of concrete obtained through various laboratory tests are summarized in Tables 1 and 2. Fig. 1, shows particle size distribution of fine aggregates and coarse aggregates (M1 and M2)

4.2 Testing of specimens

The experimental programme involve tests on nine different mix proportions (Refer Table 3) which are prepared in accordance with the guidelines given by BIS: 10262-2009. For each mix proportion, six test specimens were cast. Out of these six specimens, three specimen were used for 28 days of normal curing and remaining three are used for accelerated curing using boiling water method in accordance with IS: 9013-2004.

Cement, fine aggregates and coarse aggregates are thoroughly mixed in dry state in a pan mixer and then water is added to the dry mix to obtain uniform mixture. The compaction factor test is carried out to test workability. The respective compaction factors are recorded for all the mix proportions. For compressive strength test, standard cube specimens of size, 150×150×150 mm (IS: 516-1959) are prepared. The concrete is filled in the moulds in three layers each layer being tamped for thirty five times. The concrete filled moulds are then vibrated for compaction on table vibrator for 30 seconds (IS: 516-1959).

After casting all the specimens made of each proportion are dried for a period of 24 hours for normal curing and 23 hours for accelerated curing. Out of the six specimens, the three specimens (1set) are subjected to normal curing for 28 days while remaining three specimens (1set) are then gently lowered into the curing tank containing water preboiled at 100°C as stipulated in IS: 9013-2004 and are cured for a time period 3½ hours as shown in (Fig. 1). The temperature of water shall not drop more than 3°C after the specimens are placed and shall return to boiling within 15 minutes. After curing for 3½ hours ±5 minutes in the curing tank the specimen are removed from the boiling water, then removed from the moulds and cooled by immersing in cooling tank at 27±2°C for 2 h as shown in (Fig. 2).

On the completion of normal curing and accelerated curing the specimens are tested in compression testing machine to obtain compressive strength as per the procedure prescribed in IS: 516-1959.

Fig. 2 In mould specimens in accelerated curing tank

Fig. 3 Accelerated curing in progress

5. Methodology of investigation

Simple and Multiple Regression Analysis technique are adopted to develop expressions and predict the characteristic strength of concrete. The data generated in the laboratory is used for the analysis. The strength of concrete normally cured for 28 days as well as the strength of concrete exposed to accelerated curing are recorded. Further, by employing Regression Analysis techniques, 28 days normal cured strength of concrete (characteristic strength of concrete) is obtained, from the accelerated strength of concrete using the equations developed.

In regression analysis, various formulae are developed by varying the input parameters to predict the strength of concrete corresponding to 28 days' normal curing. In the present study, equation for predicting the compressive strength corresponding to 28 days normal curing as given by IS: 9013-2004 based on simple regression, is considered as Model-I, reported in Eq. (1) as follows

$$f_{28}=1.64 * \text{accelerated compressive strength} + 8.09 \tag{1}$$

Model-II, is developed using data generated in the laboratory by employing Multiple Regression Analysis technique in which the independent variable parameters used are cement content per cubic meter of concrete, compaction factor and accelerated strength and the dependent variable is characteristic strength of concrete. Model - II is represented by Eq. (2) as follows

$$f_{28}=4.568 + 0.108\text{*Cement Content} + 4.667\text{*Compaction Factor}$$
$$+ 0.099\text{*Accelerated compressive strength} \tag{2}$$

In the Model-III, only one dependent variable parameter that is accelerated strength is used (simple regression) to predict the characteristic strength of concrete. Model-III is represented by Eq. (3) as follows

$$f_{28}=42.891 + 0.416 \text{*Accelerated Strength} \tag{3}$$

The selection of equations which would help the user to predict the characteristic strength of concrete with available data / input parameters, are based on the results of analysis.

6. Result and discussion

The formulae derived by the regression analysis were applied on nine mix proportions to predict the strength of concrete after 28 days' normal curing. The 28 days compressive strength of the concrete observed experimentally and that predicted using the relation specified by IS: 9013-2004 (Model-I) and also using the two regression models, i.e., Model-II containing three independent variables and model-III contain only single variable as given by Eq. (2) and Eq. (3) in are compared in Table 4.

Further, the percentage difference between the actual strength observed experimentally and the predicted strength using the relation stipulated by IS: 9013-2004 (model-I) is also given in Table 4. In addition to this, the percentage difference between the actual strength and the strength predicted using regression model-II and model-III is also evaluated and presented in Table 4.

From Table 4, it is observed that the strengths predicted using the relation specified by IS: 9013-2004 (model-I) are on higher side in respect of seven mix proportions as compared to the actual strength and in respect of two mix proportions, the actual strength is on higher side as

Table 4 Summary of the actual and predicted characteristic strength (MPa)

Mix	Actual Strength	Predicted Strength using IS:9013-2004 Model I	Percentage Difference	Predicted Strength using Regression Model II	Percentage Difference	Predicted Strength using Regression Model III	Percentage Difference
1	52.94	62.82	15.72	54.99	3.72	56.77	6.74
2	52.81	62.07	14.91	57.96	8.88	56.43	6.41
3	56.07	61.51	8.85	55.73	-0.61	56.44	0.65
4	52.34	63.23	17.22	60.37	13.30	56.87	7.96
5	54.44	46.93	-16.00	55.15	1.28	52.74	-3.22
6	50.56	66.13	23.54	62.81	19.50	57.61	12.23
7	48.54	54.18	10.40	53.08	8.55	54.58	11.06
8	48.27	46.35	-4.14	54.26	11.03	52.59	8.21
9	52.72	54.19	2.71	56.55	6.77	54.58	3.40

compared to the predicted strength. The variation in the percentage difference varies largely from -16% to +23.54%.

Further, predicted strengths using regression model II, involving three variables viz: cement content, compaction factor and accelerated strength, developed in the present study are on higher side as compared to the actual strength in case of eight mix proportions and in case of the remaining one mix proportion, the actual strength is slightly greater than the predicted strength. The percentage difference is less than 15% in all mix proportions.

In prediction model-III, only one variable is involved and i.e., accelerated strength, when compared with the actual strength, the predicted strength is found to be on higher side in case of eight mix proportions and in one mix proportion, the actual strength is on higher side. Model-III is similar to model-I as given by IS: 9013-2004 and model-III predicts the actual strength well within 10% for all the mix proportion except two.

It is worth comparing the strength prediction by model-I and model-III since they are similar in terms of a single variable i.e., accelerated strength. Further, when the values of the strength predicted using the equation given by IS: 9013-2004 and those predicted using regression model-II developed in the present study are compared with the actual strength, it is observed that the regression model-III, developed on the basis of the parameter of accelerated strength alone, is found to show more closer agreement with the actual strengths, the variation being in the range of as compared to those predicted using the equation specified by IS: 9013-2004 (model-I).

The results indicate that the two regression equations developed in the present investigation are capable of predicting the compressive strengths on the basis of the accelerated strengths more accurately than the equation suggested by IS: 9013-2014. In view of the results observed in the present investigation, it seems that the revision of BIS specification is required.

7. Conclusions

The earlier and accurate estimation of the strength of concrete 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 the quality (quality control process) and economics (saving time and expenses). This model could be used in construction to make necessary adjustments on the mix proportion used. It would also help avoid situations in which either concrete does not reach the required design strength or the concrete is unnecessarily strong. Pursuant to this, the present investigation dealt with establishing the model for predicting the strength of the concrete based on the strength gained with the accelerated curing. In view of this, in the first instance the strength of the normal 28 days cured concrete was predicted using the equation given by IS: 9013-2004. Then, the regression models were developed-firstly, using the three variables viz: cement content, compaction factor and accelerated strength; and secondly, using the only variable, i.e., accelerated strength.

Based on the results discussed in the preceding section, following broad conclusions are deduced:

1. The strength predicted using the regression model developed using accelerated strength are in fairly better agreement with the actual strengths as compared to that predicted using the equation given by IS: 9013-2004.
2. The strengths predicted using regression model developed using regression model containing three variables are in fair agreement with the actual strengths as compared to that predicted using the equation suggested by IS: 9013-2004.
3. The strength predicted using regression model developed using one variable in the present study is similar to the model suggested by IS: 9013-2004. While, when predicted strength by both models is compared, it is observed that present model is more efficient than the one given by IS: 9013-2004.
4. The normal compressive strength and that predicted seems to achieve the target strength of the mix.

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