AN EXPERIMENTAL STUDY: STRENGTH PREDICTION MODEL AND STATISTICAL ANALYSIS OF CONCRETE MIX DESIGN

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ABSTRACT

The predominant criterion for assessing concrete quality is its 28-day compressive strength. Concrete mix design by ACI method is popularly used in Bangladesh for producing concrete of required strength, but for determining its compressive strength one has to wait 28-day after casting. Predicting 28-day compressive strength of concrete has been a significant research challenge for many years. In this work, early age strength of concrete was considered as the tool for concrete strength prediction so that early age, for example 7-day, strength can be regarded as another criterion for concrete quality assessment. Although prediction of 28-day strength from early strength data is already proposed by ACI, it is still not used by construction Engineers in the country. Considering its potential as a powerful tool in mix design, extensive laboratory research has been carried out focusing on this specific area using locally available materials. Three hundred concrete cylinders were cast varying their water cement ratio, cement content, aggregate cement ratio and concrete strength at 7 and 28 days was observed. Along with predicting 28-day compressive strength from early strength data this paper also analyses the standard deviation of the data set to check its acceptability.

Keywords: Concrete; mix design; ACI method; compressive strength; early strength; standard deviation

INTRODUCTION

Majority of structures found in Bangladesh are made of concrete. The guideline generally followed in this country for producing concrete is the one provided by ACI mix design (ACI Committee 211. 1-91). The criterion used is primarily 28-day strength of concrete. However, often it becomes necessary to predict 28-day strength from early age strength of concrete. There is no Code prescribed formula for such prediction. As a result, a number of research endeavours have been carried out in this field (Hasan & Kabir, 2012; Abd Elaty, 2013; Telisak et al., 1991) and different strength prediction models have been proposed. Telisak et al. (1991) studied the applicability of some non-destructive test methods for assessing concrete strength in field and Abd Elaty (2013) proposed a new model for predicting concrete strength using data taken from previous research papers (Colak, 2006; Givi et. al, 2011; Wild et. al, 1995 and Han & Kim, 2004). Hasan and Kabir (2012) took data from a previous experimental study conducted in Patiala (Garg, 2003) and proposed a mathematical model, then validated it using an experimental data set of 23, prepared using materials found in Bangladesh. However, mathematical model developed using test data of samples prepared by local materials and larger sample size may provide more accurate prediction of strength. With this end in view, a research endeavour is conducted using locally available materials in Bangladesh and then proposing a model to predict 28-day strength based on early age test data.

The objectives of this research were to:

- Conduct a detailed experimental study with large sample size (consisting of 300 cylinders) to observe the 7-day and 28-day compressive strength of concrete having different water cement ratios and cement content.
- Obtain simplified equations to predict 28-day strength from 7-day strength of concrete based on different water-cement ratios.
- Validate the equations with results obtained from previous researches.

- Obtain normal distribution curves of 28-day strength at different characteristic strength and find out the statistical variance for each band of experimental data.

METHODOLOGY

The mix design of concrete has been carried out as per ACI Mix Design Method (ACI Committee 211.1-91). The concrete samples were prepared using locally available materials. Stone Chips were used as coarse aggregate and local sand with fineness modulus 3.09 was used as fine aggregate. Gradation curves for coarse aggregate and fine aggregate are shown in Fig. 1 and Fig. 2, respectively.

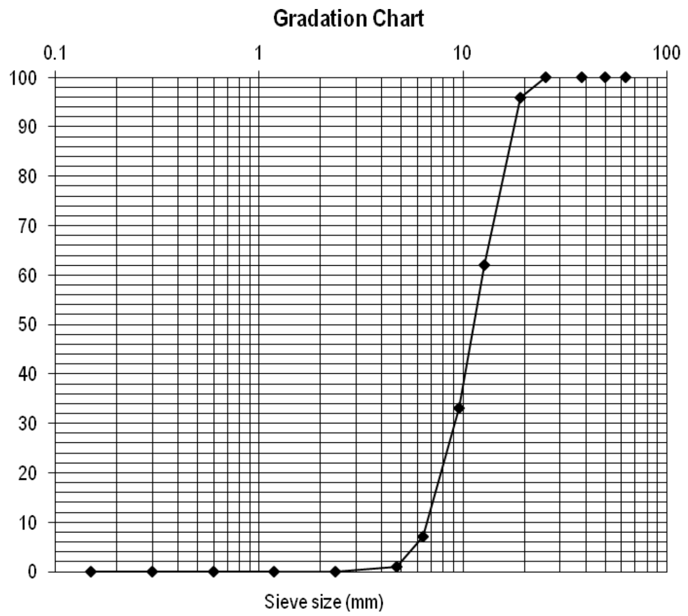


Fig. 1: Gradation curve for coarse aggregate

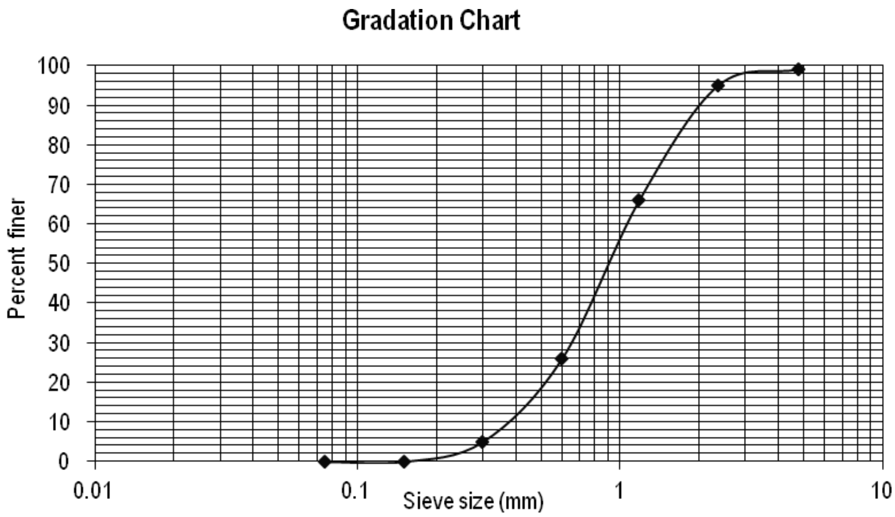


Fig. 2: Gradation curve for fine aggregate

The compressive strength of the cylinders has been tested conforming to the ASTM specifications (ASTM C39 / C39M - 16a). Following self-explanatory figures (Fig. 3) show the total procedure of mix design and compressive strength test of concrete in concise form.

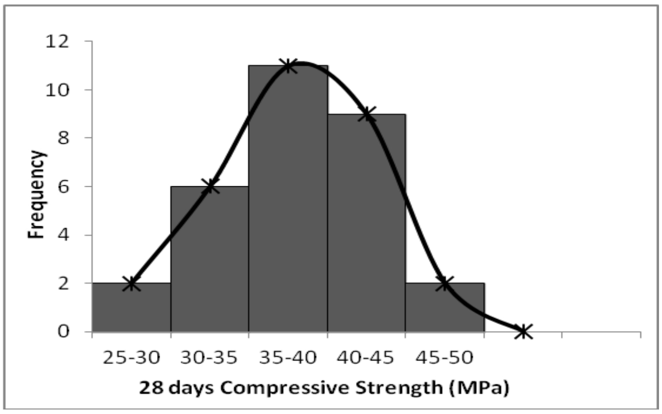
(a)

(b)

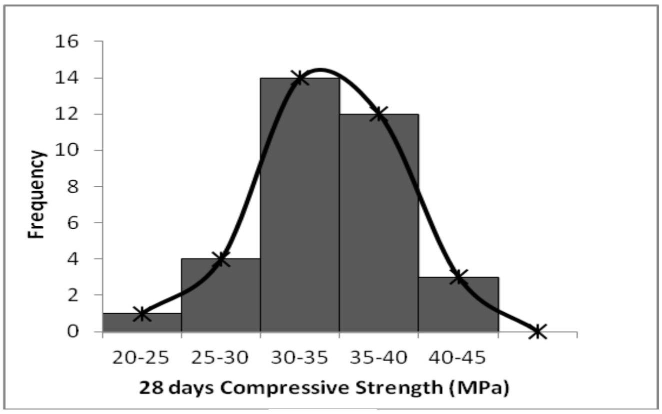
Fig. 3: (a) Compaction of the freshly cast cylinders and cubes (b) Determination of compressive strength of

STATISTICAL ANALYSIS

The experimental data obtained for 28-day compressive strength based on the characteristic strength were tallied and normal distribution curves were drawn. The results, as shown in the graphs below (Fig. 4), show fairly bell shaped normal distribution curves as were expected. Standard deviations of the experimental data from characteristic strength were determined for each of the three target strength data; each consisting 30 (or more) data sets as specified by ACI Committee118 (1991).



(a)



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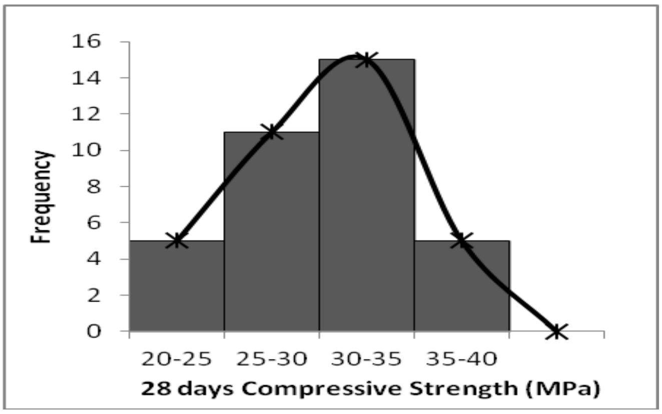


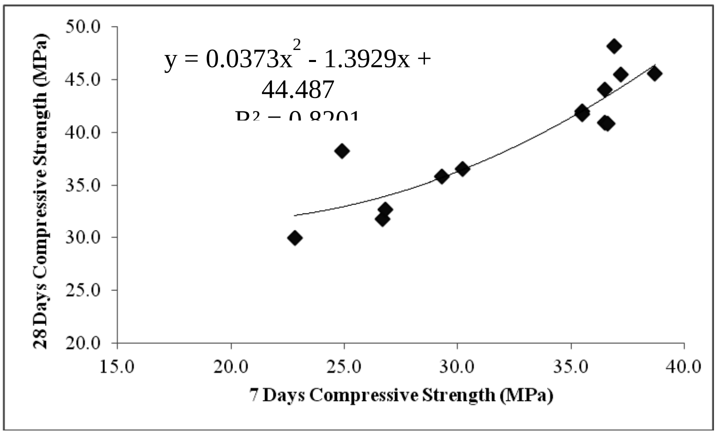
(c)

Fig. 4: Normal Distribution of 28-day compressive strength obtained in the laboratory based on the characteristic strength of (a) 43.75 MPa, (b) 37.5 MPa and (c) 34.35 MPa

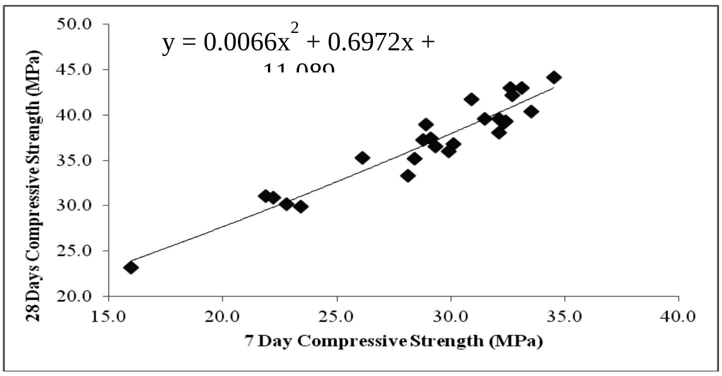
Standard deviations of the three range of compressive strength data set were calculated to be 5.43 MPa, 4.52 MPa and 4.88 MPa respectively whereas the mean strength of the data ranges were calculated to be 38 MPa, 34 MPa and 29 MPa respectively. The standard deviation values are relatively low, so the acceptibility of the utilized experimental strength results is verified.

RESULTS AND DISCUSSIONS

A mix design data set of 100 was taken varying their water cement ratio (w/c) and cement content. Fine aggregate to total aggregate ratio (fa/ta) and aggregate gradation were kept constant (0.40). Their water cement ratio was varied from 0.35 to 0.5. All the data were then divided into three ranges of w/c ratio: 0.35 to 0.40, 0.41 to 0.44 and 0.45 to 0.50. 28-day strength versus 7-day strength values were plotted for these three ranges of w/c.



(a)



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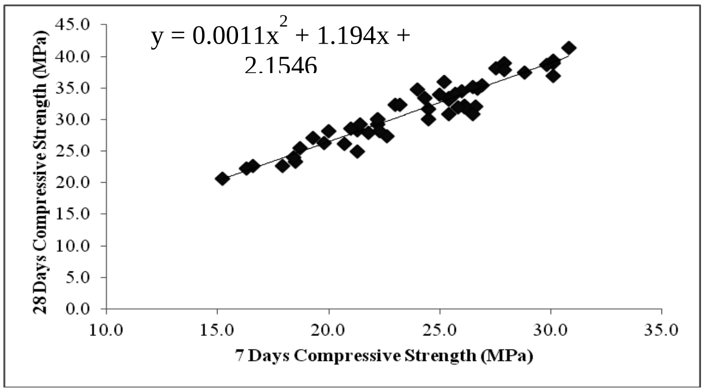

(c)

Fig. 5: Plot of 28-day versus 7-day compressive strength at water cement ratio of (a) 0.35 to 0.40 (b) 0.41 to 0.44 and (c) 0.45 to 0.50

The above three figures (Fig. 5) show the plots of 28-day compressive strength versus 7-day compressive strength for the three-different water cement ratio range. They show the regular trend of increasing 28-day strength resulting from increased 7-day strength.

DERIVATION AND VALIDATION OF MODEL

The next step was to determine three sets of equations which would assist in predicting 28-day strength from 7-day strength. The following three equations were developed [Eq. (1), Eq. (2) and Eq. (3)] for w/c ratio ranges of 0.35 to 0.40, 0.41 to 0.44 and 0.45 to 0.50, respectively.

$$y = 0.0373x^2 - 1.3929x + 44.487 \quad (1)$$

$$y = 0.0066x^2 + 0.6972x + 11.089 \quad (2)$$

$$y = 0.0011x^2 + 1.194x + 2.1546 \quad (3)$$

Where, y is the 28-day compressive strength and x is the 7-day compressive strength of a specific sample. As can be seen from the R^2 values, the experimental data reasonably satisfies the proposed equations.

Table 1: Validation of previous research results with the derived equations

w/c Range	w/c	7-day strength	28-day predicted strength	28-day Actual strength
		MPa	MPa	MPa
upto 0.4	0.4	23.33	32.29262	32.34
	0.35	39.29	47.34012	47.29
	0.375	34.76	41.1378	41.5
0.41-0.44	0.42	18.04	25.8144	24.64
	0.42	26.15	33.83401	34.2
	0.44	20	27.673	25.97
0.45-0.50	0.47	21.26	28.03623	27.67
	0.48	23.38	30.67161	30.9
	0.5	20.36	26.92042	27.51

The derived equations were validated using data taken from previous researches (Kamal & Rumman, 2014; Garg, 2003; Hasan & Kabir, 2012). Table 1 shows the validation of the three equations for three water cement ratios ranges. From Table 1, it can be observed that for each range of water cement ratio, the 28-day predicted strength and actual strength are almost similar. Numerically, a maximum deviation of 4.8% is observed.

CONCLUSIONS

ACI mix design, although generally used all over the globe, may need modifications at different regions of the world due to differences in ambient conditions and materials. Equations and statistical data obtained from this study from rigorous experimental research can assist the practicing engineers of the country and south-east Asian regions as an important tool in early evaluation of a concrete mix. In addition, early prediction of strength may assist in taking important decisions regarding quality control of concrete work. Such decision may save both time and cost of a construction project.

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