

Linear Regression Model Based on Accelerated Curing Method to Predict the 28-Day Strength of Concrete

Obam Sylvester Ogah, Abubakar Jibrin and Abdulrazak Sheidu

Department of Civil Engineering, Joseph Sarwuan Tarka University Makurdi, Nigeria.

Corresponding author: jibo008@yahoo.com

Abstract

Control tests are essential in the construction industry. The results of these tests need to be timely, to avoid waste of materials, and save the cost of production and labour. This may also lead to the delivery of the project in record time. In this study, a mathematical linear regression model is established to predict the 28-day compressive strength of concrete, using the boiling water accelerated curing method. Two concrete mix ratios of 1:2:4 and 1:2:3 were used for the design of the regression model. The mean compressive strength of the accelerated cured concrete is 5.2 and 7.4 N/mm² for 1:2:4 and 1:2:3 respectively. The mean compressive strength for the 28-day moist cured concrete is 16.0 and 20.6 N/mm² for 1:2:4 and 1:2:3 respectively. The SPSS Statistics software was used to determine the coefficients of the regression equation. The value of the 28-day strengths predicted by the model equation, agrees favorably with the observed 28-day moist cured concrete strengths, using Statistical Student's t-test, at a 5% significant level. The model is recommended for concrete made from similar materials.

Keywords: Concrete, Control, Accelerated Curing, Compressive Strength, T-Test.

Introduction

Concrete is composed of cement, aggregate, water, and sometimes admixture. The strength of concrete at 28 days of moist curing is what is generally used as the standard. Concrete is required to meet some minimum specifications for construction work. Therefore, control tests are needed to ensure that concrete meets the required specifications. This research aims to determine a linear regression model that can predict the 28-day compressive strength of concrete. Models are required for concrete batch materials because the coefficients of the regression model depend on concrete materials. If after 28 days, the quality of the concrete is found to be unsatisfactory, it would have considerably hardened by that time and a considerable quantity of additional concrete may have been placed in the structure; making access to it very difficult or impossible. This would be an obvious advantage if the 28-day strength can be predicted within a few hours of casting concrete (Neville & Brooks, 1994). Therefore, the standard 28-day concrete cube compressive test is not very convenient for quality control. This study develops a model that can predict the 28-day compressive strength of concrete using an accelerated curing method. It provides results of compressive strength within 48 hours, thereby allowing the speed of work on-site to be increased and also saving cost.

By the use of an appropriate correlation curve obtained by testing normally cured and accelerated cured concrete specimens, rapid and reliable prediction of the strength of concrete would be of great significance (Macginley & Choo, 2001). For example, it provides a chance to do the necessary adjustment on the mix proportions used to avoid a 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 concrete strength, therefore, has been an active area of research and a considerable number of studies have been carried out. Many attempts have been made to obtain a suitable mathematical model which is capable of predicting the strength of concrete at various ages with acceptable accuracy (Kheder et al., 2003). Concrete is a composite material comprising of binder e.g. cement, mineral inert filler, or aggregates and water. Aggregates are of two categories: fine and coarse. There are two types of concrete: lightweight and heavy-weight (dense) concrete. Lightweight concrete can be defined as those weighing less than 1920kg/m³ and dense concrete, is the most common form of concrete for reinforced concrete work with an average density of 240 kg/m³ (Arum & Alhassan, 2005).

The application of a moist membrane is the most commonly used method of curing concrete. These are organic materials that form a skin over the surface of concrete and help reduce the loss of mixing water by evaporation to about 20% of that of unprotected concrete. These curing compounds are merely temporary coatings on the surface, and will break down and degrade with exposure to sunlight and traffic (Taylor, 2006). In the construction industry, strength is a primary criterion in selecting concrete for a particular application. Concrete used for construction gains strength over a long period. The normally cured concrete is usually immersed in water for 28 days. American Standard for Testing Materials (ASTM) C 684-74 (1979), describes 3 methods of accelerated curing of concrete: Warm Water, Boiling Water, and Autogenous methods.

Cement is powdered material that develops bonding properties when mixed with water. It has the property of setting and hardening under water, under chemical reaction. It is generally referred to as hydraulic cement. Cement is classified as Portland and non-Portland cement. The most widely used type is Portland cement. It approximately accounts for about 90% of all cement produced all over the world. Aggregates are inert fillers in the concrete mixture consisting of between 70-75% by volume of the whole mixture. They are categorized as fine, for example, sand, and coarse aggregate, for example, crushed granite. For effective performances, aggregates must be clean, hard, tough, strong, and durable and of proper grading (Neville, 1997). Water for the production of concrete has to be portable. Curing is the process that controls the loss of moisture from concrete, thereby providing time for the hydration of cement to occur. It also includes control of temperature that affects the rate of hydration and hardening of concrete. The higher the temperature, the faster the rate of hydration and hardening of concrete.

Statistical methods have been used to predict concrete strength gain. Apart from speed,

statistical modeling has advantages over other techniques and can be used to define confidence intervals for the prediction (Palika, 2014). The concept of linear regression was first proposed by Sir Francis Galton in 1894. Linear regression is a statistical test applied to a data set to define and quantify the relationship between the considered variables. Univariate statistical tests such as Chi-square, Fisher's exact test, t-test, and analysis of variance (ANOVA) do not allow taking into account the effect of other covariates during analyses. However, partial correlation and regression are the tests that allow the researcher to control the effect of covariates in the understanding of the relation between two variables (Freedman, 2009). In biomedical or clinical research, the researcher often tries to understand or relate two or more independent (predictor) variables to predict an outcome or dependent variable (Freedman, 2009). In linear regression, the relationships are modeled using linear predictor functions whose unknown model parameters are estimated from data. Such models are called linear models (Hilary, 1967). Linear regression models are often fitted using the least squares approach (Zain et al., 2008).

Linear regression is given in equation (1) (Murray & Larry, 2011).

$$Y = a_0 + a_1X_1 + a_2X_2 + a_3X_3 \dots + a_nX_n \quad (1)$$

n is digit number.

Y is a dependent variable, the 28-day compressive strength of concrete.

X_1 , X_2 , and X_n are independent variables, the accelerated strength of concrete after 2, 3, and 4 hours of curing in boiling water respectively.

a_0 , a_1 , a_2 , a_3 , and a_n are constants of the regression equation, and they depend on concrete ingredients.

Suhad et al, (2015) gave a general linear and multiple regression equations for the prediction of normally cured concrete strength as shown in equations 2 and 3.

$$f = b_0 + b_1w/c \quad (2)$$

$$f = b_0 + b_1w/c + b_2CA + b_3FA + C \quad (3)$$

f: compressive strength of concrete

b_i (i=0-3) : coefficients of regression equation

C: proportion of cement in the mix

w/c : water-cement ratio

CA and FA: proportions of coarse and fine aggregates in the concrete mix respectively.

Ahmed (2019) developed a regression model based on Oven controlled temperature.

This is represented in equation (4). The model is based on the curing temperature of 90°C.

$$Y = 217.78 - 30.67X_1 - 2.19X_2 + 6.65X_3 \quad (4)$$

Y: Predicted 28-day concrete cube compressive strength

X_i (i = 1-3): Accelerated cured concrete cube compressive strength

Predicted strengths and actual strengths are usually subjected to statistical tests to show if there exist significant difference between the two different sets of data generated.

The Student's t-test Statistic is given in equation (5) and standard deviation is represented by equation (6) (Murray & Spigiel, 2011).

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sigma \sqrt{\left(\frac{1}{N_1} + \frac{1}{N_2}\right)}} \quad (5)$$

$$\sigma = \left(\frac{N_1 S_1^2 + N_2 S_2^2}{N_1 + N_2 - 2} \right)^{1/2} \quad (6)$$

Variance (S^2) of set of data is given by equation (7)

$$S^2 = \frac{\sum (x_i - \bar{x})^2}{N} \quad (7)$$

N = Number of data

$\bar{x}$ = Mean of set of data

σ = Standard deviation

Statement of the problem

Concrete is one of the most used materials in the construction industry. Control tests are essential before they can be mass-produced. The results of these tests need to be timely, to avoid waste of materials, and save the cost of production, and labour. This may also lead to the delivery of a project in record time. The strength of concrete at 28 days of moist curing is what is generally used as the standard. Concrete is required to meet some minimum specifications for construction work. The model helps to predict this strength within 4 hours.

Aim and Objectives

This research aims to formulate a linear regression model to predict the 28-day compressive strength of concrete. The specific objectives are to;

- Determine the grading of river sand and crushed granite to be used for the concrete production.
- Determine specific gravity and water absorption properties of the aggregates.
- Find the slump of the concrete.
- Determine the compressive strength of the concrete.

Materials and Method

Hydraulic Portland cement, of grade 44.3, obtained in Makurdi, Nigeria, was used as supply. The coarse aggregate used was crushed granite with a maximum size of 20mm, while the fine aggregate was River Benue sand obtained in Makurdi, Nigeria. They were graded according to the method described in BS EN 933-1 (1997). The specific gravity and water absorption tests of the aggregates were carried out according to the method described in BS EN 1097-6 (2013). The water used for the concrete was pipe-borne water obtained at the Civil Engineering Laboratory, Joseph Sarwuan Tarka University Makurdi, Nigeria.

Concrete Production and Testing

Two mix ratios, 1:2:4 (I) and 1:2:3 (II) were used to produce the concrete. Twelve, 150mm concrete cylinders were cast for each mix ratio as prescribed in BS 1881 methods. The slump

for each concrete ratio was carried out as specified in BS EN (European Code) 12350-2-2009. The 12 concrete cylinders were allowed to cure for 24 hours (1 day) at room temperature (about 25 degrees Celsius). They were then de-molded. Three of the concrete cylinders were transferred to curing water at room temperature for 27 days and then tested for compression on the 28th day as prescribed in BS EN 12390-3 (2009). The remaining 9 concrete cylinders were immersed in boiling water at the same time. After 2 hours, three of the concrete cylinders were removed from the boiling water; allowed to cool for one hour, and then tested for compression. After 3 hours, 3 of the 6 remaining concrete cylinders were removed from the boiling water; allowed to cool for one hour, and then tested for compression. Lastly, after 4 hours, the remaining 3 cylinders were removed from the boiling water; allowed to cool for one hour, and then tested for compression. It should be noted that the duration of curing is as follows:

- a. for normally cured concrete, it was for 28 days (24 hours or 1 day before the de-molding plus 27 days of normal curing)

Accelerated curing (boiling water method) of the concrete specimen:

- b. 2 hours in boiling water, making a total of 26 hours (24 hours before the de-molding plus 2 hours in boiling water)
- c. 3 hours in boiling water, making a total of 27 hours (24 hours before the de-molding plus 3 hours in boiling water)
- d. 4 hours in boiling water, making a total of 28 hours (24 hours before the de-molding plus 4 hours in boiling water)

The same process was followed for the mix ratio 1:2:3 (II).

Results of the compressive strength shown in Table 4 (Numbers 1-6, 12 strength values) were used for analysis using SPSS Statistics Software; and the values of the constants a_0 , a_1 , a_2 , and a_3 in the regression equation (8) were determined.

$$Y = a_0 + a_1X_1 + a_2X_2 + a_3X_3 \quad (8)$$

Results and Discussion

The values of the regression constants from SPSS Statistics Software output are:

$$a_0 = -16.78$$

$$a_1 = -11.89$$

$$a_2 = 4.43 \text{ and}$$

$$a_3 = 10.35.$$

Hence, the model regression equation for the concrete is given in equation (9).

$$Y = -16.78 - 11.89X_1 + 4.43X_2 + 10.35X_3 \quad (9)$$

Figures 1 and 2 show the particle size distribution of river sand and granite aggregates. The river sand distribution curve falls within the overall limits for fine aggregates from natural sources for concrete as specified in BS 882 (1992). The granite aggregates distribution curve falls within the range prescribed for single-sized coarse aggregates of 20mm according to BS 882 (1992). The average specific gravity results for the river sand and granite are 2.65

and 2.72 respectively as shown in Table 1. These values compare favorably with the 2.6-2.7 and 2.6-3.0 range for sand and granite respectively, given by Neville (1997).

The slump of the concrete, shown in Table 2 is 15mm for both mix I and II. These indicate low workability. The average 28-day compressive strength for the concrete mix I and II, shown in Table 3 are 21.1 and 24.6 N/mm² respectively. The concrete could be used as structural concrete (Neville, 1997).

Table 4 shows the comparison between the actual 28-day compressive strength values and the predicted ones, using the model equation (equation 9). The two sets of data were subjected to statistical Student's t-test (equation 5) at a 5 percent significance level. It shows that there is no significant difference between the predicted and actual strengths of the concrete. Therefore, the model could be used to predict the 28-day strength of the concrete, for quality control tests.

Figure 3, shows the relationship between accelerated curing time and percentage increase in strength of the two batches of concrete (I and II). As expected, it shows a linear correlation between the duration of accelerated curing and an increase in strength. However, the rate of increase in strength of the two concretes differs slightly.

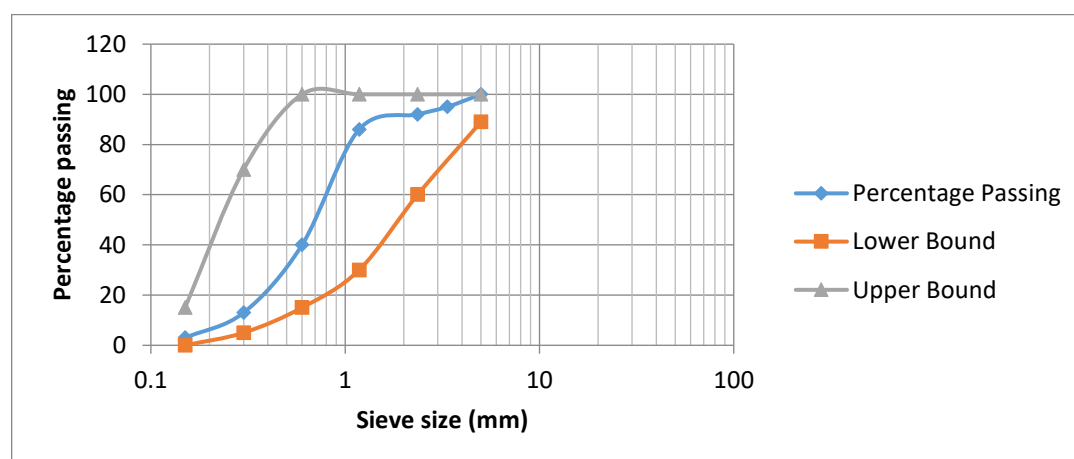


Figure 1: Particle Size Distribution Curve for the River sand Aggregate

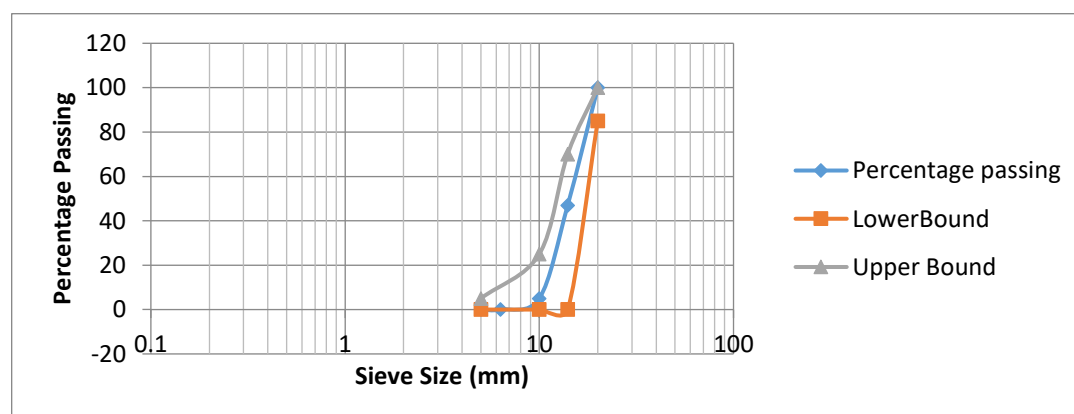


Figure 2: Particle Size Distribution Curve for the Crushed Granite Aggregate

Table 1: Test Results of the Physical Properties of the Aggregates

Property	Crushed Granite	River Sand
Average specific gravity	2.72	2.65
Average water absorption (%)	1.32	1.08

Table 2: The Concrete Slump

Mix Ratio	I	II
Slump (mm)	15	15

Table 3: The Compressive Strength Test Results

Mix Number	Sample	Accelerated Strength (N/mm ²)			28-Day Strength (N/mm ²)
		Age (Hours)			
		2	3	4	
I	1	6.50	7.00	7.80	17.5
	2	5.80	6.60	7.20	18.00
	3	5.20	5.60	7.00	18.60
	Mean	5.83	6.40	7.33	21.12
II	4	8.00	8.80	9.50	24.60
	5	7.50	8.20	9.00	25.00
	6	7.80	8.40	9.40	24.80
	Mean	7.77	8.47	9.30	24.61

Table 4: 28-day Strengths versus the Predicted Strengths

Mix Number	Sample	28-Day Strength (N/mm ²)	Predicted Strength (N/mm ²)	Difference (%)
I	1	17.50	16.84	+3.8
	2	18.00	18.13	-0.7
	3	18.6	21.31	-14.7
	Mean	18.03	21.12	-17.1
II	4	24.60	25.41	-3.3
	5	25.00	23.52	+5.9
	6	24.80	24.98	-0.7
	Mean	24.80	24.61	+0.8

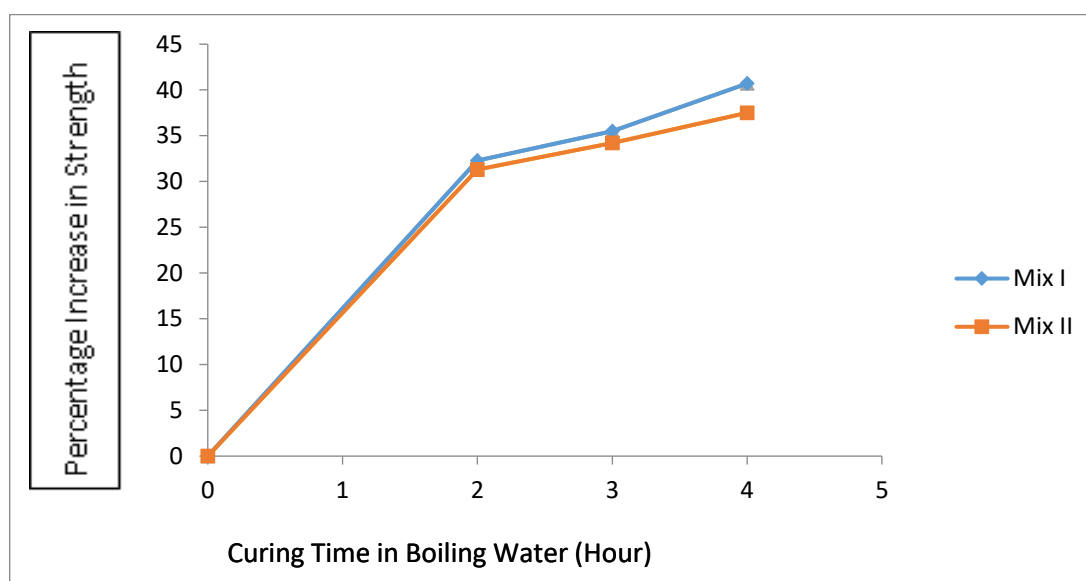


Figure 3: Accelerated Curing Time Vs Percentage Increase in Strength of the Concrete

Conclusion

Early and accurate estimation of concrete strength is valuable for control tests in the construction industry. The research uses an accelerated boiling method of curing to establish a linear regression model to predict the 28-day compressive strength of concrete. The mean 28-day compressive strength of mix ratios I and II are 16.0 and 20.6 N/mm² respectively. The analysis of the concrete regression coefficients was carried out using Statistics SPSS Software, and the values of the constants in the regression equation were determined. The student's t-test analysis on the predicted and actual compressive strengths, at a 5% significance level, indicates that there is no significant difference between the two sets of strength. Hence, the model equation could be used to predict the 28-day compressive strength of concrete produced from the batch materials.

Recommendations

- The regression model could be used to predict the 28-day strength of concrete produced from similar or identical materials.
- Trial mixes are necessary when using the model.

References

- American Society for Testing Materials (ASTM) CE 84-49, (1983). Prescribe Methods of Accelerated Curing of Concrete in Cylinders or Cubes.
- ASTM C 684-74 (1979). Accelerated Curing and Testing Concrete Compression Test Specimens.
- Ahmed, E. A. (2019). An accelerated test for predicting the 28-day compressive strength of concrete. *The Arabian Journal for Science and Engineering*, 15 (1), 26-33.
- Arum, C., & Alhassan, Y. (2005). Combined effects of aggregate shape, texture and size on concrete strength. *Journal of Science, Engineering and Technology*, 13 (25), 6876- 6887.

- BS 882 (1992). Specification of Aggregates from Natural Sources for Concrete. British Standard Institution.
- BS EN 933-1 (1997). Tests for Geometrical Properties of Aggregates- Determination of Particle Size Distribution-Sieving Method. British Standard Institution.
- BS EN 1097-6 (2013). Determination of Particle Density and Water Absorption. British Standard Institution.
- BS EN 12350-2 (2009). Testing Fresh Concrete- Slump Test. British Standard Institution.
- BS EN 12390-3 (2009). Testing Hardened Concrete-Compressive Strength of Test Specimens. British Standard Institution.
- Freedman, D. A. (2009). Statistical Models: Theory and Practice. Cambridge University Press, London.
- Hilary L. S. (1967). The historical development of the gauss linear model. *Biometrika*, 54, 1–24.
- Kheder G. F., Al-Gabban, A. M., & Suhad, M. A. (2003). Mathematical Model for the Prediction of Cement Compressive Strength at the Ages of 7 and 28 days within 24 hours. *Materials and Structures*, 36, 693-701.
- MacGinley, T., & Choo, B. (2001). Reinforced Concrete Design. Theory and Examples. E & FN Publishers.
- Murray, R., & Larry, J. S. (2011). Statistics. 4th Edition. New York: McGraw Hill Publishers.
- Neville, A. M. (1997). Properties of concrete. John Willey and Sons Inc.
- Neville, A. M., & Brooks, J. J. (1994). Concrete Technology. Longman Group Ltd.
- Palika, C. (2014). Predicting compressive strength of concrete for varying workability using regression models. *International Journal of Engineering and Applied Sciences (IJEAS)*, 6 (4), 10-22.
- Suhad, M.A., Zain, M.F., Sopian, K., Jamil, M. & Che-Ani, A.I. (2015). Mathematical regression models for prediction of concrete. <https://www.researchgate.net/publication/26229210>; accessed in March 23, 2023, 16:12 Hours.
- Taylor, P. C. (2006). Integrated Materials and Construction Practices for Concrete Pavement: A State of the Practice Manual. U.S. Department of Transportation.
- FHWA HIF-07-004 (2012). Federal Highway Administration, Washington D. C.
- Zain, S. M. (2008). Mathematical regression model for the prediction of concrete strength. *Australian Journal of Basic and Applied Sciences*, 1(2), 87-95.