Research Journal of Earth Sciences 12 (1): 09-14, 2020
ISSN 1995-9044

DOI: 10.5829/idosi.rjes.2020.09.14

Response Evaluation of Compressive Strength of Concrete Based on the Cement-Water Ratio and Input Concentration of Superplasticizer

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Abstract: The response of concrete compressive strength to the water-cement ratio and input concentration of super plasticizer has been evaluated. The process parameters considered were of range 15.99 - 1168(N/mm^2), 2.0- 4.0 and 0.47- 0.575 (%) for compressive strength, water-cement ratio and input concentration of super plasticizer respectively. The hydration period was 7 days. A derived model; $V = 11.35(e^{-0.1616\vartheta} + 3.114e^{-3.082\S})$ evaluates the compressive strength of the concrete as a function of the sum of exponentials of the water-cement ratio and input concentration of super plasticizer. Results from the model derivation indicate a decrease in the concrete compressive strength with increase in input concentration of super plasticizer and water-cement ratio, in agreement with previous work. The validity of the model was rooted on the core model expression $0.0881V = e^{-0.1616\vartheta} + 3.114e^{-3.082\S}$ where both sides of the expression are correspondingly almost equal. The standard error incurred in predicting the model-based concrete compressive strength relative to the actual results was 0.44%. Further evaluations show that the compressive strength of the concrete per unit input concentration of super plasticizer were 2.16 and 2.28(N/mm^2)/ % as obtained from actual and model-predicted results respectively. The maximum deviation of model-predicted results with respect to actual results was < 4%. This translated into over 96% operational confidence levels for the derived model as well as 0.96 dependency coefficient of concrete compressive strength on water-cement ratio & input concentration of super plasticizer. The correlation coefficients between concrete compressive strength and water-cement ratio & input concentration of super plasticizer were all > 0.97.

Key words: Response - Concrete - Compressive strength - Water - Cement ratio - Super plasticizer addition

INTRODUCTION

Concrete structure is basically a mixture of cement, water, sand, and coarse aggregate. High strength concrete has found application much more than conventional concretes because most of the rheological, mechanical and durability properties of these materials are better.

Addition of super plasticizer to concretes inputs very high workability or very high strength. Super plasticizer are of four main categories: (a) sulfonated melamine- formaldehyde condensates, (b) sulfonated naphthalene-formaldehyde condensates, (c) modified lignosulfonates and (d) sulfonic- acid esters and carbohydrate esters. The mechanism of super plasticizing involves giving the cement particles high negative charge so that they repel each other due to the same electrostatic charge.

Research [1] has shown that deflocculating the cement particles provides more water for concrete mixing. The research shows that the dosage of super plasticizer is between 1- 3 l/m^3 or as high as 5-20l/m^3. The study clearly indicates that the effectiveness of a given dosage of super plasticizer depends on the water/cement ratio. The effectiveness increases when water-cement ratio decreases. It has been shown [2] that usage of super plasticizer goes with advantages such as provision of high workability concrete with constant

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cement content and strength, producing concrete with normal workability, but lower water requirement, production of concrete with combination of high workability and low water content, ensuring easy placing and compaction as well as designing a normal strength and workability concrete with less cement content.

Scientists [3] revealed that super plasticizers have positive effects on the properties of concrete, both in the fresh and hardened states. In the fresh state, super plasticizer was observed to reduce tendency to bleeding due to the reduction in water/ cement ratio or water content of concrete. The research further established that super plasticizer in the hardened concrete state increases compressive strength of the concrete by enhancing the effectiveness of compaction to produce denser concrete.

Results of the investigation [4] on the risk of drying shrinkage show that super plasticizer reduces shrinkage by retaining the concrete in liquid state for longer period of time. It was observed that the rate of carbonation becomes slower when water/ cement ratio is decreased with the presence of super plasticizer.

Studies [5] have clearly shown that addition of super plasticizer optionally controls slump of fresh concrete in all mix- designs and thus influences workability of concrete. Similar research [6] shows that addition of super plasticizer can successfully maintain the initial slump of mixed concrete owing to the fact that workability of low water/cement ratio concrete is difficult to control. Findings from this work clearly indicate that super plasticizer can really produce a good quality concrete by increasing the density of concrete, through significant reduction in water requirement and slump loss.

Admixtures have been reported [5,6] to impart considerable physical and economic benefits on produced concrete. These reports all submitted that admixture is not a remedy for poor quality concrete produced due to usage of low quality raw materials, incorrect mix proportions of the constituents of concrete and poor mix-ability.

Observation [7] has shown that addition of chemical admixtures results to full compaction most especially when shortage of skilled workers and reinforcement congestion is prevalent. The research also under scored the merits in the use of super plasticizer for concrete making in that it imparts greater compressive strength than normal concrete mix.

The aim of this research is to evaluate the response of concrete compressive strength to the water-cement ratio and input concentration of super plasticizer.

MATERIALS AND METHODS

The concrete cube size measuring 150x150x150mm in dimension was used. The batching of the concrete cubes was by weight. The concrete was produced using different water-cement ratio ranging from 0.47-0.575 and 2.0-4.0% input concentration of super plasticizer by weight of cement. The cement used is Ordinary Portland Cement (Eagle) and the super plasticizer (Polycarboxylic ether) produced and marketed by Chinese company in Lagos was also used as an admixture. The coarse aggregate used is granite and clean river sand was used as fine aggregate. Both aggregate conformed to BS877 (1967) and BS3797 (1964) respectively for coarse and fine aggregate while the cement conformed to BS12 (1978). The concrete cubes were lubricated with oil before the mixed concrete was placed inside it in order to reduce friction between the concrete and the cube surface. When the concrete was properly mixed, the concrete cubes were filled one-third of their height and compacted 150 times. The cubes were later filled to two-third of their height and finally filled completely. In each of the layer, the concrete cubes were compacted 150 times respectively. The concrete cubes were cast and cured for 7, 14, 21 and 28 days respectively. At the end of each hydration period, the concrete cubes were crushed to determine, their compressive strength [8].

RESULTS AND DISCUSSION

Table 1: Variation of concrete compressive strength Ʋ with water-cement ratio ʆ and input concentration of super plasticizer ϑ respectively at 7days hydration period [8]

(ϑ)	(ʆ)	(Ʋ)
2.0	0.470	15.99
2.5	0.500	15.51
3.0	0.525	14.24
3.5	0.550	12.96
4.0	0.575	11.68

Computational analysis of the actual results shown in Table 1, gave rise to Table 2 which indicate that;

$$K\text{Ʋ} = e^{-N\vartheta} + ƀ\, e^{-S\text{ʆ}} \quad (1)$$

Introducing the value of K, N,Ђ and S into equation (1) reduces it to;

$$0.0881V = e^{-0.1616\vartheta} + 3.114\, e^{-3.082\S} \quad (2)$$

Dividing both sides of equation (2) by 0.0881 gives;

$$V = 11.35\,(e^{-0.1616\vartheta} + 3.114\, e^{-3.082\S}) \quad (3)$$

The derived model is equation (3).

where,

K = 0.0881, N = 0.1616,Ђ = 3.114, S = 3.082; equalizing constants and Ä= 11.35; empirical constant (determined using C-NIKBRAN [9])

($\S$) = Water-cement ratio
(ϑ) = Input concentration of super plasticizer (%)
(V) = Compressive strength of concrete (N/mm^2)

Boundary and Initial Conditions: A cube sized concrete block 150 x 150 x 150mmproduced from a mixture of water, sand, aggregates and cement was considered and subjected to compressive test using appropriate crushing loads. The concrete was assumed to be unaffected by dissolved gases in the atmosphere.

The considered range of the concrete compressive strength, water-cement ratio and input concentration of super plasticizerare15.99– 11.68(N/mm^2), 2.0- 4.0 and 0.47-0.575 (%) respectively. The hydration period was 7 days.

Table 2: Variation of 0.0881V with $e^{-0.1616\vartheta} + 3.114\, e^{-3.082\S}$

0.0881V	$e^{-0.1616\vartheta}+3.114\, e^{-3.082\S}$
1.4087	1.4553
1.3664	1.3345
1.2545	1.2332
1.1418	1.1397
1.0290	1.0532

Model Validity: Equation (3) is the derived model. The validity of the model is rooted on the core model equation (2) where both sides of the equation are correspondingly almost equal. Table 2 also agrees with equation (2) considering values of 0.0881Vand$e^{-0.1616\vartheta}$ $+3.114\, e^{-3.082\S}$ evaluated from the actual results in Table 1. Furthermore, the derived model was validated by comparing the compressive strength predicted by the model and that obtained from the experiment. This was done using various analytical techniques which includes computational, statistical, graphical and deviational analyses.

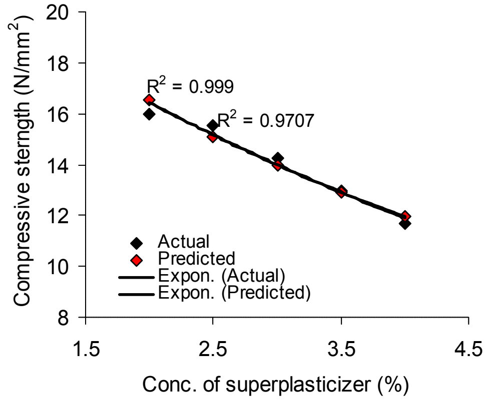

Fig.1: Coefficient of determination between compressive strength of concrete and input concentration of super plasticizer as obtained from actual and model-predicted results

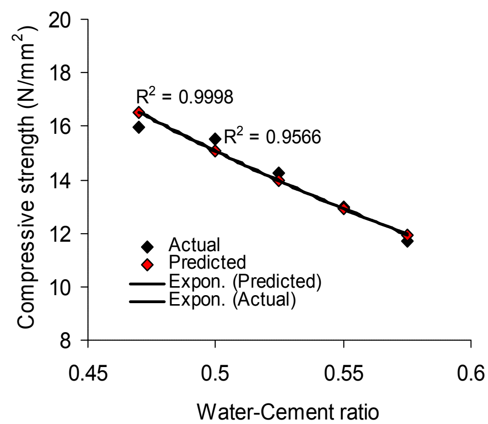

Fig. 2: Coefficient of determination between compressive strength of concrete and water-cement ratio as obtained from actual and model-predicted results

Computational Analysis: Compressive strength per unit input concentration of super plasticizer.

The compressive strength per unit input concentration of super plasticizer V_ϑ (N/mm^2)/ % was calculated from the equation;

$$V_\vartheta = V / \vartheta \quad (4)$$

Re-written as

$$V_\vartheta = \Delta V / \Delta\vartheta \quad (5)$$

Equation (5) is detailed as

$$V_\vartheta = V_2 - V_1/\vartheta_2 - \vartheta_1 \quad (6)$$

where,
V_ϑ= Change in the compressive strengths V_2, V_1 at Input concentrations of super plasticizer ϑ_2, ϑ_1.

Considering the points (2, 15.99) & (4, 11.68) and (2,16.5177) & (4,11.9538) as shown in Fig. 3, designating them as (ϑ_1, V_1) & (ϑ_2, V_2) for actual and model-predicted results, and then substituting them into equation (6), gives the slopes: - 2.16 and – 2.28N/mm^2/% respectively as compressive strength per unit input concentration of super plasticizer. The negative signs preceding the values indicate that the slopes of the curves (Fig. 3) relating compressive strength and concentration of super plasticizer are all negative. Therefore, the real values of the concrete compressive strength per unit input concentration of super plasticizer are 2.16 and 2.28N/mm^2/% for the actual and model-predicted results respectively.

Previous work [8] indicates that the compressive strength of concrete increases with increase in the input percent level of super plasticizer and decrease in the water cement-ratio. Results of the model derivation have also shown a remarkable degree of reliability by predicting decrease in the concrete compressive strength with increase in input concentration of super plasticizer and water-cement ratio, in agreement with the results of the previous work [8].

Statistical Analysis

Correlation: The correlation coefficients between compressive strength and concentration of super plasticizer & water-cement ratio were evaluated (using Microsoft Excel Version 2003) from results of the actual and derived model. These results are 0.9852 and 0.9995 & 0.9781 and 0.9999, respectively. The evaluations were based on the coefficients of determination $R^2$from Figs. 1and 2using equation (7).

$$R=\sqrt{R^2} \qquad (7)$$

Standard Error (STEYX): The standard error incurred in predicting the model-based compressive strength relative to values of the actual results is 0.44%. The standard error was evaluated using Microsoft Excel version 2003.

Graphical Analysis: The validity of the derived model was further verified by plotting values of the actual, besides the model-predicted results using Microsoft Excel (version 2003) to evaluate the trend of both results. Figs. 3 and 4 indicate very close alignment of curves and shapes which depicted significantly similar trend of data point's distribution for the actual and derived model-predicted compressive strength. This shows proximate agreement between both results.

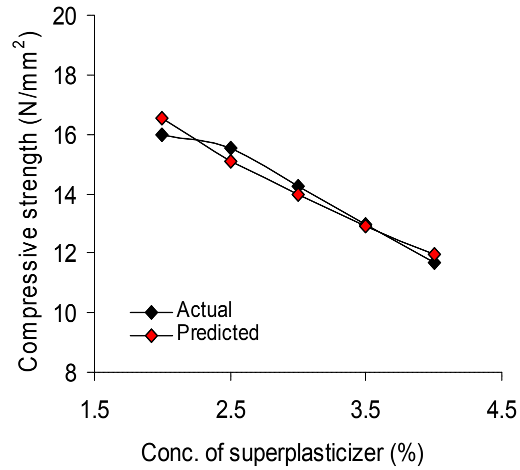

Fig. 3: Variation of concrete compressive strengths with input concentrations of super plasticizer as obtained from actual and model-predicted results

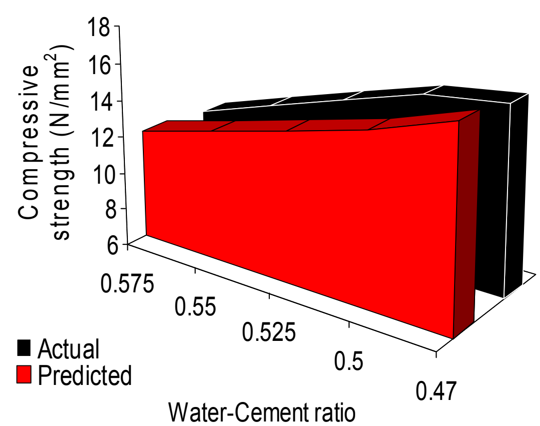

Fig. 4: Variation of concrete compressive strengths with water-cement ratio as obtained from actual and model-predicted results

Deviational Analysis: A critical comparative analysis of the concrete compressive strength obtained from the actual and model-predicted results shows single digit deviation on the part of model-predicted results. This was attributed to the fact that the effects of the surface properties of the cement which played vital roles during the hydration were not considered during the model formulation. This necessitated the introduction of correction factor, to bring the model-predicted concrete compressive strength to those of the corresponding experimental values.

The deviation Dv, of model-predicted compressive strength from the corresponding actual result was given by;

$$Dv = \left(\frac{V_P - V_E}{V_E}\right) \text{x } 100 \qquad (8)$$

where
V_E and V_P are compressive strengths evaluated from experiment and derived model respectively

Figure 5 shows that maximum deviation of model-predicted compressive strength from the actual results was less than 4%.This translates into over 96% model operational confidence. The figure shows that the least and highest deviations of model-predicted results (from actual results) are -0.19 and 3.3 %.

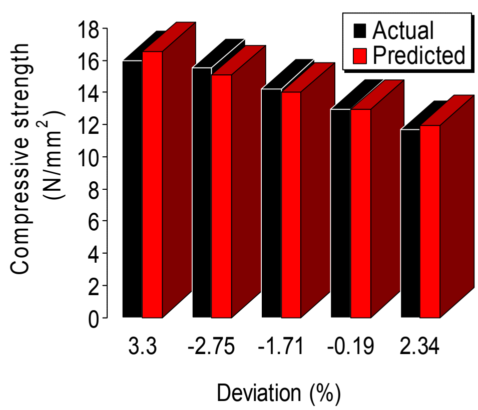

Fig. 5: Deviation of model–predicted results from actual values relative to compressive strength

These deviations correspond to model-predicted compressive strengths: 12.9356 and 16.5177 (N/mm^2); concentrations of super plasticizer: 3.5 and 2.0(%) and water-cement ratios: 0.55 and 0.47 respectively.

Correction factor, Cf to the model-predicted results was given by;

$$Cf = -\left(\frac{V_P - V_E}{V_E}\right) \text{x } 100 \qquad (9)$$

Comparative analysis of Figs. 5 and 6 shows that the evaluated correction factors are negative of the deviation as shown in equations (8) and (9).

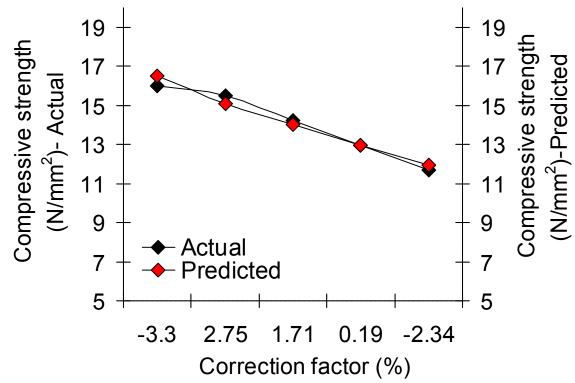

Fig. 6: Correction factor to model–predicted results relative to compressive strength

The correction factor took care of the negligence of operational contributions of the effects of surface properties of the cement which actually affected the concrete hydration process. Introduction of the corresponding values of Cf from equation (9) into the model gives exactly the corresponding actual compressive strength. Fig. 6 indicates that the maximum correction factor to the model-predicted results was less than 4%. Fig. 6 shows that the least and highest correction factors to the model-predicted results are 0.19 and - 3.3%. These correction factors also correspond to model-predicted compressive strengths: 12.9356 and 16.5177 (N/mm^2); input concentrations of super plasticizer: 3.5 and 2.0 (%) and water-cement ratios: 0.55 and 0.47 respectively.

The deviation of model predicted results from that of the actual is just the magnitude of the value. The associated sign preceding the value signifies deviation deficit (negative sign) or surplus (positive sign).

CONCLUSION

The response of concrete compressive strength to the water-cement ratio and input concentration of super plasticizer were evaluated. A derived model; $V = 11.35 (e^{-0.1616\vartheta} + 3.114\ e^{-3.082\S})$ evaluates the compressive strength of the concrete as a function of the sum of exponentials of the water-cement ratio and input concentration of super plasticizer. The model predicts a decrease in the concrete compressive strength with increase in input concentration of super plasticizer and water-cement ratio, in agreement with the previous work. The validity of the model was rooted on the core model expression $0.0881V = e^{-0.1616\ \vartheta} + 3.114\ e^{-3.082\S}$ where both sides of the expression are correspondingly almost equal. The standard error incurred in predicting the model-based concrete compressive strength relative to the actual results was 0.44%. Compressive strength of the concrete per unit input concentration of super plasticizer were 2.16 and 2.28 (N/mm^2)/ % as obtained from actual and model-predicted results respectively. The maximum deviation of model-predicted results with respect to actual results was $< 4\%$. This translated into over 96% operational confidence levels for the derived model as well as 0.96 dependency coefficient of concrete compressive strength on water-cement ratio & input concentration of super plasticizer. The correlation coefficients between concrete compressive strength and water-cement ratio & input concentration of super plasticizer were all > 0.97.

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